Fundamentals of Earth Sciences (ESO 213A)

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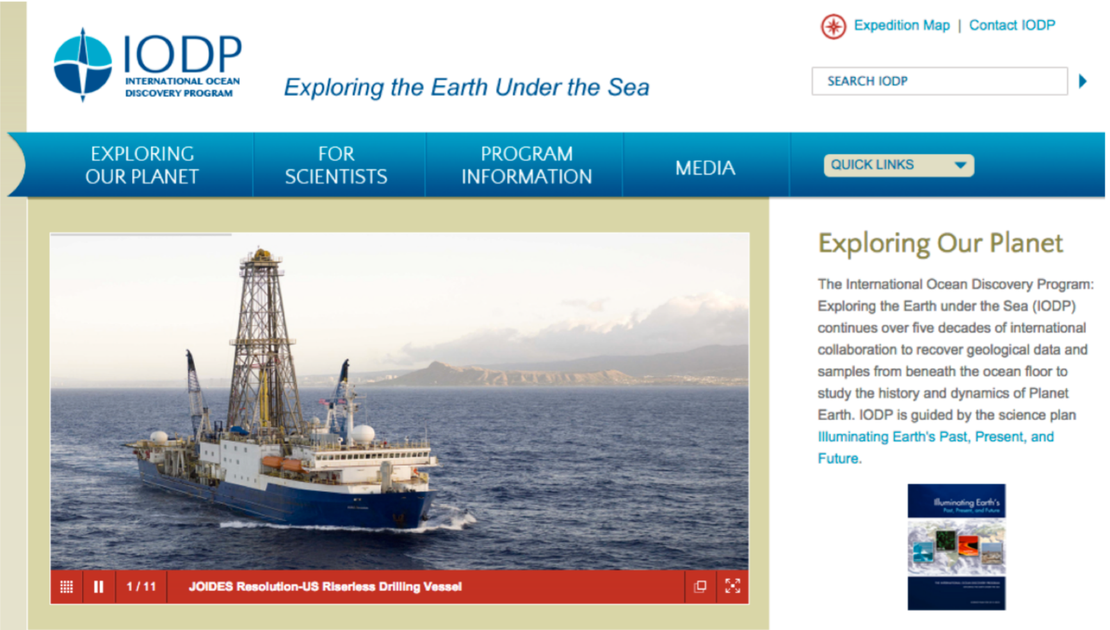


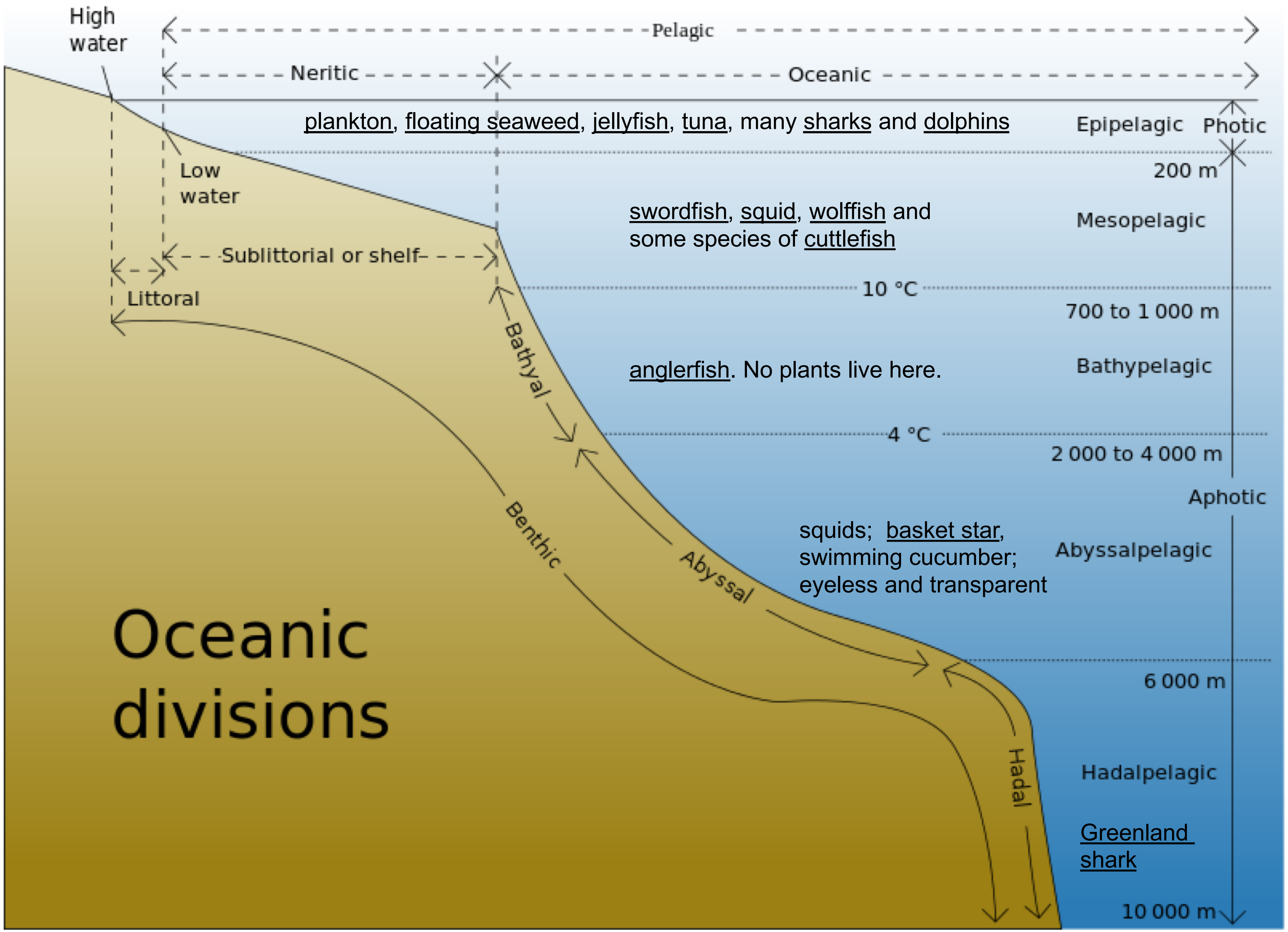
Ocean sediments & acidification

Previous Class: Oceans and winds

Ocean Zones

Based on nutrient supply and sunlight penetration oceanic zones are divided as follows:

1. Littoral zones
2. Neritic zone
3. Photic zone
4. Aphotic zone
5. Pelazic zone
6. Benthic zone



Significance of ocean sediments

a. Continents are sites of erosion. Ocean is site of deposition.
b. Therefore oceans retain a more complete and organized record of Earth history.
c. Law of superposition (sedimentary layers are deposited in a time sequence, the oldest at the bottom and the youngest at the top)

