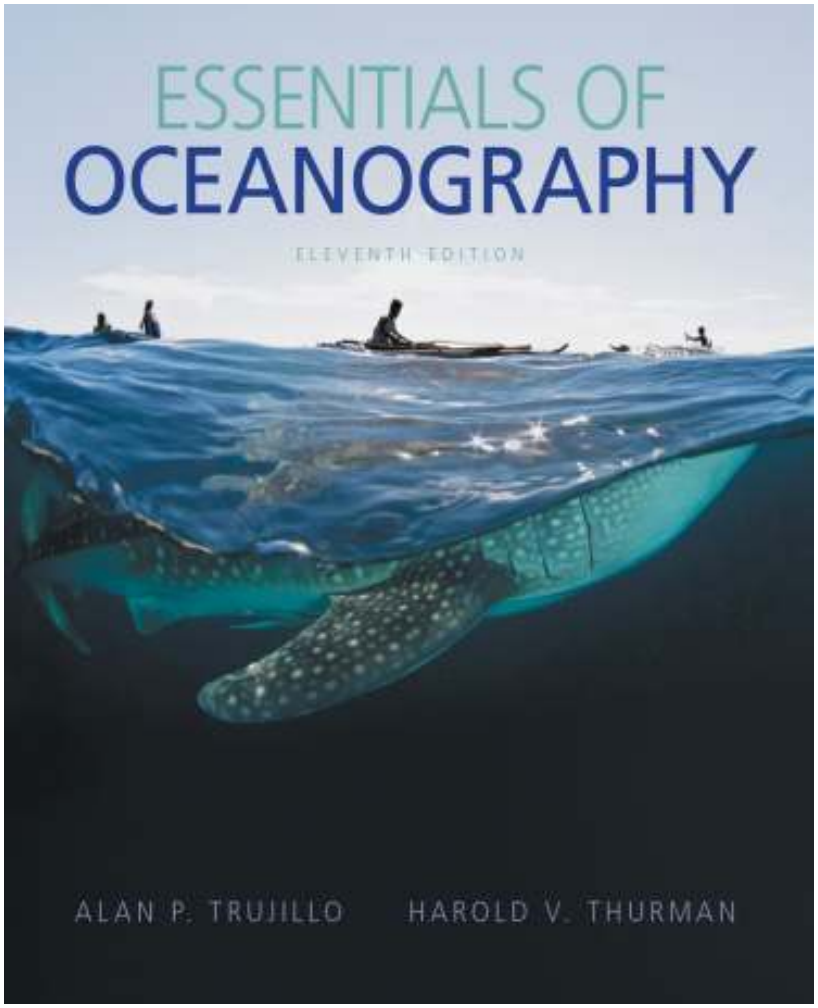
Chapter 4 Lecture

Essentials of Oceanography

Eleventh Edition



Marine Sediments

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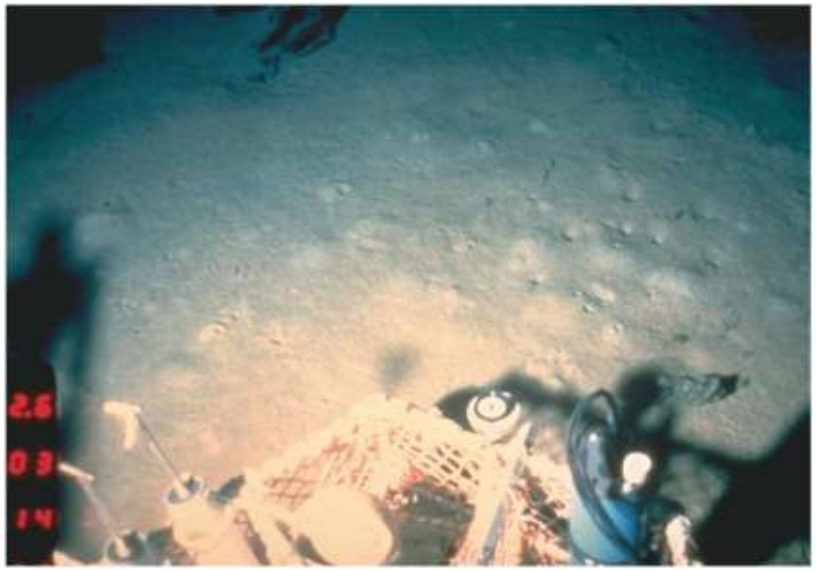
Chapter Overview

- 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

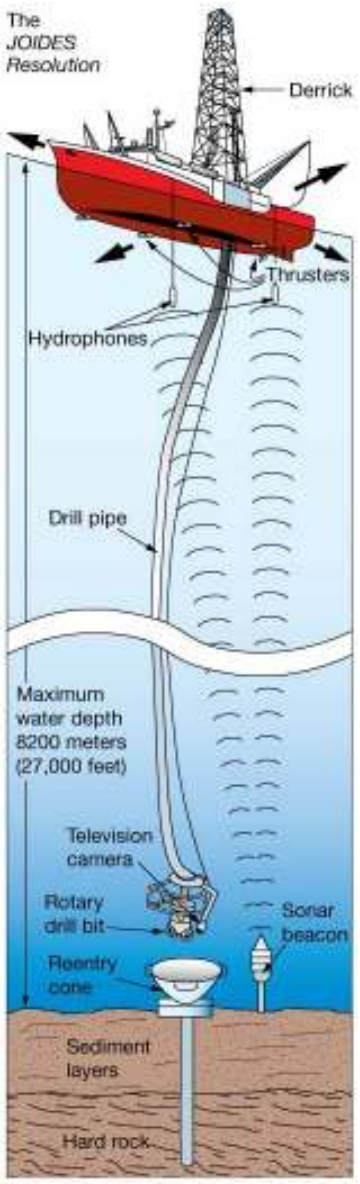
Classification of Marine Sediments

TABLE 4.1 CLASSIFICATION OF MARINE SEDIMENTS

Type	Composition		Sources		Main locations found
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 ($CaCO_3$)*	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 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

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

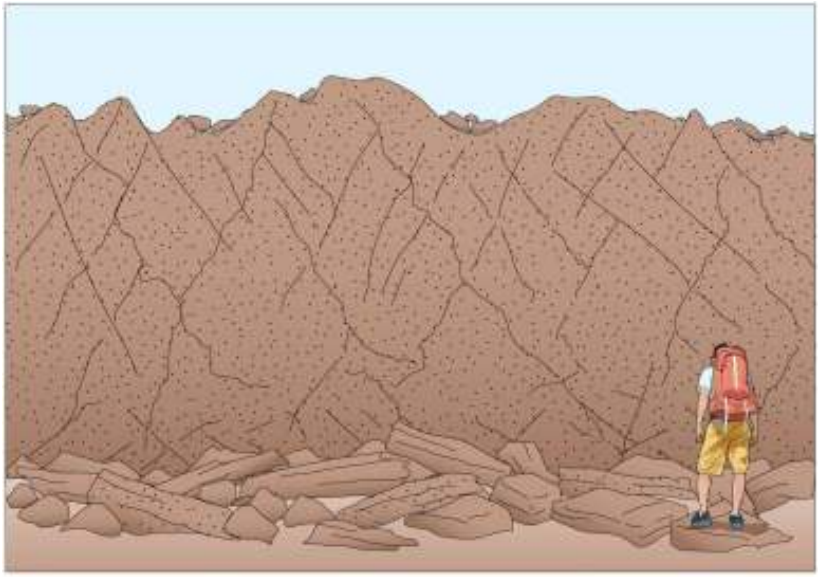
- Paleoceanography – study of how ocean, atmosphere, and land interactions have produced changes in ocean chemistry, circulation, biology, and climate
  - Marine sediments provide clues to past changes.

