Chapter 4 – Marine Sediments

Chapter Overview

- Marine sediments are important because
  - contain a record of Earth history & provide clues to understand it
    - ✓ Marine organism distribution
    - ✓ Ocean floor movements
    - ✓ Ocean circulation patterns
    - ✓ Climate change
    - ✓ Global extinction events
  - and provide many important resources
- Marine sediments have origins from a variety of sources.

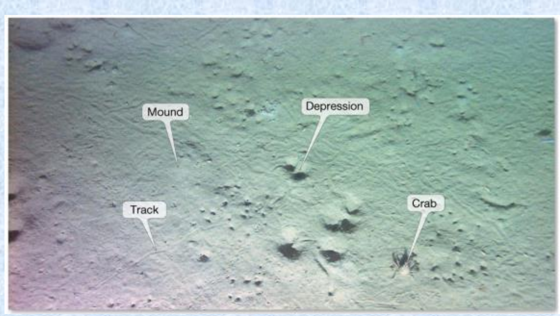
Paleoceanography and Marine Sediments

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 environmental conditions.
- Cores of sediment collected from sea floor.

Marine Sediments

- **Sediments**
  - Eroded particles
  - Fragments of dust, dirt, other debris
- **Suspension settling** – sediments settle out of water and accumulate on ocean floor.



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 4.1 CLASSIFICATION OF MARINE SEDIMENTS

Type		Composition		Sources/Origin	Distribution/Main locations where sediment currently forms
Lithogenous	Continental margin	Rock fragments Quartz sand Quartz silt Clay		Rivers; coastal erosion; landslides	Continental shelf
				Glaciers	Continental shelf in high latitudes
				Turbidity currents	Continental slope and rise; ocean basin margins
	Oceanic	Quartz silt Clay		Wind-blown dust; rivers	Abyssal plains and other regions of the deep-ocean basins
		Volcanic ash		Volcanic eruptions	
Biogenous	Calcium carbonate/ calcite ($CaCO_3$)	Calcareous ooze (microscopic)	Warm surface waters	Coccolithophores (algae) Foraminifers (protozoans)	Low-latitude regions; sea floor above CCD; along mid-ocean ridges and the tops of submarine volcanic peaks
		Shells and coral fragments (macroscopic)		Macroscopic shell-producing organisms	Continental shelf; beaches
				Coral reefs	Shallow low-latitude regions
	Silica ($SiO_2 \cdot nH_2O$)	Siliceous ooze	Cold surface waters	Diatoms (algae) Radiolarians (protozoans)	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
Hydrogenous		Manganese nodules (manganese, iron, copper, nickel, cobalt)		Precipitation of dissolved materials directly from seawater due to chemical reactions	Abyssal plain
		Phosphorite (phosphorous)			Continental shelf
		Oolites ($CaCO_3$)			Shallow shelf in low-latitude regions
		Metal sulfides (iron, nickel, copper, zinc, silver)			Hydrothermal vents at mid-ocean ridges
		Evaporites (gypsum, halite, other salts)			Shallow restricted basins where evaporation is high in low-latitude regions
Cosmogenous		Iron–nickel spherules Tektites (silica glass)		Space dust	In very small proportions mixed with all types of sediment and in all marine environments
		Iron–nickel meteorites		Meteors	Localized near meteor impact structures

Sediment Classification

- **Particle Size (Grain Size)**
- **Location (where the grains are deposited)**
- **Source and Chemistry (color)**