Categories of Marine Sediments

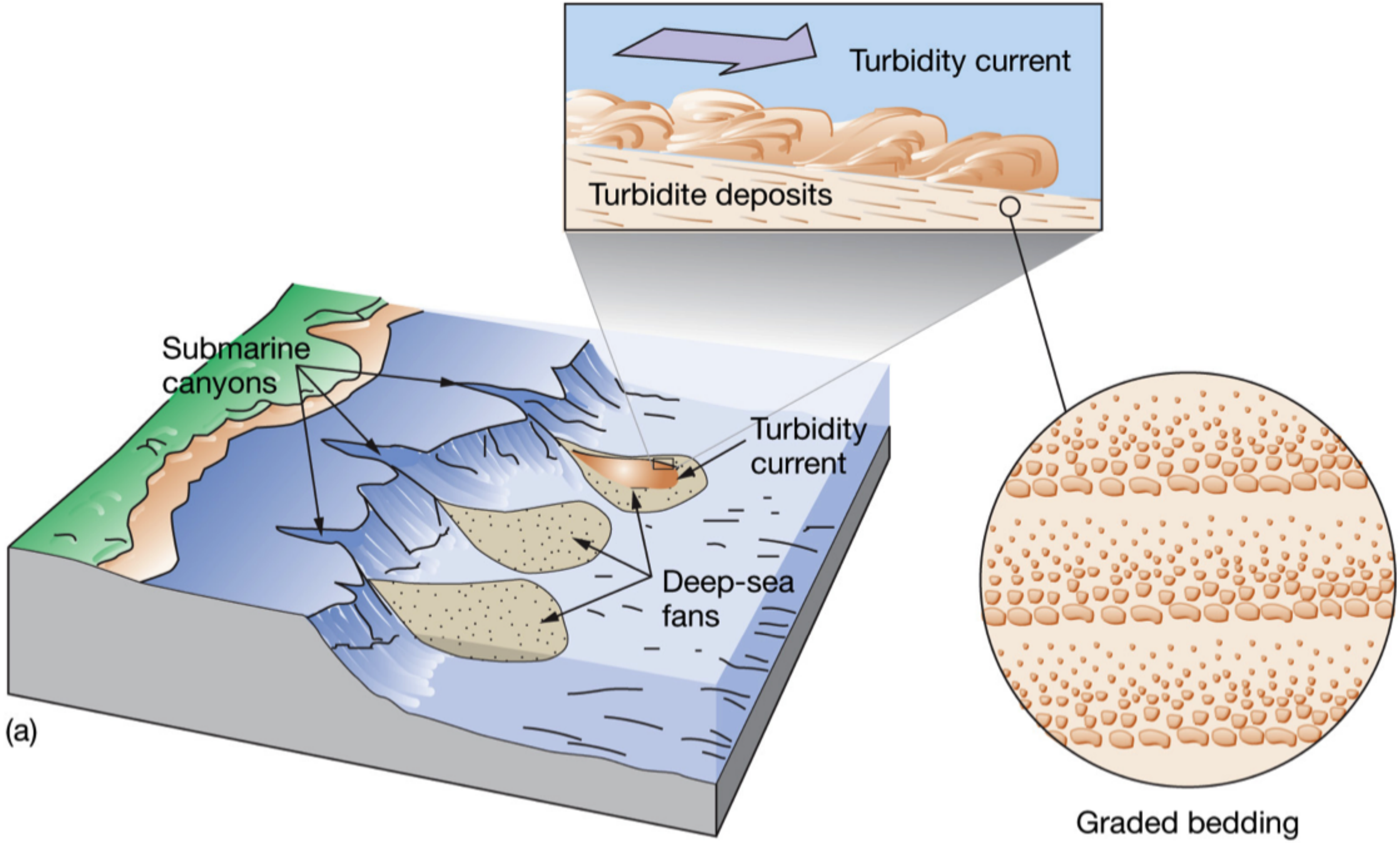
- Classification according to the origin of the components:
- Terrigenous - detritus from continental erosion and explosive vulcanism
- Authigenic-formed insitu by precipitation or submarine alteration
- Biogenic-shells or skeletons of organisms that sink to the sea floor after the organisms death; made of silicate or carbonate
- Cosmogenous-from extraterrestrial

Terrigenous: “from land”.

1. **Desert sand** blows off continent to ocean
2. **Volcanic eruptions-** dust and magma
3. **Rivers**- sediments transported onto continental shelves

4. **Turbidity Currents:** Avalanches of muddy ocean waters made heavy by terrigenous sediments. They flow down continental slopes and submarine canyons forming continental rise. Sorted by size of sediments… **gravel-sand-silt-clay**.

Mt. St. Helens


Turbidity current
Turbidite deposits
Submarine canyons
Turbidity current
Deep-sea fans
(a)
Graded bedding

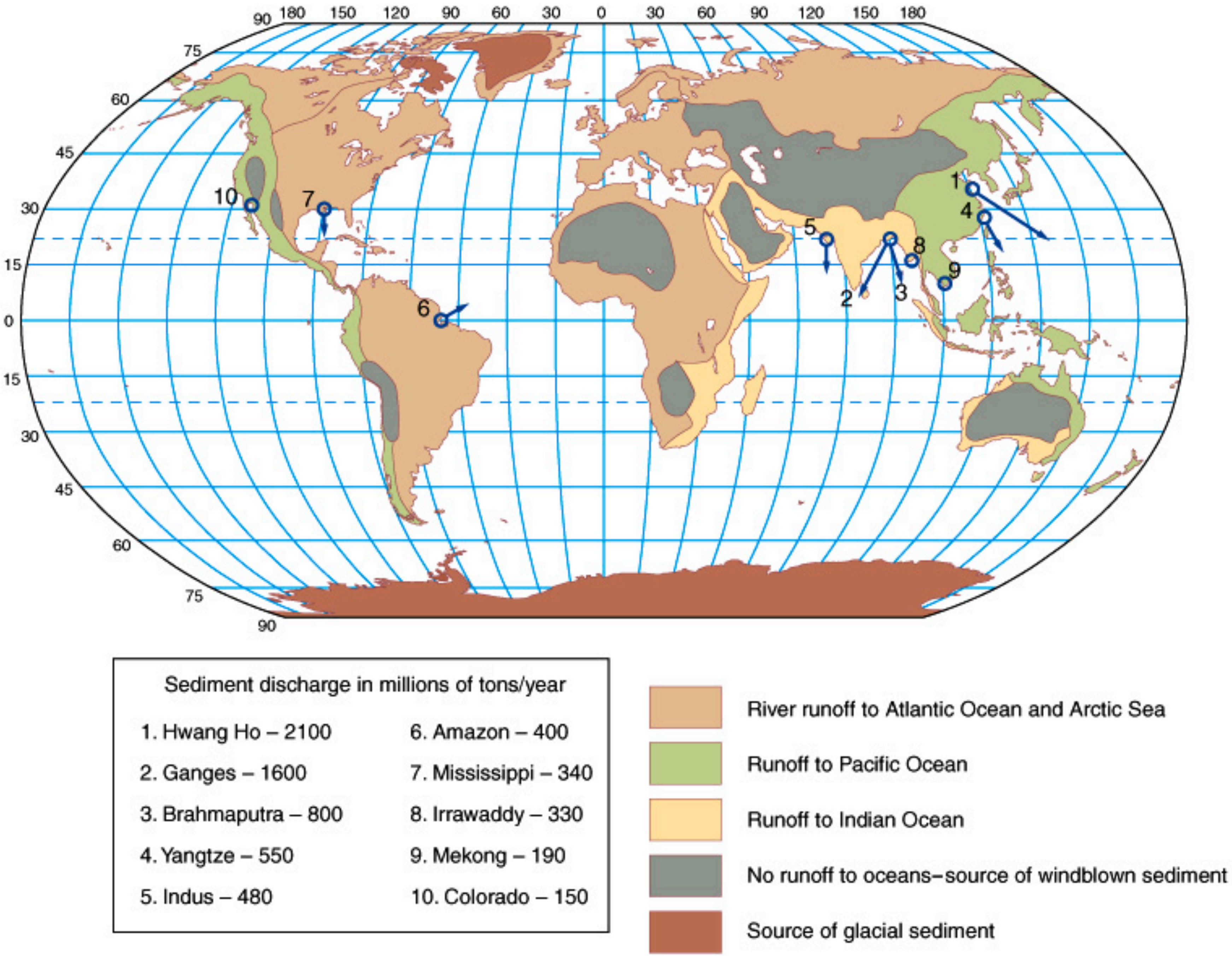
Terrigenous material to the continental margins:

- Mostly lithogenous sediments at continental margins
- Coarser sediments closer to shore
- Finer sediments farther from shore.
- Mainly mineral quartz (SiO_2).