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

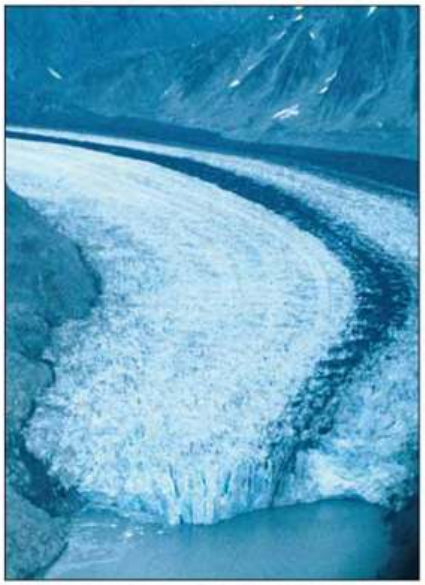
- Eroded rock fragments from land
- Also called terrigenous
- Reflect composition of rock from which derived
- Produced by weathering
  - Breaking of rocks into smaller pieces



Lithogenous Sediments

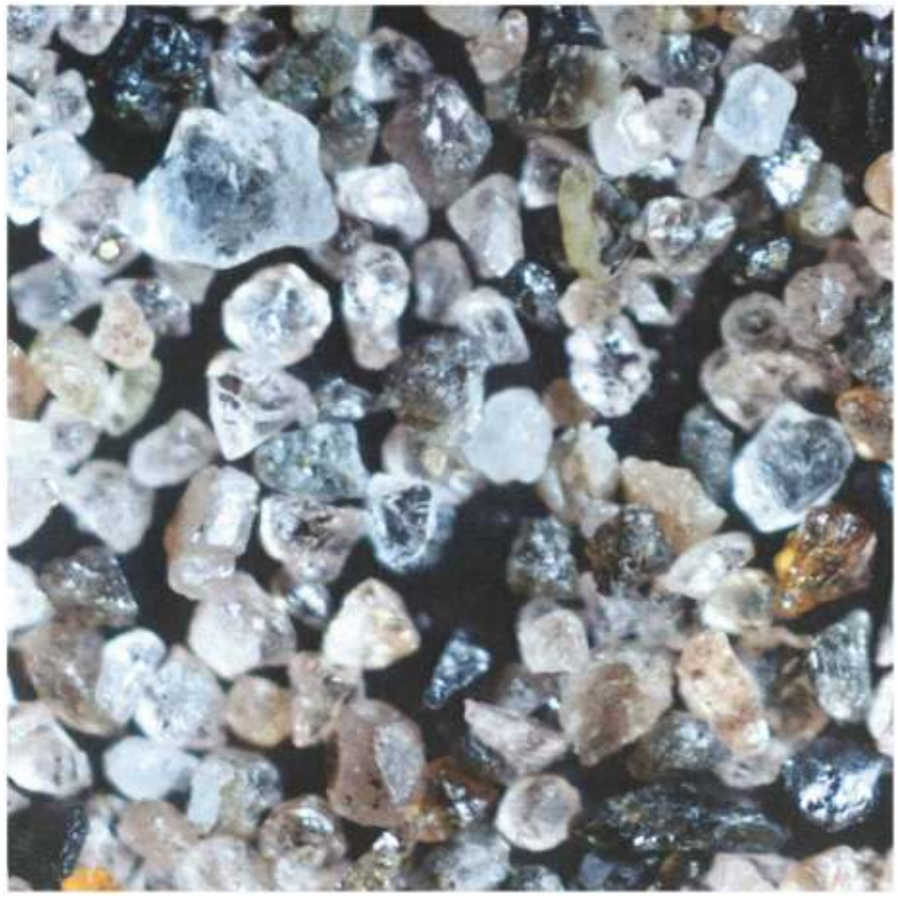
- Small particles eroded and transported
- Carried to ocean
  - Streams
  - Wind
  - Glaciers
  - Gravity
- Greatest quantity around continental margins

Lithogenous Sediment Transport

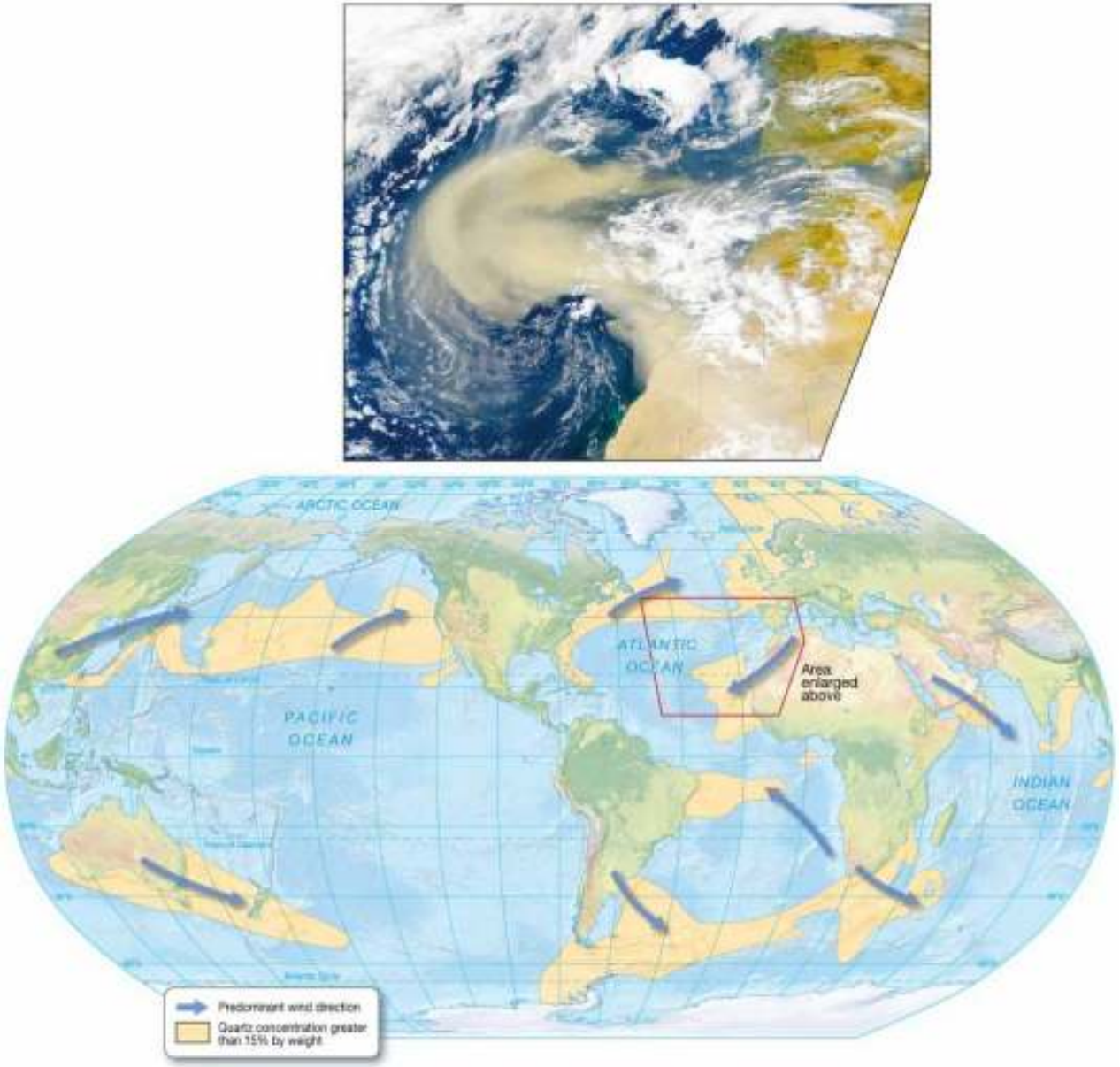


Lithogenous Sediments

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



Lithogenous Quartz and Wind Transport



Grain Size

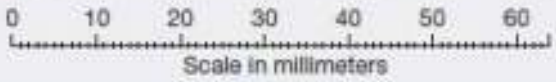
- One of the most important sediment properties
- Proportional to energy of transportation and deposition
- Classified by Wentworth scale of grain size