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Grain Size

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

Texture and Environment

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

Sediments Classified By Particle Size

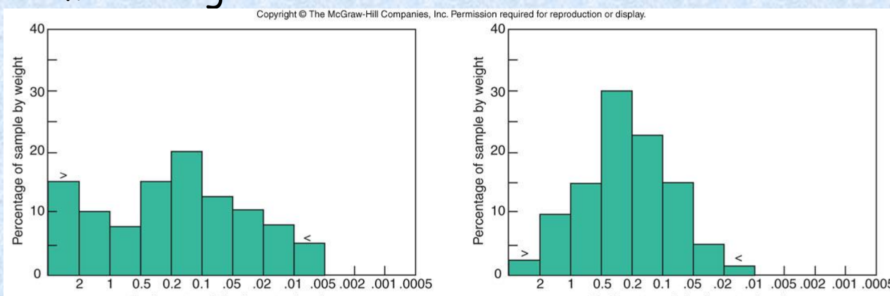
Table 5.1 Particle Sizes and Settling Rate in Sediment

	Size Class	Size	Size Comparison	Settling Velocity in Still Water	Time to Settle 4 Kilometers (2.5 Miles)
Gravel	Boulder	>256 mm	Basketball		
	Cobble	64–256 mm	Potato to grapefruit		
	Pebble	4–64 mm	Throwing and skipping size		
	Granule	2–4 mm	Pea		
Sand	Very coarse sand	1–2 mm	Peppercorns		
	Coarse sand	0.5–1 mm	Coarse sugar	2.5 cm/sec (1 inch/sec)	1.8 days
	Medium sand	0.25–0.5 mm	Granulated sugar		
	Fine sand	0.125–0.25 mm	Confectioners' sugar		
	Very fine sand	0.0625–0.125 mm	Visible to the eye		
Mud	Coarse silt	0.0310–0.0625 mm	Barely visible to the eye	0.025 cm/sec (1/100 inch/sec)	6 months
	Medium to very fine silt	0.0039–0.0310 mm	Microscopic		
	Clay	<0.0039 mm	Microscopic	0.00025 cm/sec	50 years

Based on the Udden–Wentworth Sediment Grain Size Scale.

Sorting

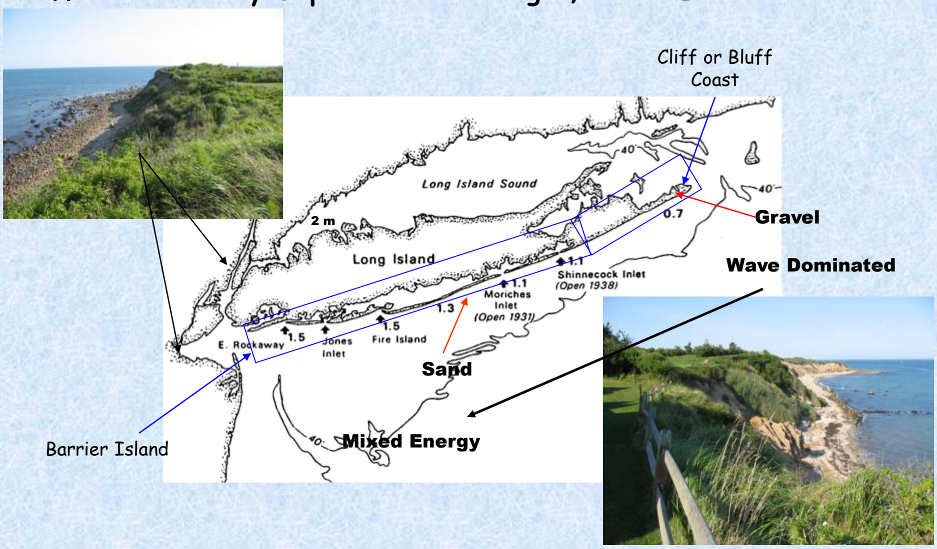
- Measure of grain size uniformity
- Indicates selectivity of transportation process
- Well-sorted – all same size particle
- Poorly sorted – different size particles mixed together