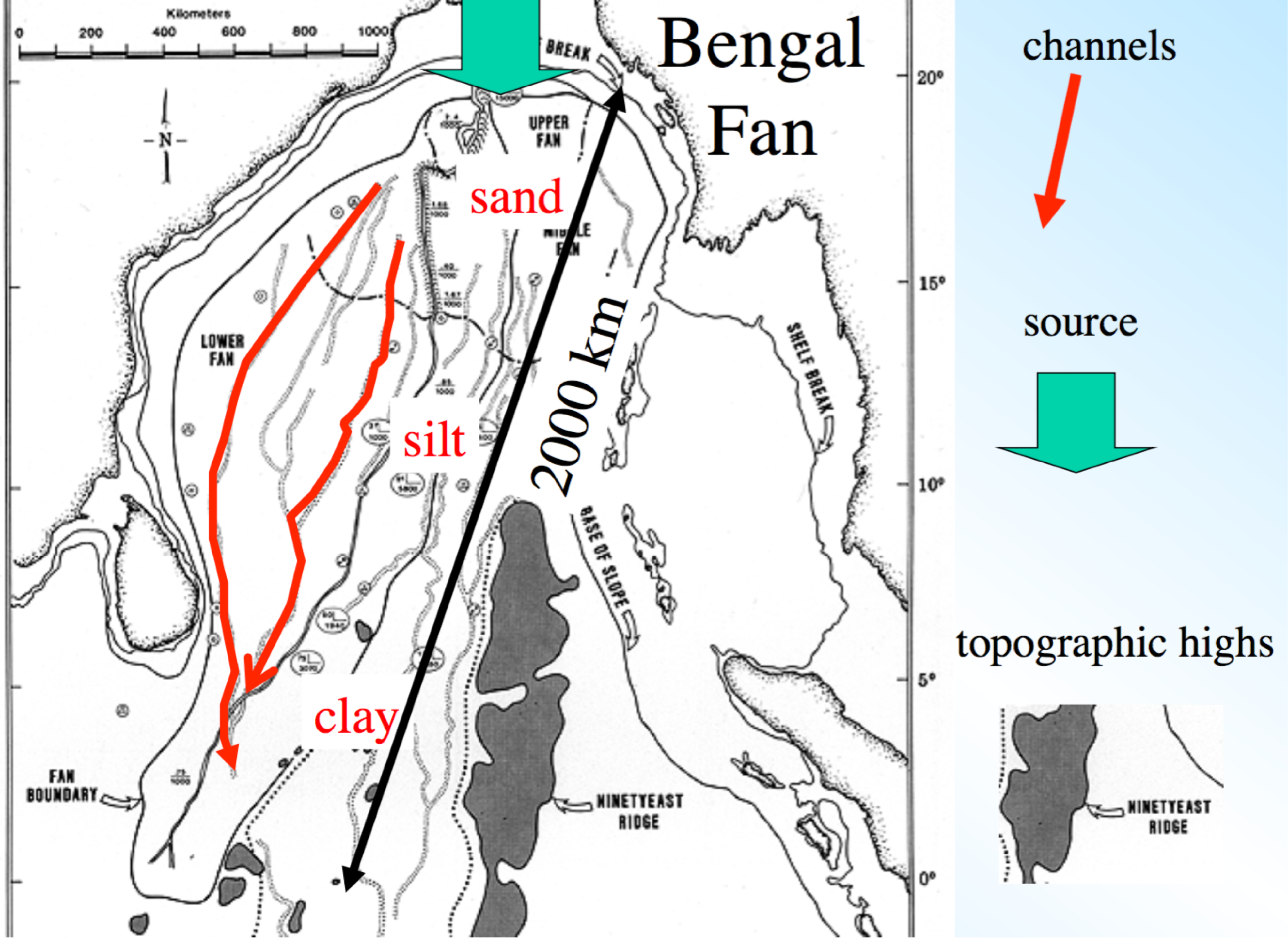
Terrigenous material to the deep sea:

- Volcanic ash, tephra
- Sand to silt sized fragments of glass exploded into the atmosphere and transported by wind
- Useful as a stratigraphic marker
- Useful for regional volcanic history
- Eolian (wind-borne dust); useful for paleo-wind direction and paleo-desert location;
- Glacial marine; dropped from icebergs, useful for paleo-ice-extent;
- Deep sea clays accumulate at very slow rates (meters per millions of years)