Wentworth Scale of Grain Size

TABLE 4.2 WENTWORTH SCALE OF GRAIN SIZE FOR SEDIMENTS

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

Gravel



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

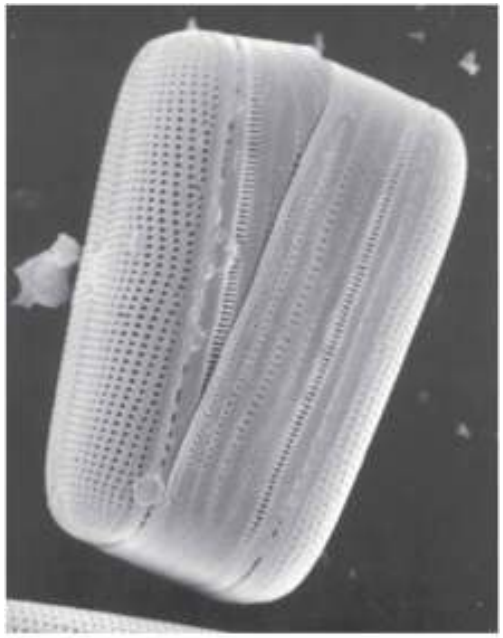
- Hard remains of once-living organisms
- Two major types:
  - Macroscopic
    - Visible to naked eye
    - Shells, bones, teeth
  - Microscopic
    - Tiny shells or tests
    - Biogenic ooze
- Mainly algae and protozoans

Biogenous Sediment Composition

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

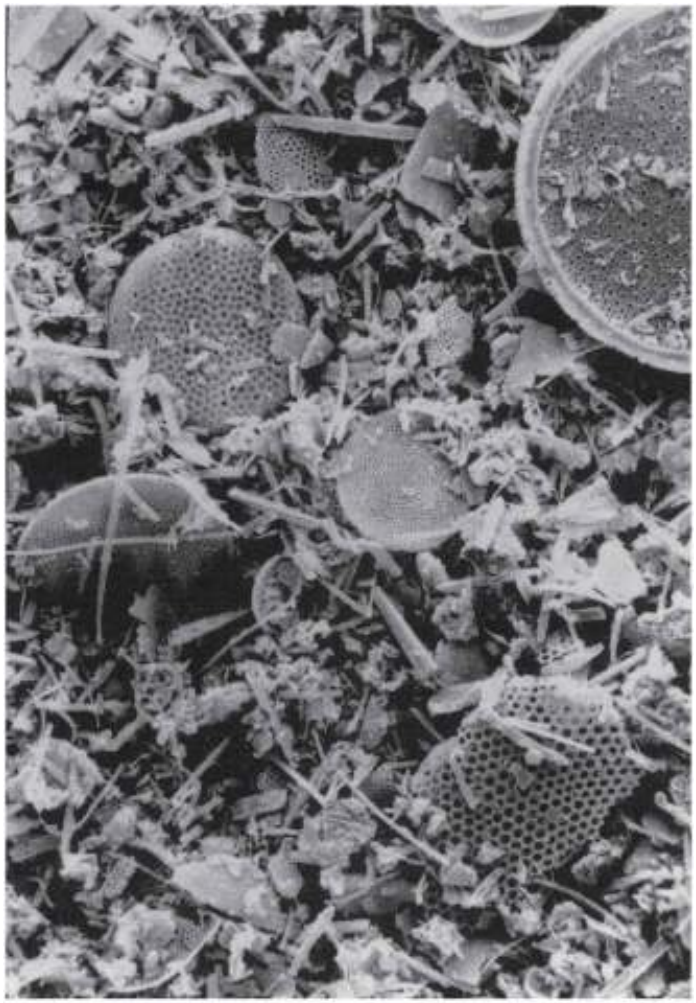
Silica in Biogenous Sediments

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



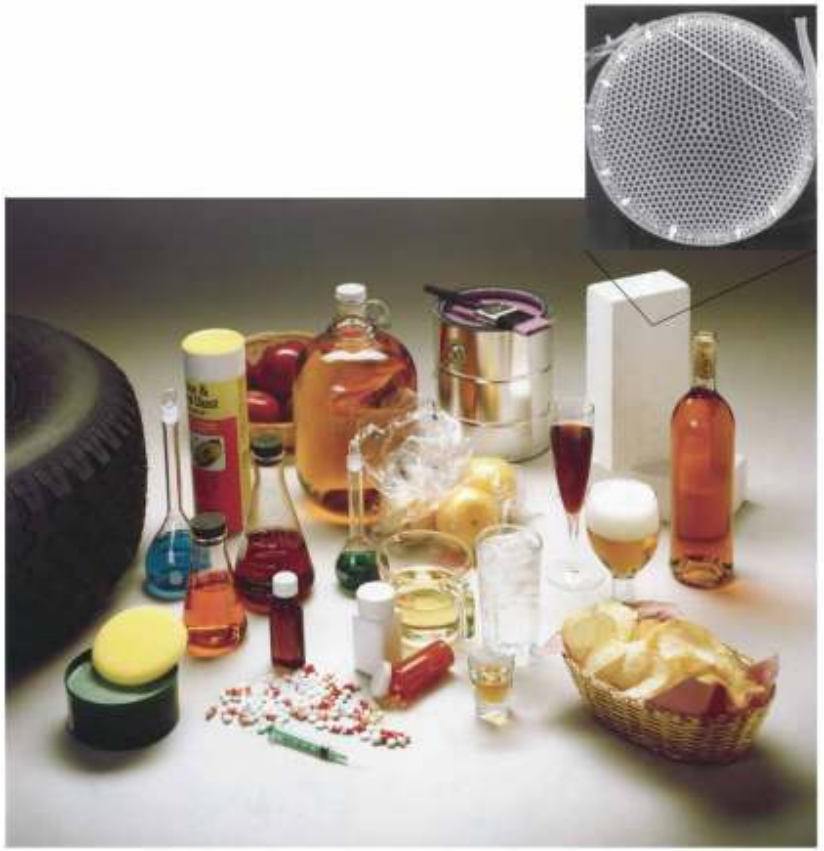
Silica in Biogenous Sediments

- 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.