Sorting of Littoral Sediments

Bluff Erosion

Offshore Glacially Deposited Sand Ridges, Relict Ebb Shoals

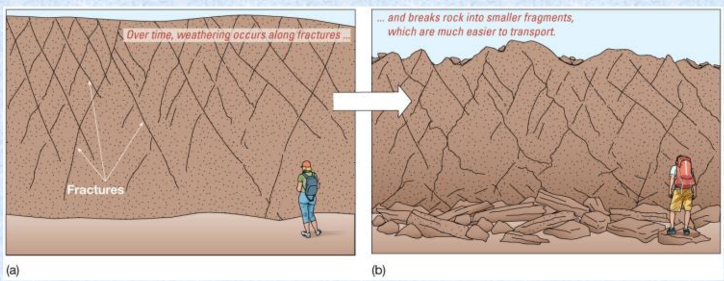


Sediment Distribution

- **Neritic**
  - Shallow-water deposits
  - Close to land - near continental margins & islands
  - Dominantly lithogenous
  - Typically deposited quickly
- **Pelagic**
  - Deeper-water deposits - deep sea floor
  - Finer-grained sediments
  - Deposited slowly

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
- Greatest quantity around continental margins

- Reflect composition of rock from which derived
- Coarser sediments closer to shore
- Finer sediments farther from shore
- Mainly mineral **quartz** (SiO_2)

Lithogenous Sediment Transport Mechanisms

Carried to ocean by

Streams (a)

Wind (b)

Glaciers (c)

Gravity (d)

(a) Stream: Po River, Italy, which displays a prominent delta and a visible sediment plume in the water.

(b) Wind: Dust storm approaching a military base, Australia.

(c) Glacier: Riggs Glacier, Glacier Bay National Park, Alaska, which displays a dark stripe of sediment along its length called a *medial moraine*.

(d) Gravity, which creates landslides: Del Mar, California.

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 – deep-sea floor

- 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

- **Abyssal Clay**
  - At least 70% clay sized particles from continents
  - **Red clays** 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

Oozes – sediment containing at least 30% biogenous material. Dominant on deep-ocean floor, 2 types of oozes:

* Calcareous ($CaCo_3$) oozes
formed by organisms which contain calcium carbonate in their shells or skeletons – dominant pelagic sediment (cocolithophorids, pteropods, foraminifera)

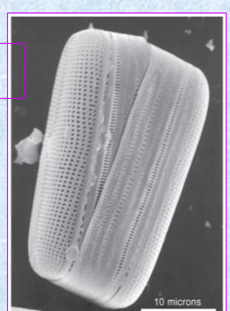
* Siliceous (SiO_2) oozes
formed by organisms that contain silica in their shells. Diatoms are one type of organism whose remains contribute to siliceous oozes. The ocean is under-saturated with respect to Si, so it can dissolve everywhere.
(large contribution from photosynthetic organisms)

Biogenous Sediment Composition

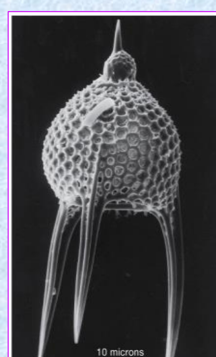
- Two most common chemical compounds are
  - **Calcium carbonate** ($CaCO_3$)
  - Silica (SiO_2 or $SiO_2 \cdot nH_2O$)

… in biogenous sediments

- **Diatoms**
  - Photosynthetic algae
  - Diatomaceous earth
- **Radiolarians**
  - Protozoans
  - Use external food



(a) Diatom, showing how the two parts of the diatom's test fit together.

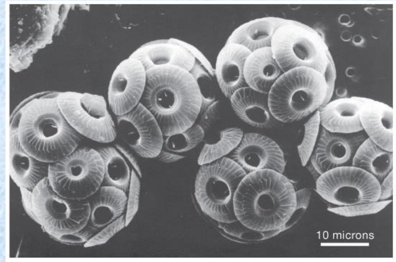


(b) Radiolarian.