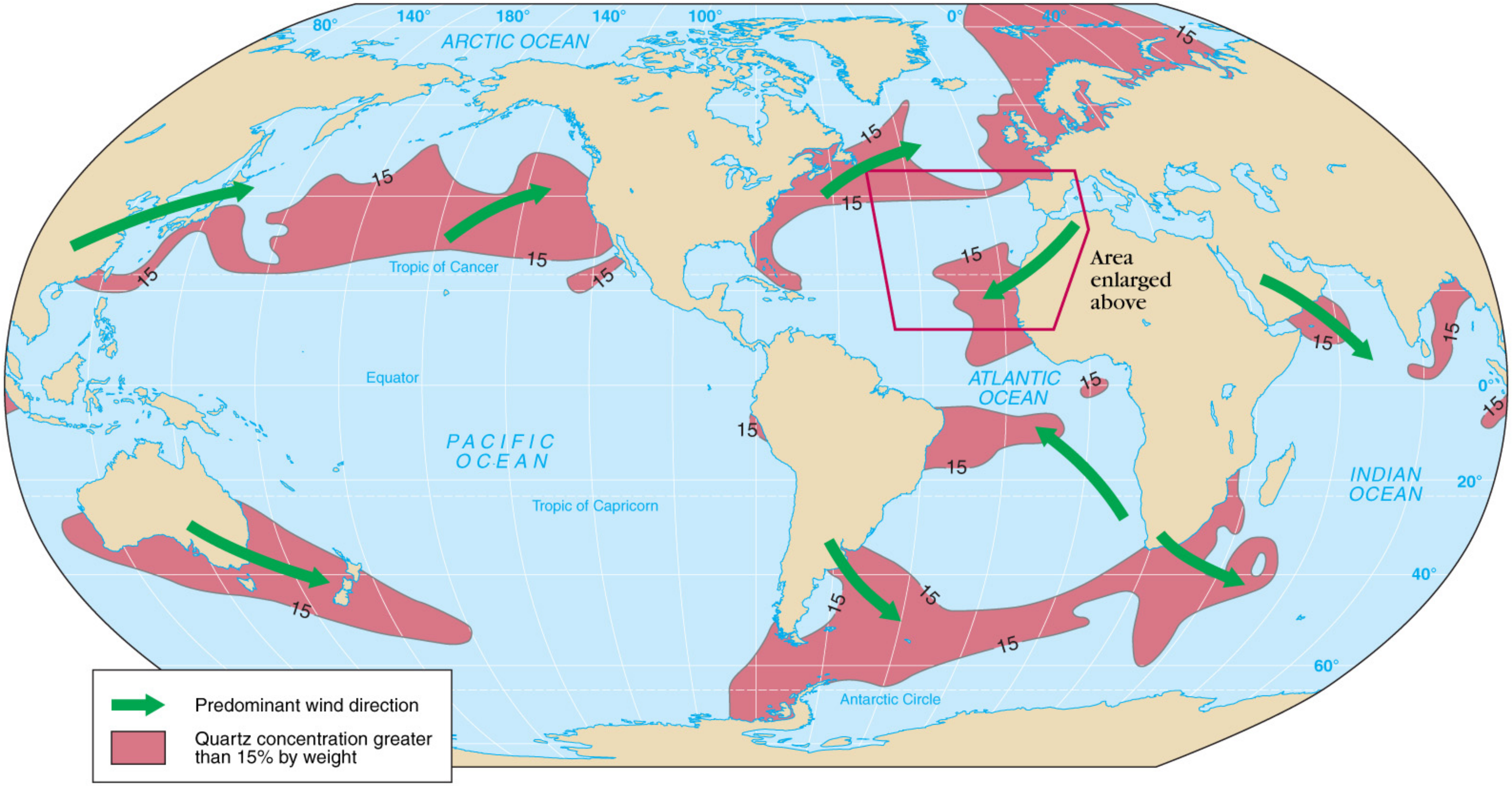
Water



Sediment discharge in millions of tons/year
1. Hwang Ho – 2100
2. Ganges – 1600
3. Brahmaputra – 800
4. Yangtze – 550
5. Indus – 480
6. Amazon – 400
7. Mississippi – 340
8. Irrawaddy – 330
9. Mekong – 190
10. Colorado – 150
River runoff to Atlantic Ocean and Arctic Sea
Runoff to Pacific Ocean
Runoff to Indian Ocean
No runoff to oceans–source of windblown sediment
Source of glacial sediment


Bengal Fan
Kilometers
0 200 400 600 800 1000
N
BREAK
UPPER FAN
LOWER FAN
sand
silt
clay
2000 km
SHELF BREAK
BASE OF SLOPE
FAN BOUNDARY
NINETYEAST RIDGE
20°
15°
10°
5°
0°
channels
source
topographic highs
NINETYEAST RIDGE

Relationship of fine-grained quartz and prevailing winds



~ fine grained clay particles from wind can make up about 38% of deep sea sediment

Authigenic sediment sources

Form when dissolved materials come out of solution as **precipitates or evaporates**.

Precipitation is caused by a change in conditions including:

a. Changes in **temperature** (evaporation)
b. Changes in **pressure**
c. Addition of chemically active fluids (**like CO_2**)

Types of authigenic/hydrogenous sediment:

1. **Manganese nodules**
2. **Phosphates**
3. **Carbonates**
4. **Metal sulfides**
5. **Evaporite salts**

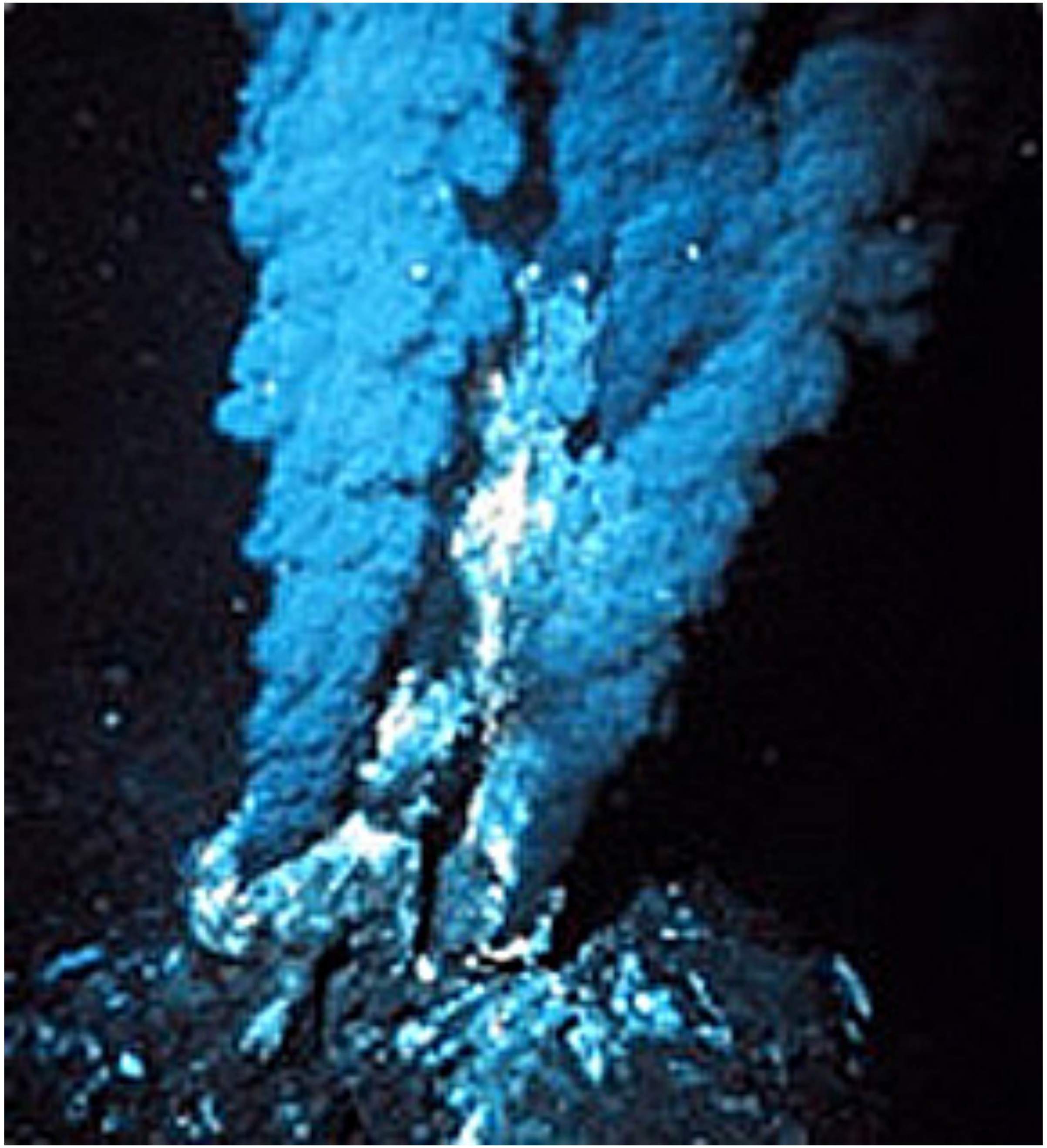
Manganese nodules

1. 1st discovered by **Challenger** expedition (**1873**)
2. **16 million tons** accumulate each year
3. Growth rate: **1-10 mm** every million years
4. Potato to beachball size- grow from nucleii of bone or teeth.
5. **Manganese** and **iron oxides**. Also, Co, Cr, Ni, Cu, Mb, and Zn.

Metal sulfides

Near hydrothermal vents, lots of metal ions are released into the water, and these ions oxidize or combine with silica and precipitate out as dark, metal-rich (Iron, Nickel, copper, zinc, silver) sediment.

→ less common than lithogenous or biogenous sediments. They are almost never the dominant sediment type.



Black smokers

Phosphorites:

• Deposits as the mineral, apatite, in shallow to mid-depths on continental shelf/slope.