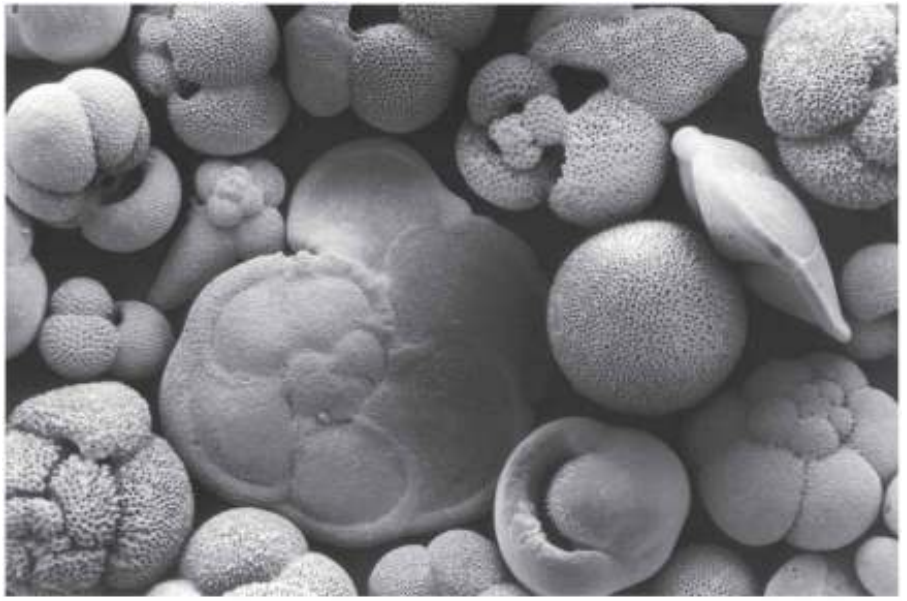


Calcium Carbonate in Biogenic Sediments

- 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

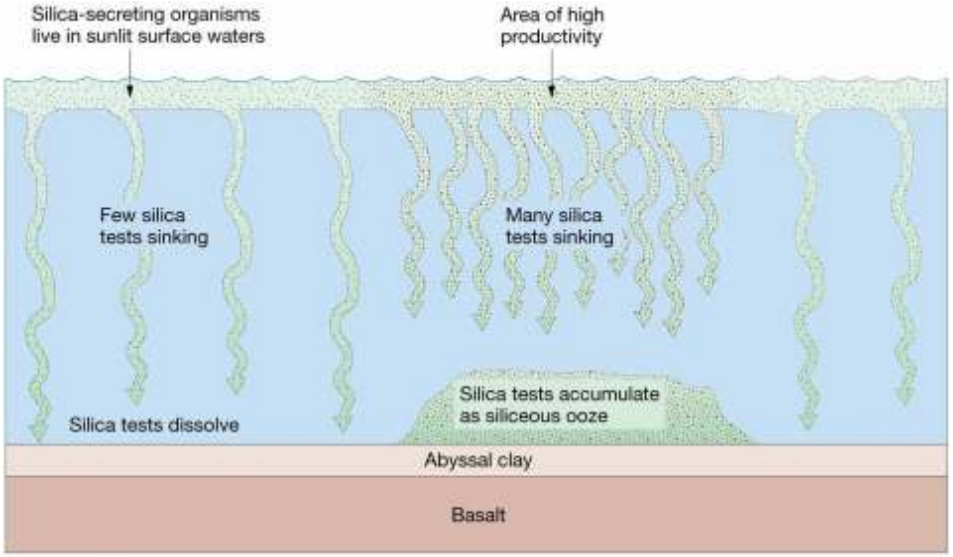


Distribution of Biogenous Sediments

- 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 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.

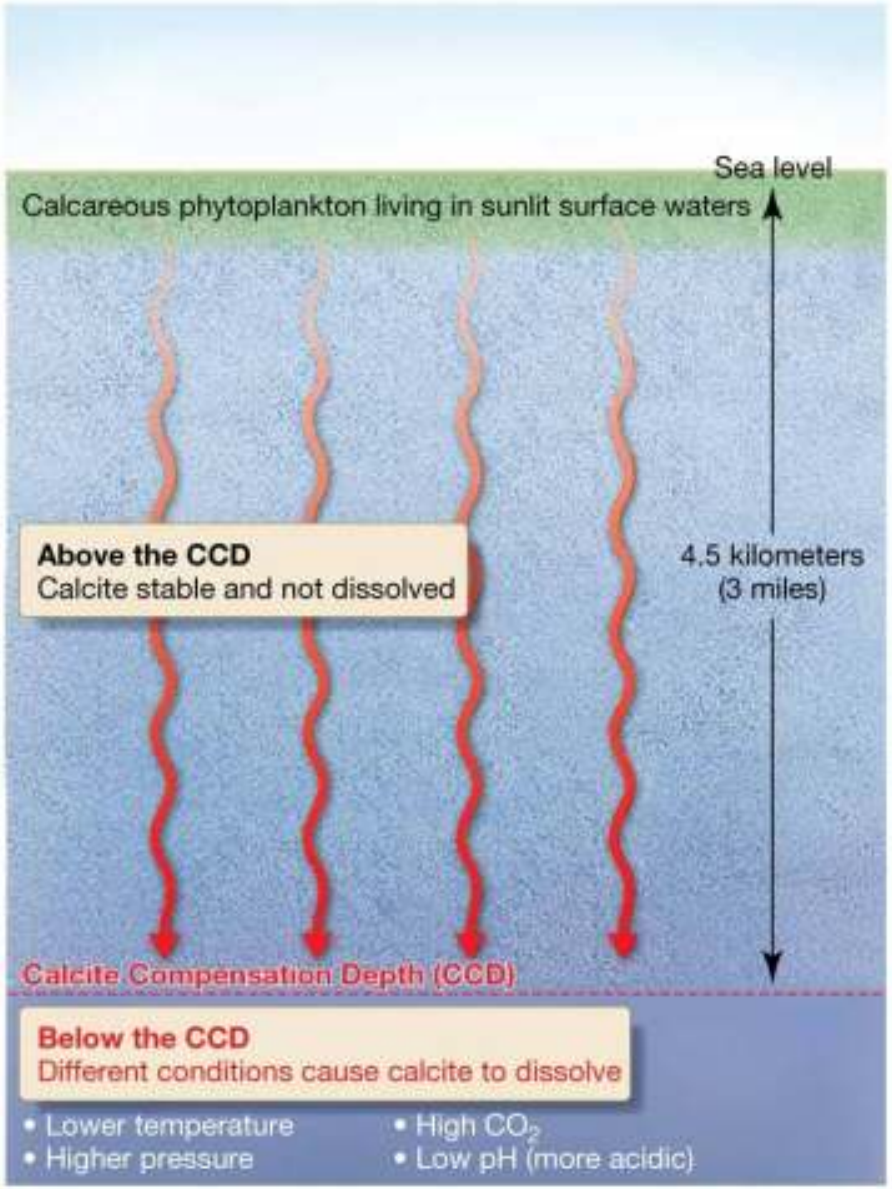
Carbonate Deposits

- Stromatolites
  - Fine layers of carbonate
  - Warm, shallow-ocean, high salinity
  - Cyanobacteria
- Lived billions of years ago
- Modern stromatolites live near 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
  - Lysocline – depth at which *a significant amount of* $CaCO_3$ begins to dissolve rapidly