Calcium Carbonate in Biogenic Sediments

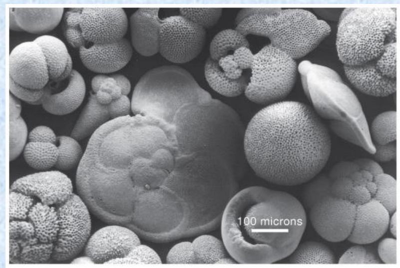
Coccolithophores

- Also called **nannoplankton**
- Photosynthetic algae
- **Coccoliths** – individual plates from dead organism



(a) Coccolithophores, which resemble tiny spheres.

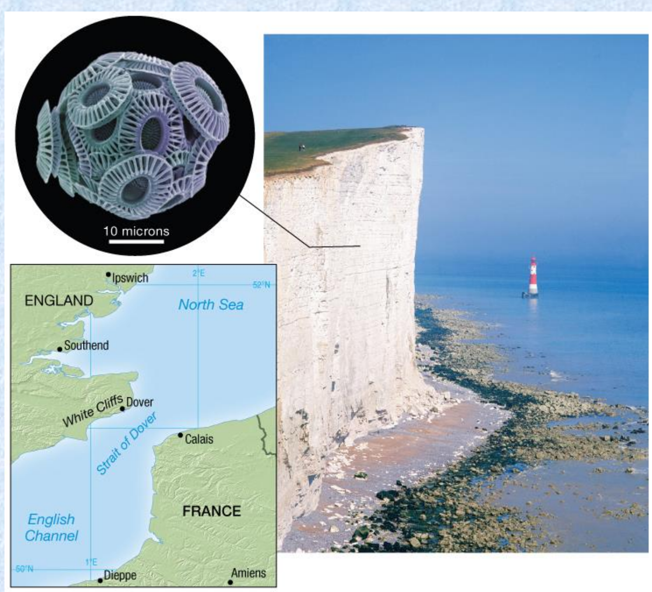
- **Foraminifera**
  - Protozoans
  - Use external food
  - Calcareous ooze



(c) Foraminifers, which resemble tiny shells found at a beach.

Calcium Carbonate in Biogenic Sediments

- **Rock chalk**
  - Lithified coccolith-rich ooze
  - White Cliffs of southern England (Dover)



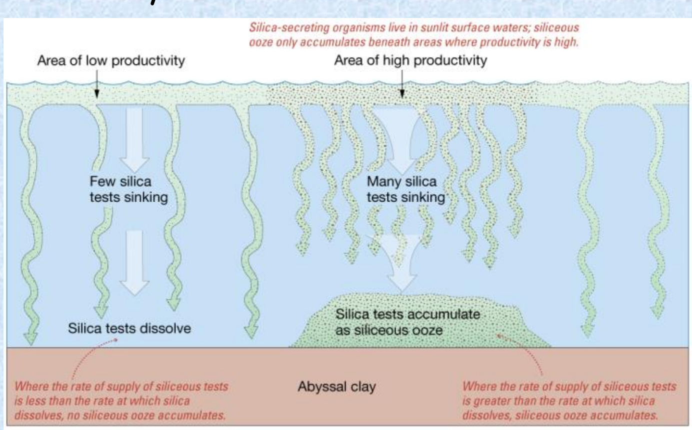
Distribution of Biogenous Sediments

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



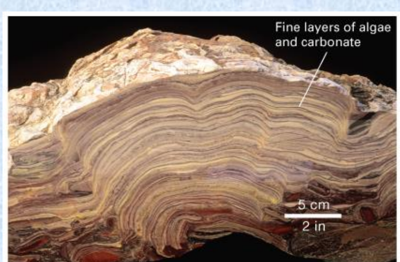
Neritic Deposits

- Dominated by lithogenous sediment, may contain biogenous sediment
- **Carbonate Deposits**
  - Carbonate minerals containing CO_3
  - Marine carbonates primarily **limestone**
    - $CaCO_3$
  - 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

(b) Shark Bay stromatolites, which form in high-salinity tidal pools and reach a maximum height of about 1 meter (3.3 feet).