•Typically concentrated in coastal areas with:

• (a)intensive upwelling,

- (b)little or no terrigenous input

Authigenic Sediment Sources - phosphorites

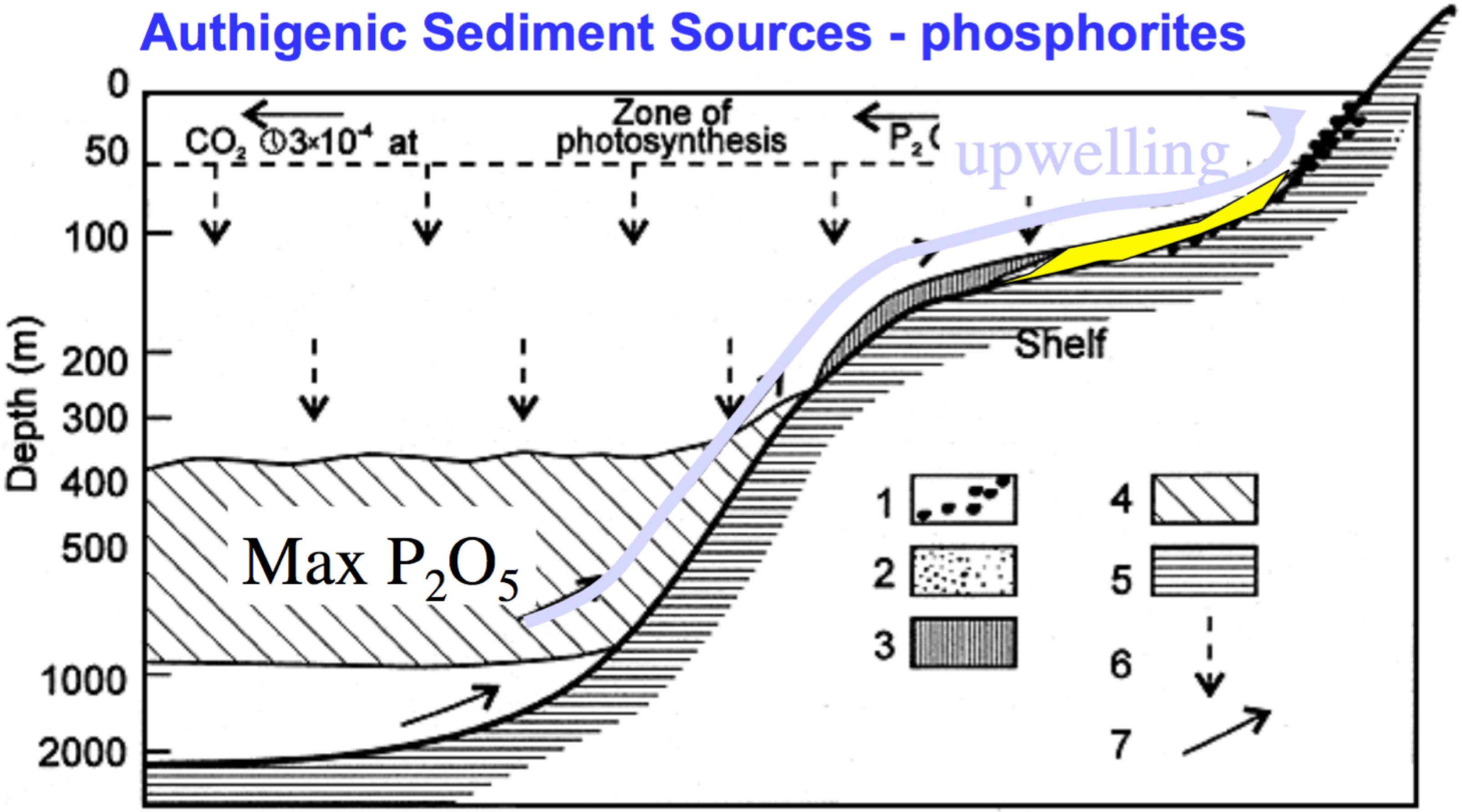
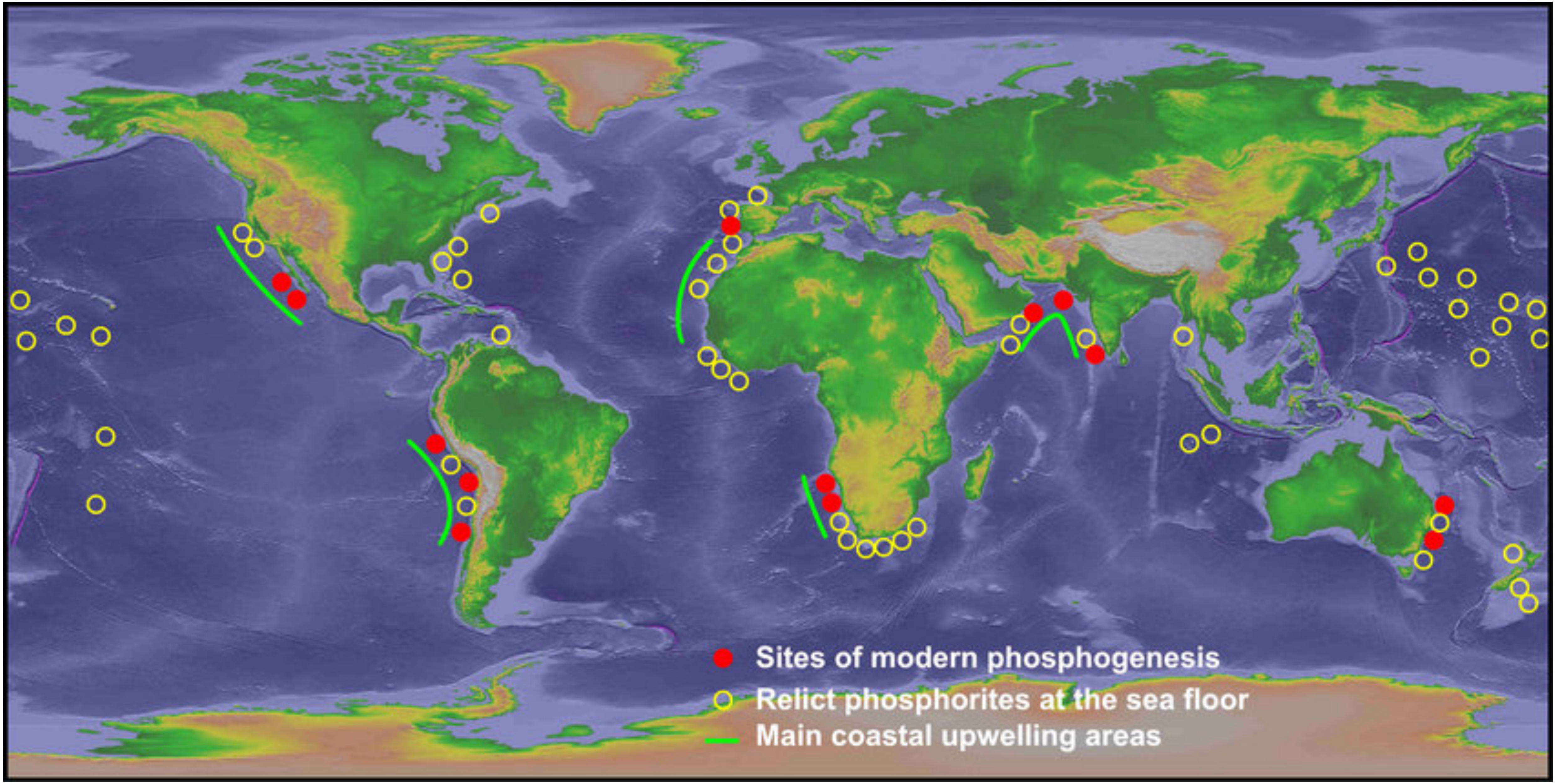