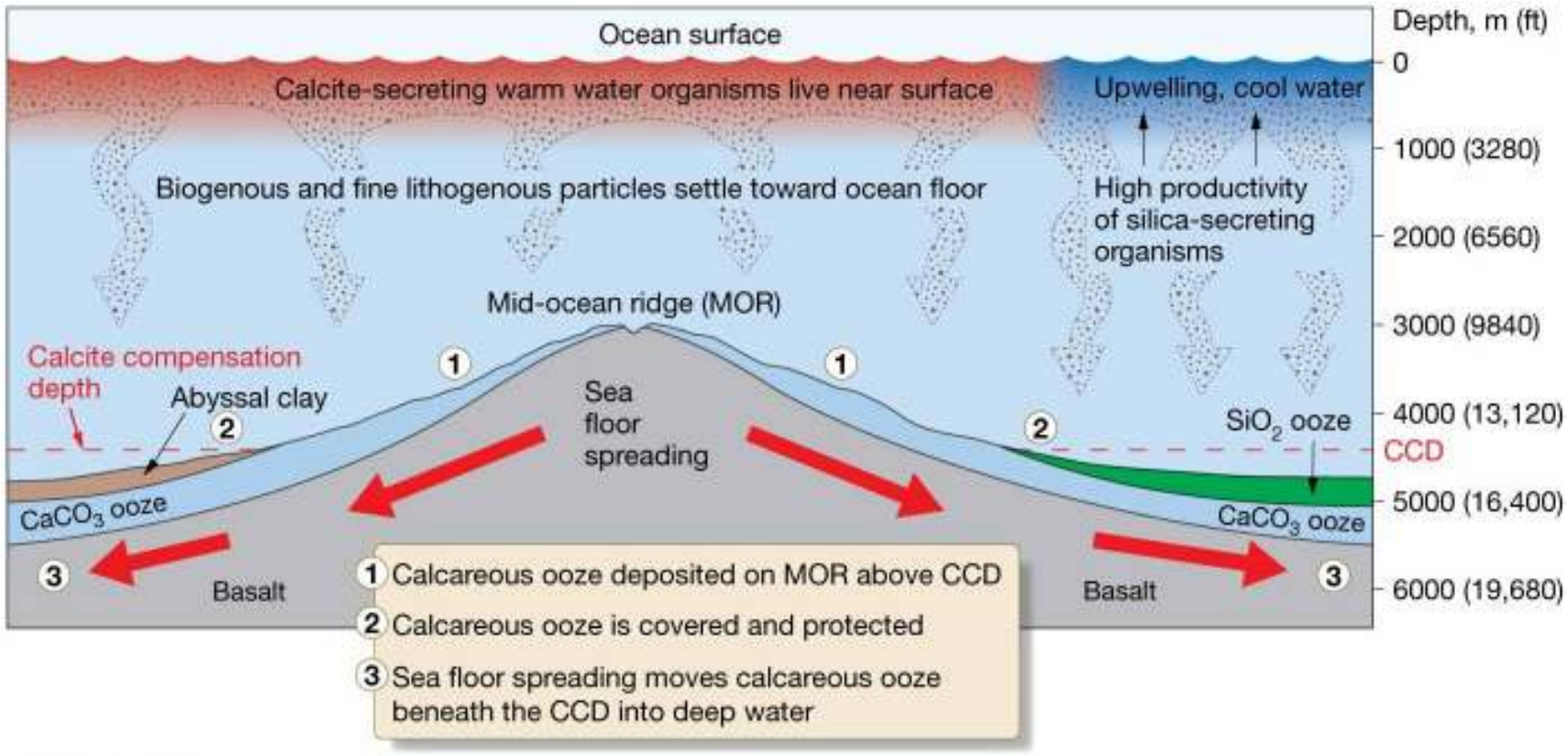
Calcareous Ooze and the CCD



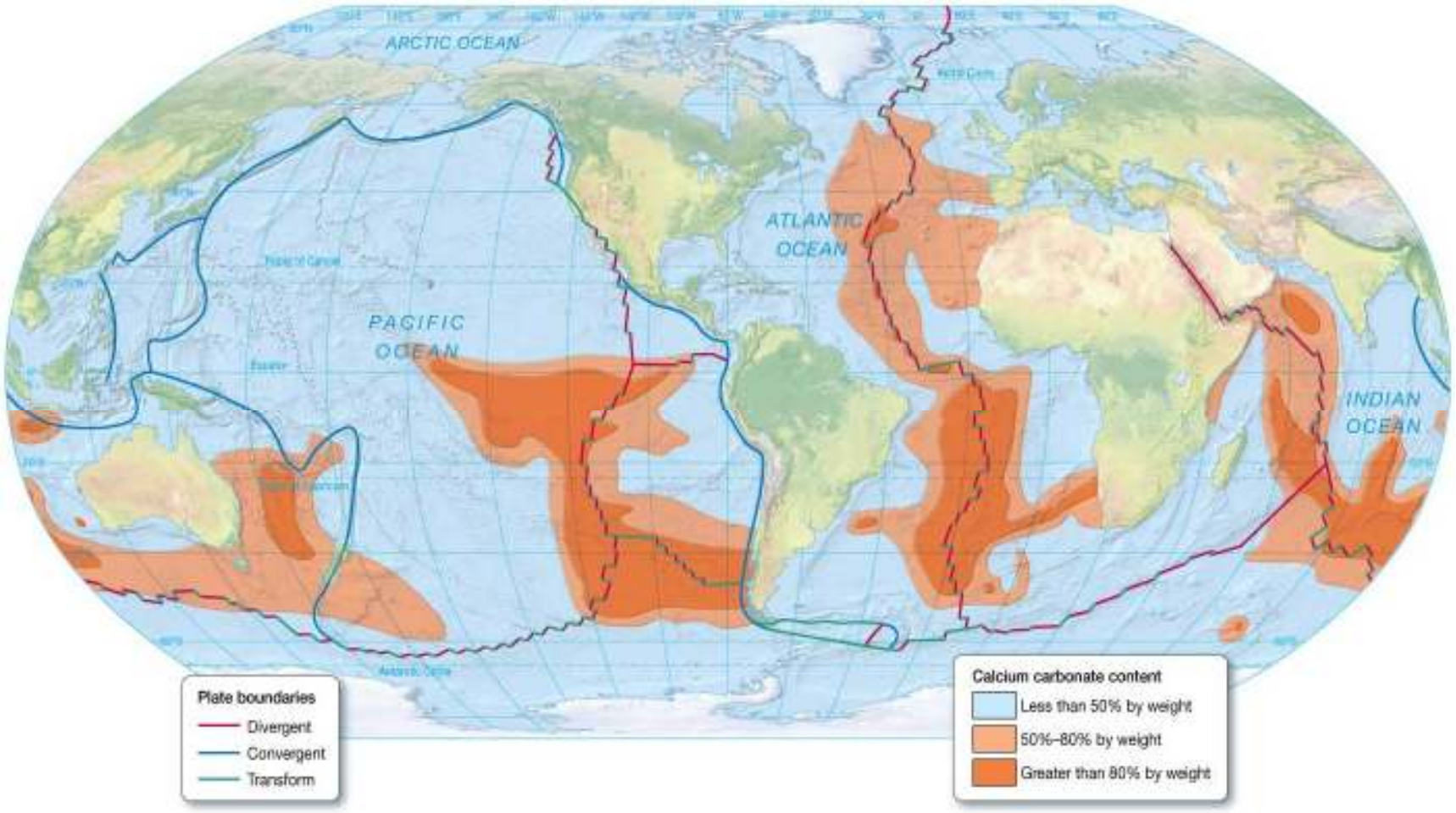
Calcareous Ooze and the CCD

- 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



Distribution of Modern Calcium Carbonate Sediments



Environmental Conditions for Oozes

TABLE 4.3 COMPARISON OF ENVIRONMENTS INTERPRETED FROM DEPOSITS OF SILICEOUS AND CALCAREOUS OOZE IN SURFACE SEDIMENTS

	Siliceous ooze	Calcareous ooze
Surface water temperature above sea floor deposits	Cool	Warm
Main location found	Sea floor beneath cool surface water in high latitudes	Sea floor beneath warm surface water in low latitudes
Other factors	Upwelling brings deep, cold, nutrient-rich water to the surface	Calcareous ooze dissolves below the CCD
Other locations found	Sea floor beneath areas of upwelling, including along the equator	Sea floor beneath warm surface water in low latitudes along the mid-ocean ridge