(c) Profile view through a stromatolite, showing its internal fine layering.

Carbonate Deposits

- **Stromatolites**
  - Modern stromatolites live near Shark Bay, Australia

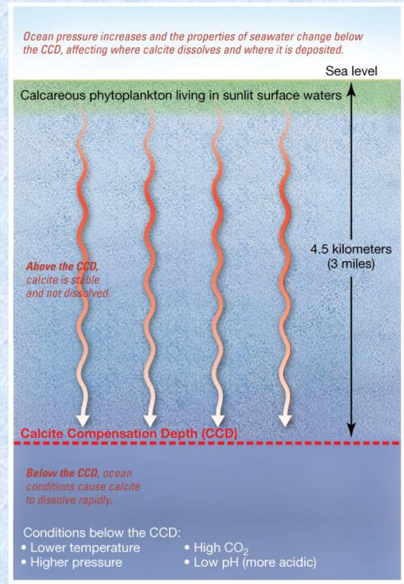
(a) Location map of Shark Bay, Australia.

Calcareous Ooze

- **CCD – Calcite compensation depth**
  - Depth where $CaCO_3$ 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

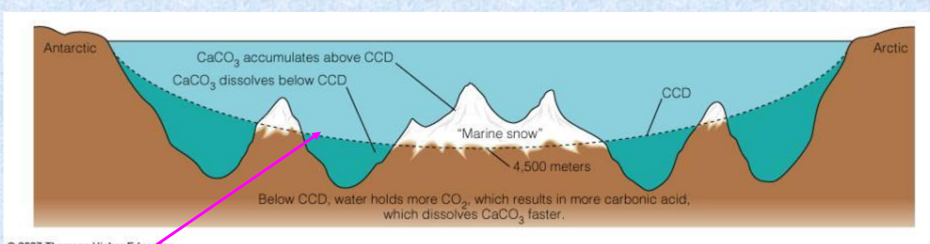
Calcareous Ooze and the CCD

- Scarce calcareous ooze below 5000 meters (16,400 feet) in modern ocean
- Ancient calcareous oozes at greater depths if moved by sea floor spreading



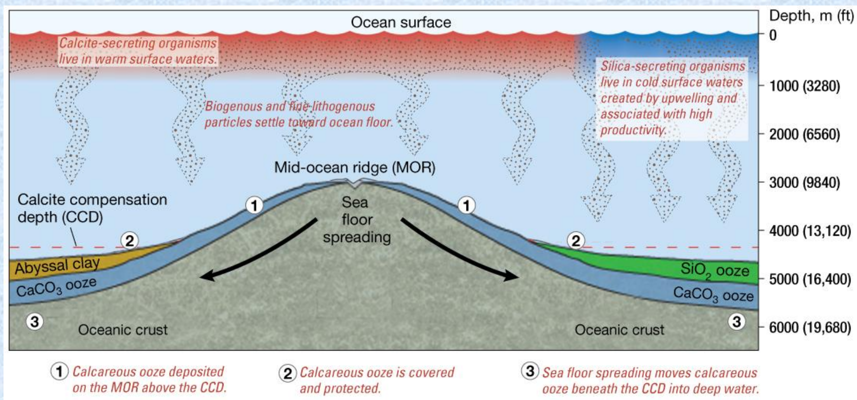
Calcareous Oozes

CCD (~4500 meters) depth where rate of dissolution of calcium carbonate is equals to its rate of accumulation