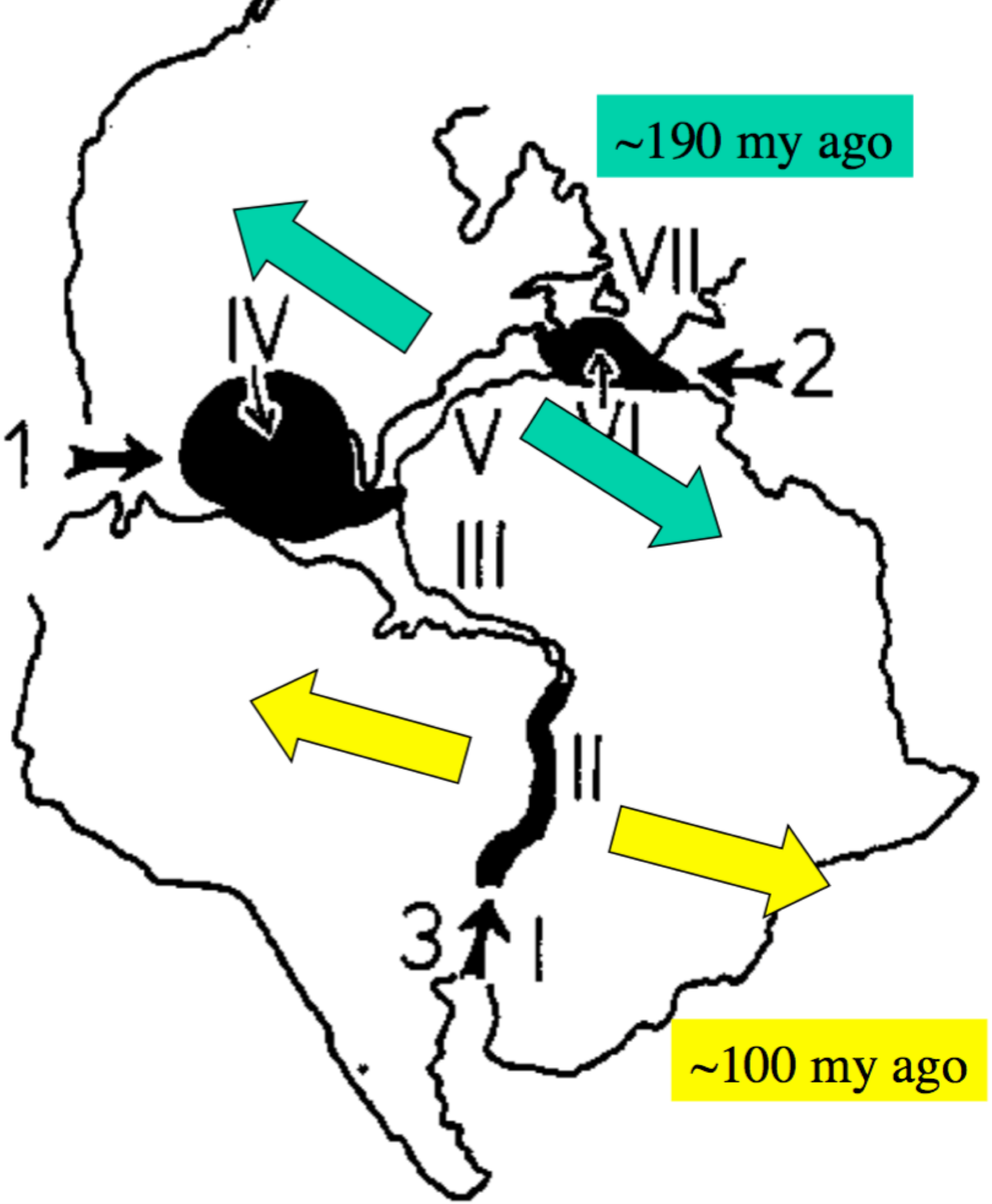
Figure 7.17. Diagram showing the formation of phosphorites (after Kazakov in Strakhov 1962). 1, facies of littoral gravel and sand; 2, phosphate facies; 3, facies of calcareous sediments; 4, zone of maximum CO_2 and organic P_2O_5 content (partial pressure of CO_2 up to 12×10^{-4} atm, P_2O_5 concentration 300-600 mg/m^3); 5, landmass; 6, sedimentation of plankton remains; 7, current directions.

Source: Holland, Heinrich D. and Ulrich Petersen (1995) Living Dangerously: The Earth, Its Resources, and the Environment. New Jersey: Princeton University Press.


Sites of modern phosphogenesis
Relict phosphorites at the sea floor
Main coastal upwelling areas

Evaporites:

- form from evaporation of seawater, (Gypsum, Halite, other Salts)
- Require unusual geological circumstances;
- Examples: (a) Mediterranean isolation from Atlantic ~6mya,
  (b) breakup of Gondwanaland
- As rift valleys form, their floors lie below adjacent oceans



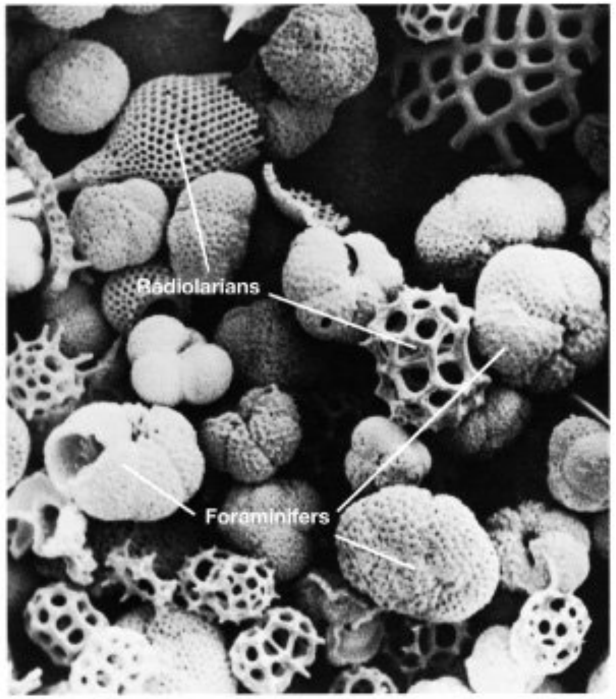
Biogenic Sediment Sources

Biogenic sediments

a. Organisms (marine plants and animals) use dissolved materials delivered from rivers (flux in), especially calcium carbonate and silica

b. Organisms remove these dissolved products from seawater (flux out) to build shells and skeletons.

<u>Oozes</u>: Fine muds with **>30%** biological materials (Shells, bones, teeth of living organisms).