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

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

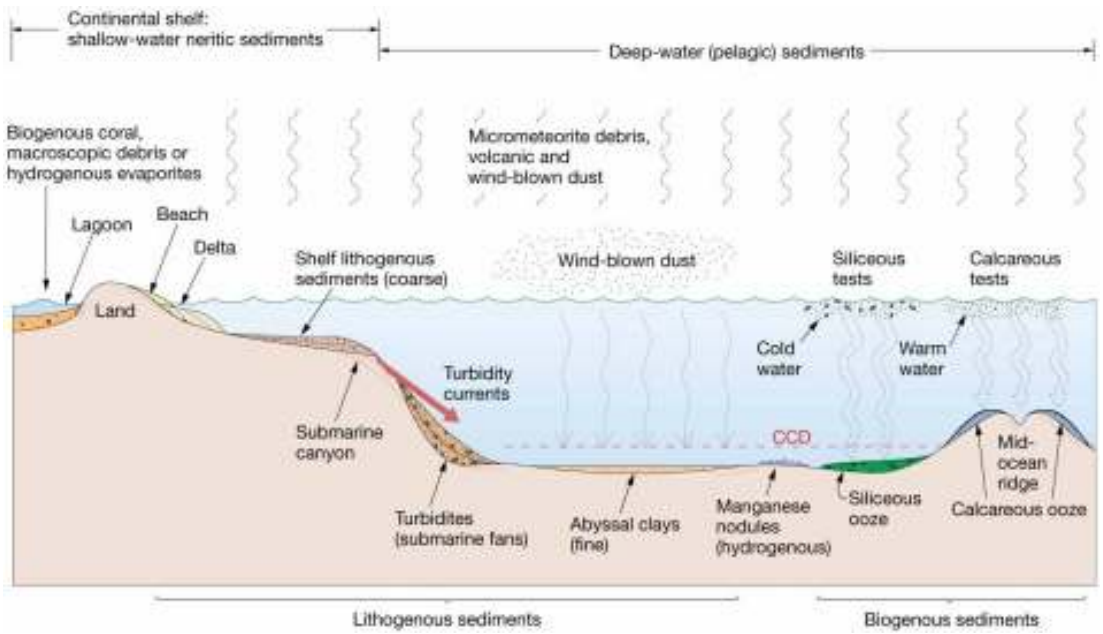
Evaporiative Salts in Death Valley

Cosmogenous Marine Sediments

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

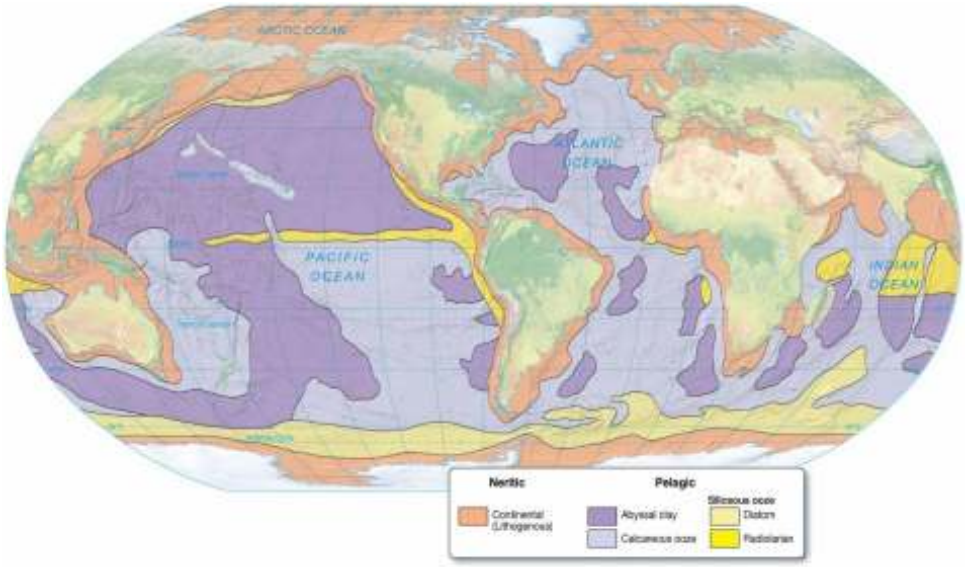
Marine Sediment Mixtures

- Usually mixture of different sediment types
- Typically one sediment type dominates in different areas of the sea floor.



Pelagic and Neritic Sediment Distribution

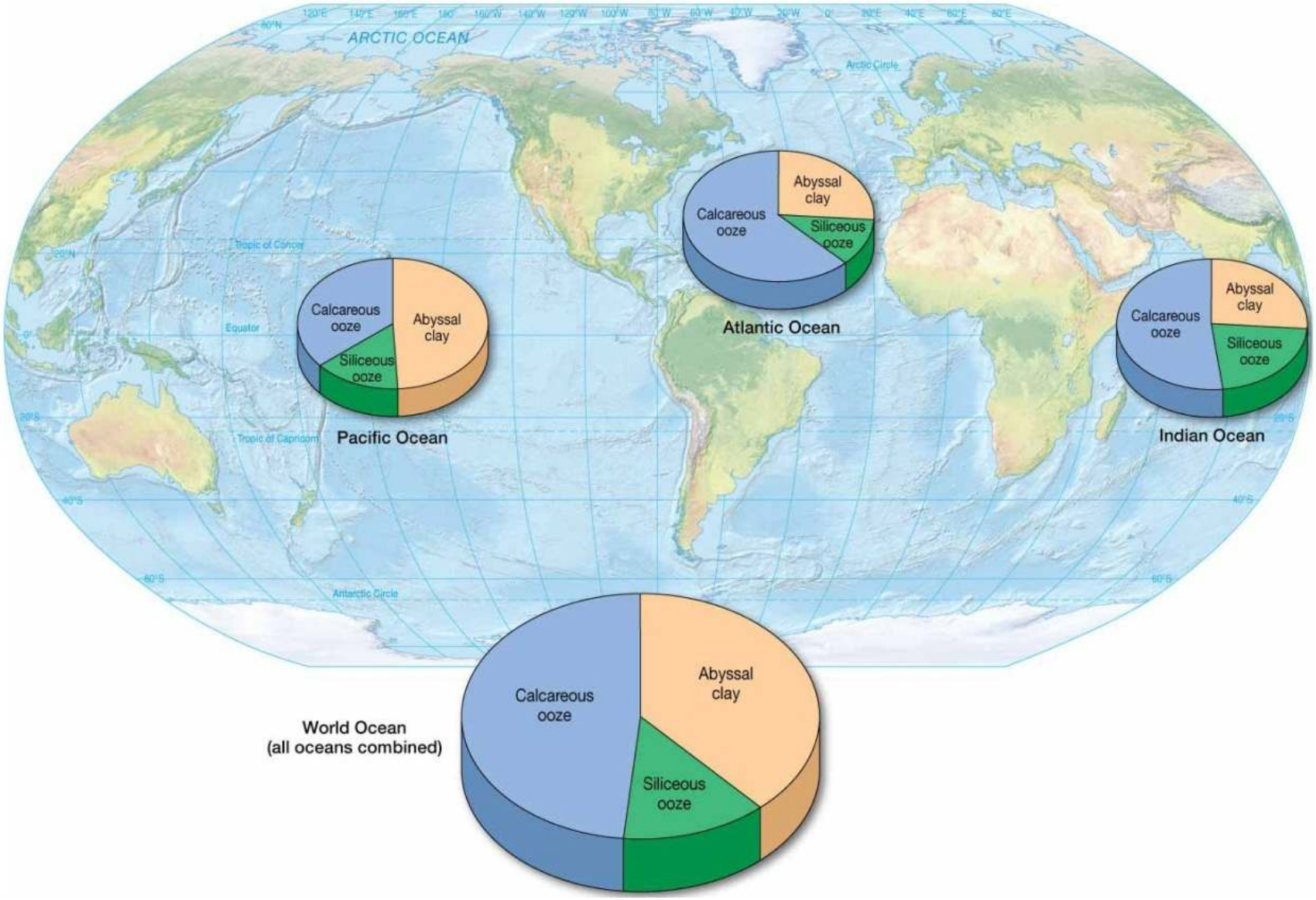
- Neritic sediments cover about ¼ of the sea floor.
- Pelagic sediments cover about ¾ of the sea floor.