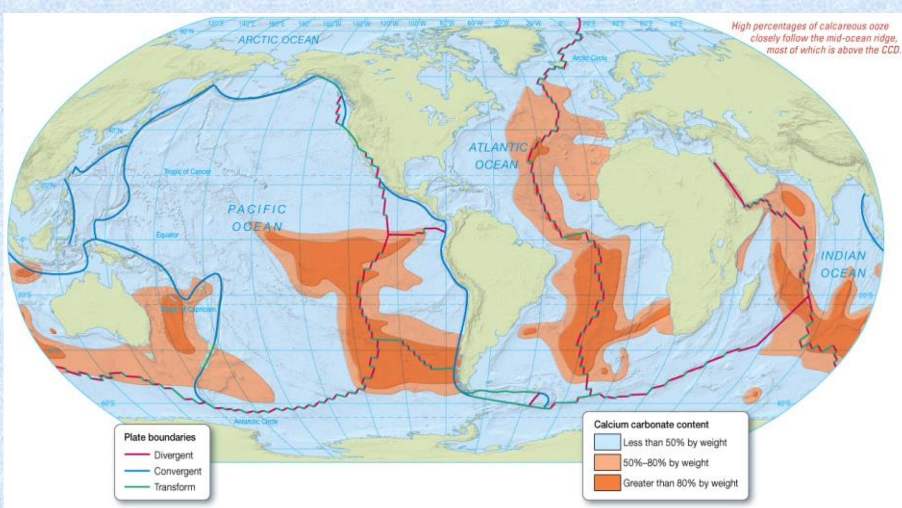


The line shows the calcium carbonate ($CaCO_3$) compensation depth (CCD). At this depth, usually about 4,500 meters (14,800 feet – about the height of some of the peaks in the Colorado Rocky Mountains, the rate at which calcareous sediments accumulate equals the rate at which those sediments dissolve.

Sea Floor Spreading and Sediment Accumulation



Distribution of Modern Calcium Carbonate Sediments



Hydrogenous Marine Sediments

- Minerals **precipitate** directly from seawater
  - ***Manganese nodules***
  - ***Phosphates***
  - ***Carbonates***
  - ***Metal sulfides***
- Small proportion of marine sediments
- Distributed in diverse environments

Hydrogenous

Originate from chemical reactions with water that occur in the existing sediment. Hydrogenous sediments are often found in the form of **nodules** containing manganese and iron oxides. Hydrogenous sediments can be:

Carbonates → direct deposition

Phosphorites → abundant in continental shelf

Salts → by evaporation

Evaporites - salts that precipitate as evaporation occurs. Evaporites include many salts with economic importance. Evaporites currently form in the Gulf of California, the Red Sea, and the Persian Gulf

Manganese nodules → Mn, Fe, Cu, Ni, Co. These are found in abyssal seafloor and continental margins, around ocean ridges and seamounts (but at higher concentrations than those found on land). The Co (cobalt) content is of strategic importance to US (used in aircraft's manufacture).

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

(a) Manganese nodules, including some that are cut in half.

Phosphates, Carbonates & Metal Sulfides

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

Evaporites

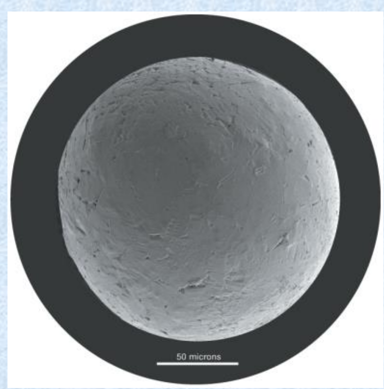
Evaporites

- Minerals that form when seawater evaporates
- Restricted open ocean circulation
- High evaporation rates
- Halite (common table salt) and gypsum