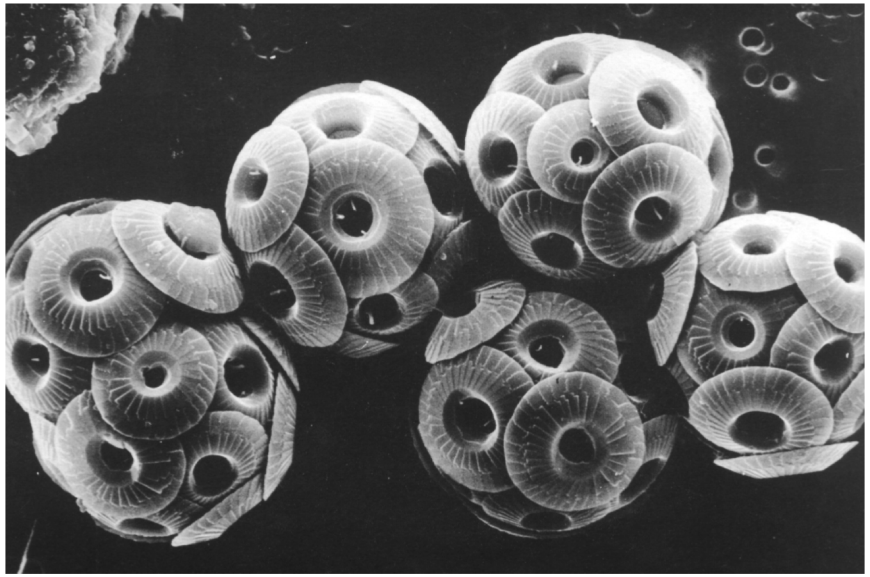
<u>Two Types of Oozes</u>:

1/ calcareous $CaCO_3$

2/ siliceous SiO_3

Abundant where ample **nutrients** encourage high biological **productivity** of **plankton** (**zoo, phyto**).

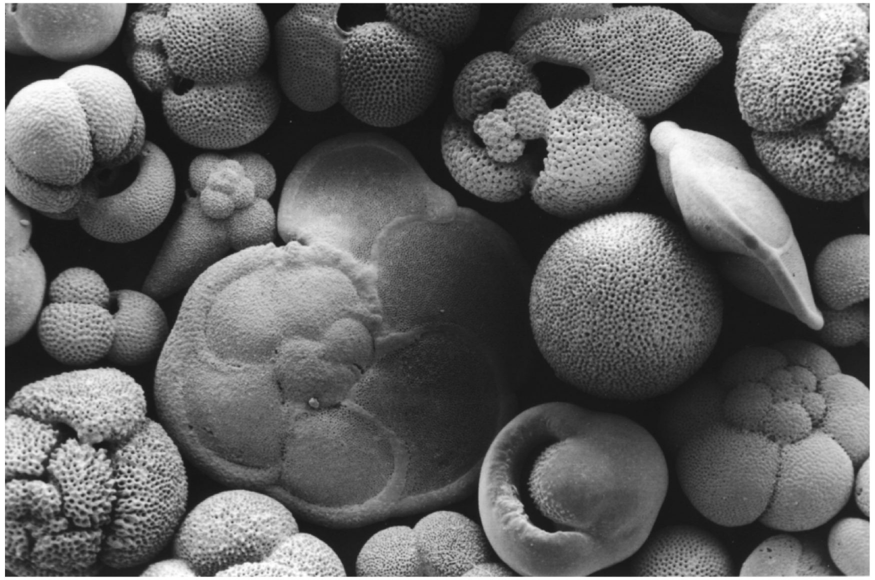
Calcareous Oozes: Composed predominantly of $CaCO_3$ shells of Foraminiferans and Coccolithophores



1. <u>Cocco</u>**lithophores**

(phytoplankton-algae that can bloom over massive areas)

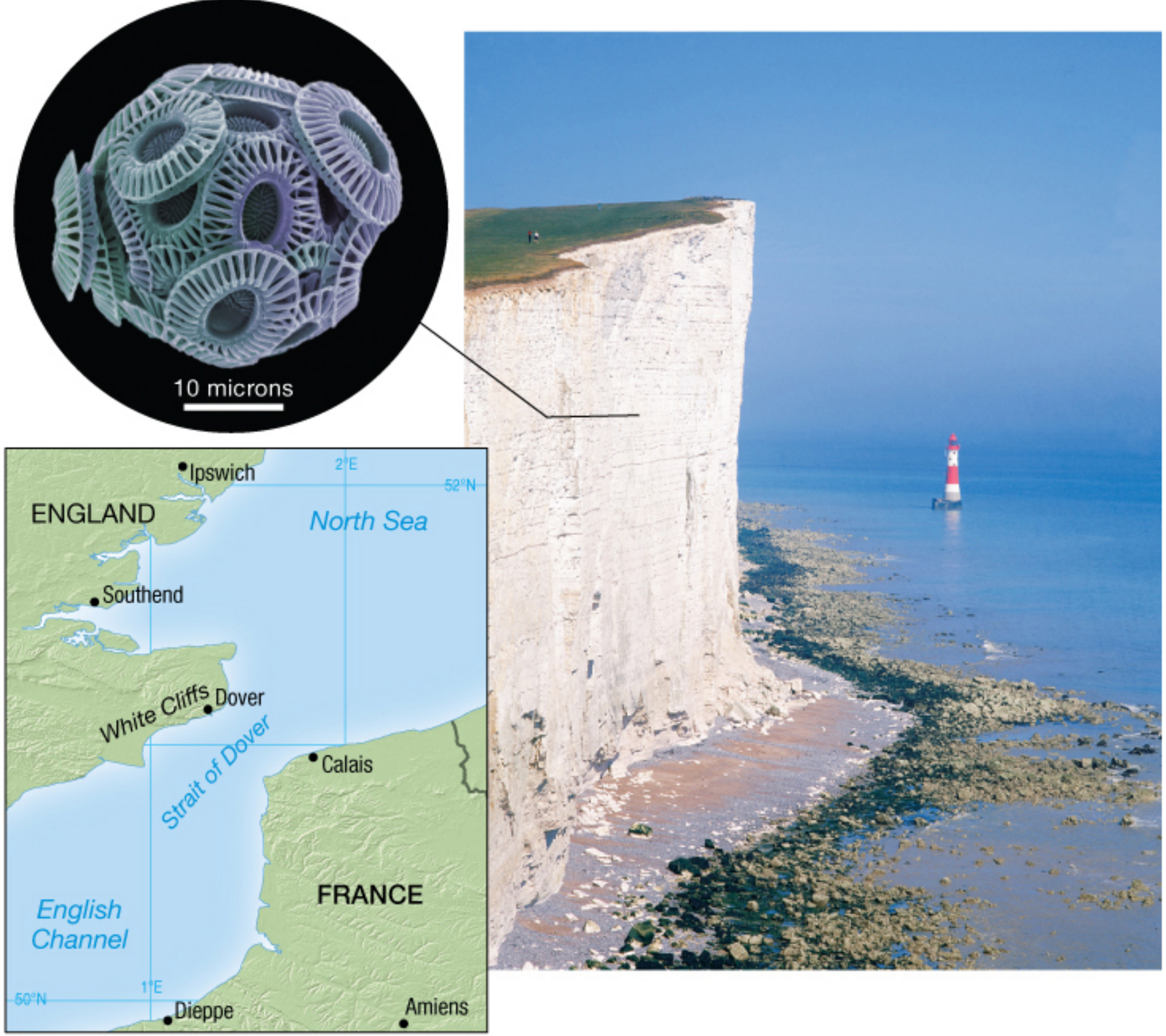
Chalk- Rock made of coccolith rich sediments. White Cliffs of Dover in England.



2. <u>Foraminifers</u>

(zooplankton-protozoa)

Dissolve in deepest waters! Below **CCD** (CaCO3 composition depth)… acidic.