Pelagic and Neritic Sediment Distribution

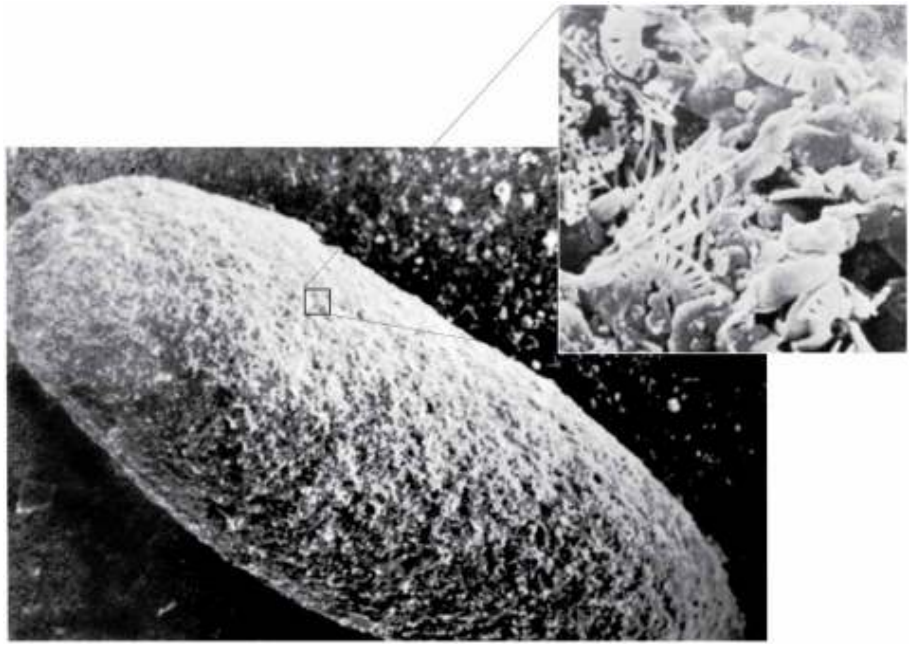
- Distribution controlled by
  - Proximity to sources of lithogenous sediments
  - Productivity of microscopic marine organisms
  - Depth of water
  - Sea floor features