Evaporative Salts in Death Valley

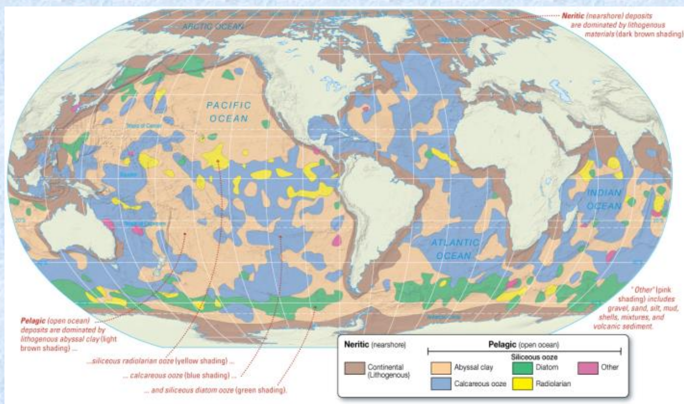
Cosmogenous Marine Sediments

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



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

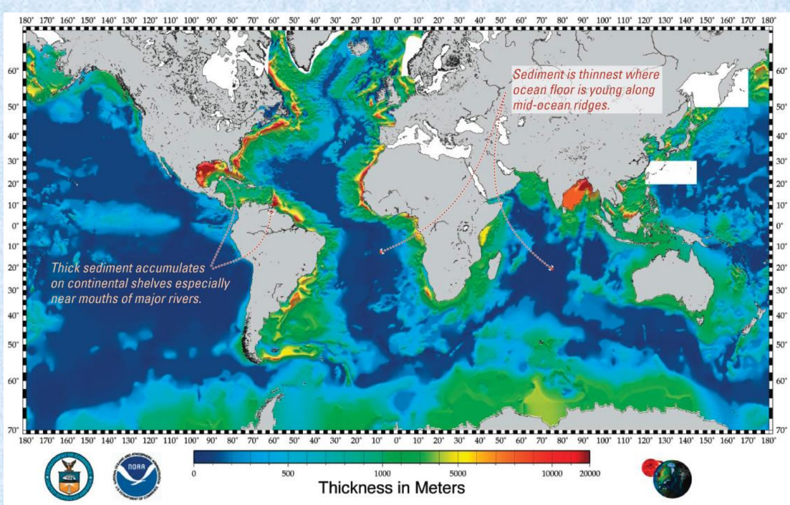
- Proximity to sources of lithogenous sediments
- Productivity of microscopic marine organisms
- Depth of water
- Sea floor features

Summary about sediment distribution

Distribution of sediments is determined by climate (temperature), environmental factors (nutrients, possible chemical reactions, activity of physical environment), supply, size and rate of accumulation.

- Terrigenous sediments are deposited along the coastal boundaries
- 75% of marine sediments are from land – coarser sediments closer to coasts and finer sediments at farther distances offshore
- Higher latitudes – coarser sediments; lower latitudes – finer sediments
- At higher latitudes rafting by glaciers and ice contribute significant amounts of sediments from land (coarse)
- Red clay (fine, pelagic lithogenous) found where there is not much of anything else – deep ocean basins
- Calcareous are not found in deep-sea areas below 4500 m or where ocean primary productivity is low. Fund in warm, tropical latitudes, shallow areas (Caribbean), elevated ridges and seamounts
- Siliceous (photosynthesis) found below areas of very high biological productivity - abound in areas of N. Pacific and Antarctic Ocean: cold but nutrients and sun light good for photosynthesis.

Worldwide Marine Sediment Thickness



Resources

Both mineral and organic resources

- Sand and Gravel → construction
- Phosphorite → fertilizers
- Sulfur → sulfuric acid for industry
- Coal → energy
- Oil and Gas → energy, transportation
  (20-25% of US production comes from offshore areas)
- Maganese Nodules → Mn, Fe, Co, Cu, Ni
- Gas Hydrates → energy in the future?