Pelagic Sediment Types

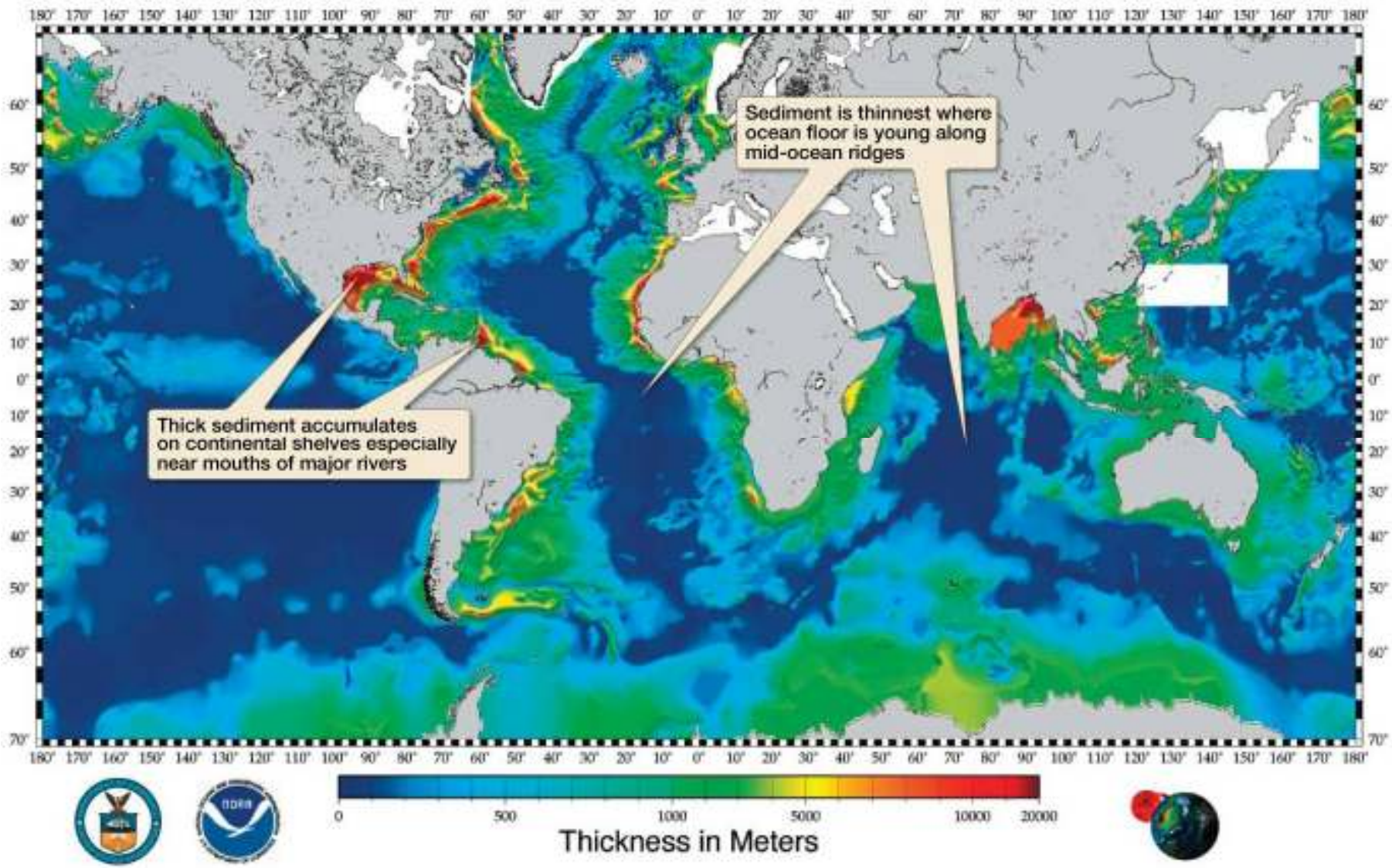


Sea Floor Sediments Represent Surface Ocean Conditions

- 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



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

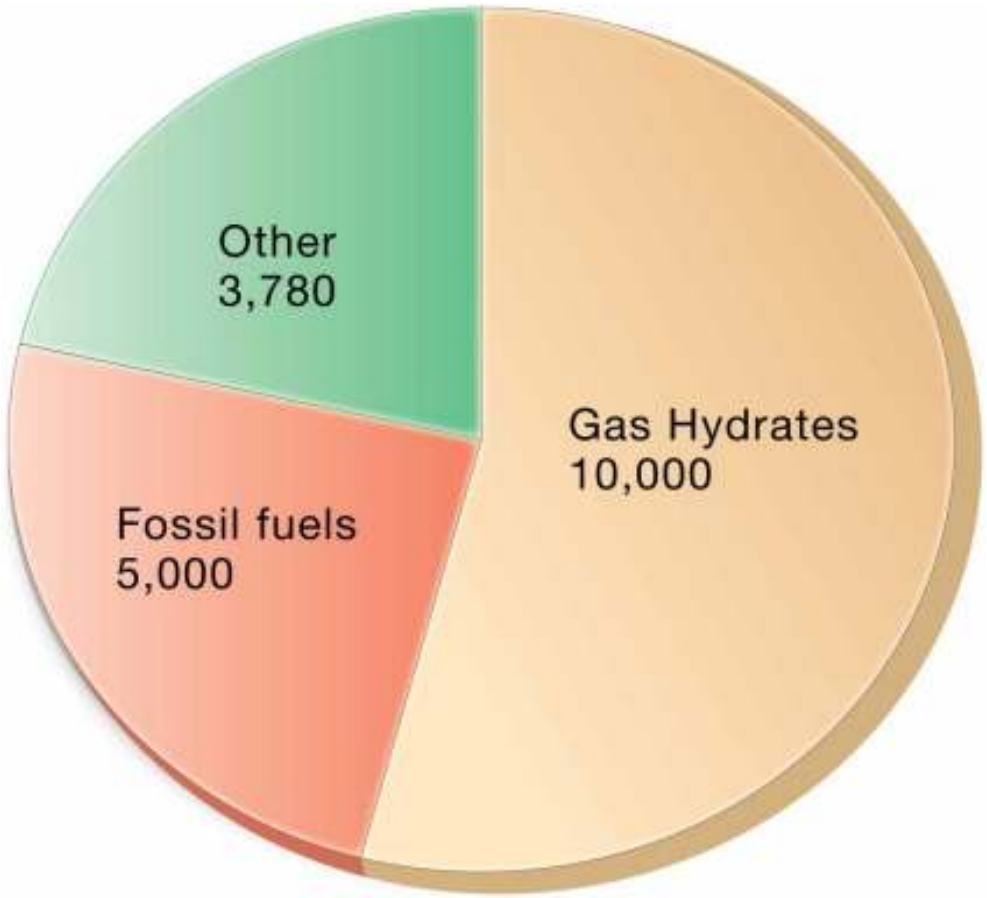
- Gas hydrates resemble ice but burn when lit
- May form on sea floor
  - Sea floor methane supports rich community of organisms
- Most deposits on continental shelf

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

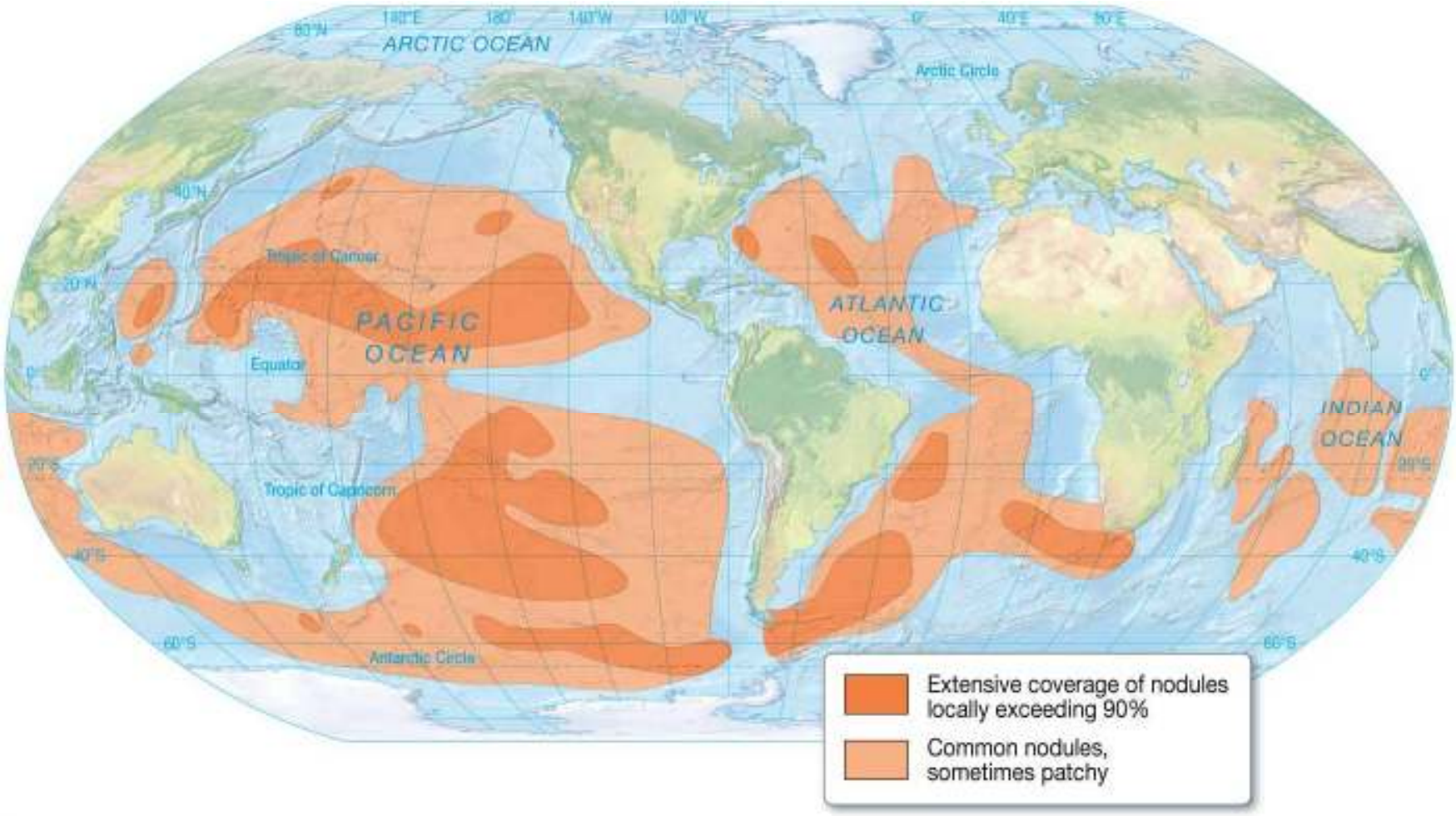
Other Resources

- 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



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