But note: Not easily accessible - Technological challenges, High costs

Energy Resources

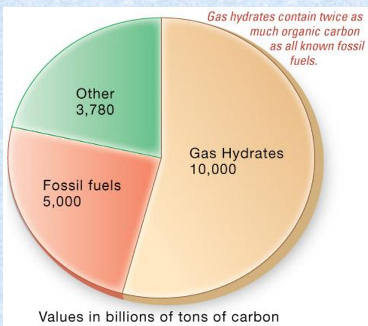
- **Petroleum**
  - Ancient remains of microscopic organisms
  - More than 95% of economic value of oceanic nonliving resources
- More than 30% of world's oil from offshore resources
- Future offshore exploration will be intense
  - Potential for oil spills

Energy Resources

Gas Hydrates

- Also called clathrates
- High pressures squeeze chilled water and gas into icelike solid
- **Methane hydrates** most common

(a) A sample retrieved from the ocean floor shows layers of white icelike gas hydrate mixed with mud.



- Gas hydrates may be largest store of usable energy in organic carbon form.
- Rapidly decompose at surface pressures and temperatures

Energy Resources

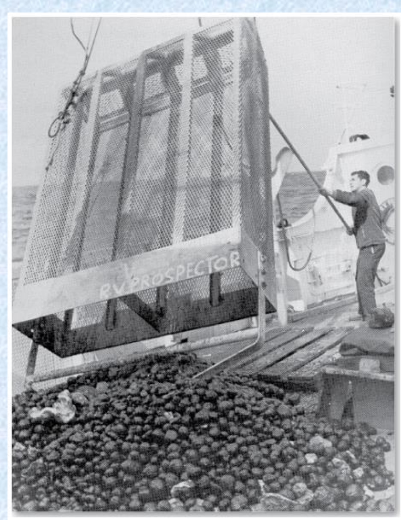
- Gas hydrates resemble ice but burn when lit
- May form on sea floor
  - Sea floor methane supports rich community of organisms
- Most deposits on continental shelf
- Release of sea floor methane may alter global climate.
- Warmer waters may release more methane.
- Methane release may cause underwater slope failure.
  - Tsunami hazard

Other Resources

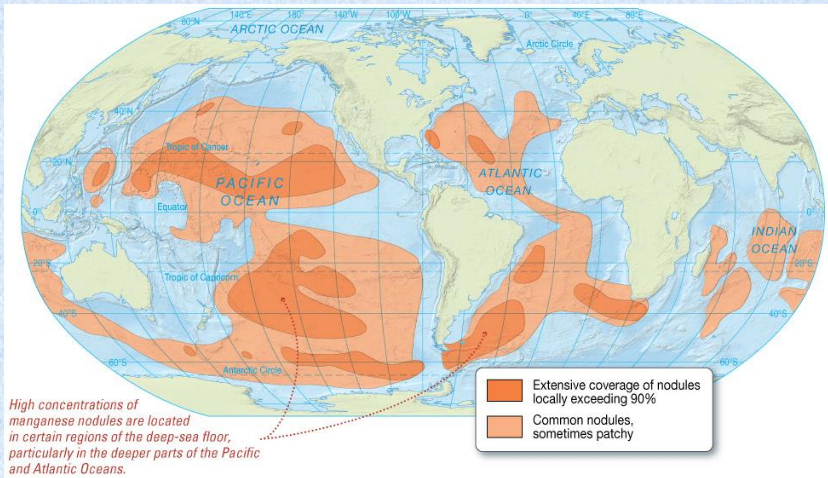
- **Sand and gravel**
  - Aggregate in concrete
  - Some is mineral-rich
- **Phosphorite** – phosphate minerals
  - Fertilizer for plants
  - Found on continental shelf and slope
- **Evaporative salts**
  - Form **salt deposits**
  - Gypsum – used in drywall
  - Halite – common table salt

Other Resources

- **Manganese nodules and crusts**
  - Lumps of metal
  - Contain manganese, iron, copper, nickel, cobalt
  - Economically useful



Distribution of Sea Floor Manganese Nodules



Other Resources

- Rare Earth elements
  - Assortment of 17 chemically similar metals
  - Used in technology, e.g., cell phones, television screens, etc.
- Sea floor may hold more rare Earth element deposits than found on land