White Cliffs of Dover

Calcareous Ooze

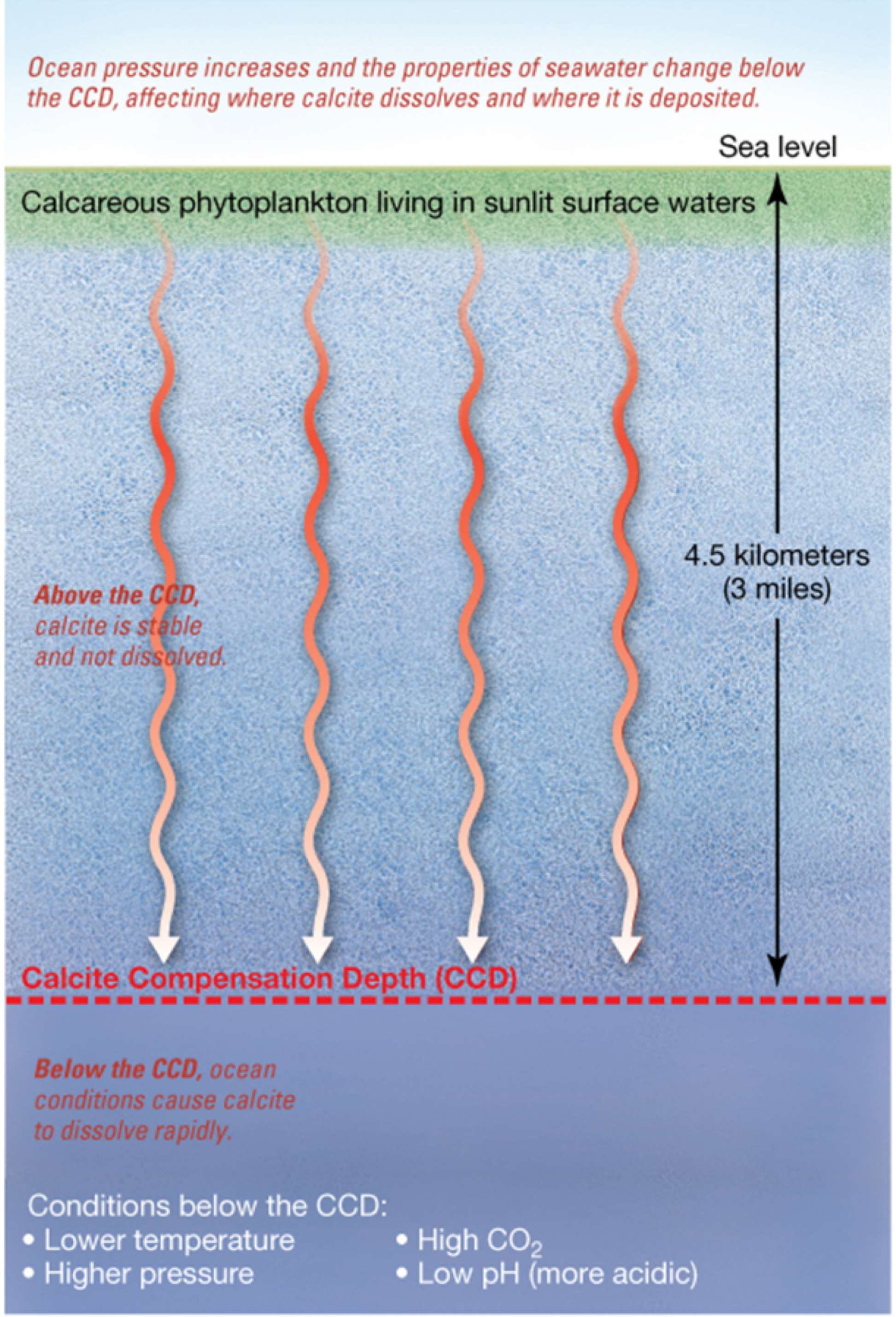
Dominant at low latitudes above the CCD.

<u>Warm, shallow ocean </u>saturated with calcium carbonate

Along the mid-ocean ridges, seamounts and other peaks

- Scarce calcareous ooze below 5000 meters (16,400 feet) in modern ocean

CCD occurs around 6000m in Atlantic and 3500-4000 m in parts of the Pacific.



Kinetic Considerations

- ***Saturation Horizon***
- ***Lysocline*** is where dissolution rate increases in carbonate grains

– Since degree of saturation decreases with depth, dissolution rates should increase with depth...

- ***Carbonate Compensation Depth (CCD)*** is

Depth where $CaCO_3$ readily dissolves

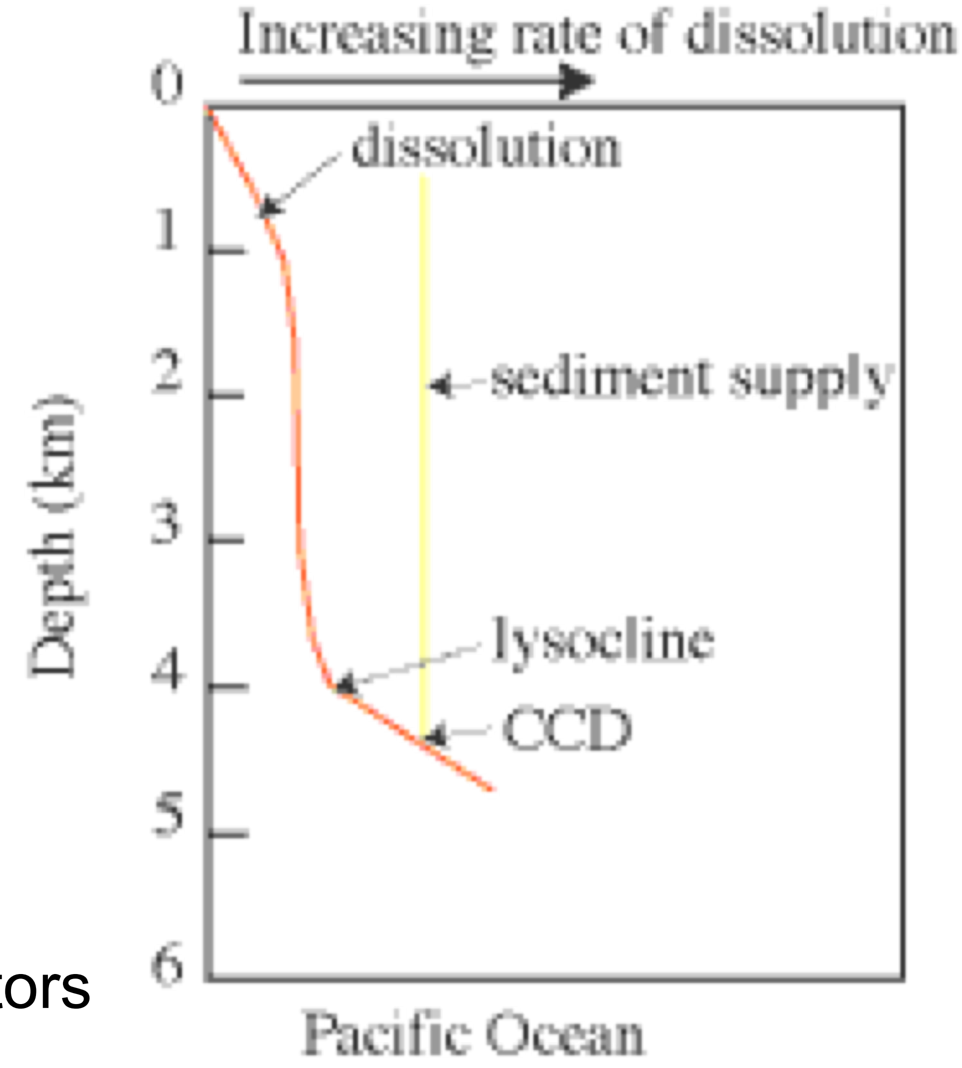
Rate of supply = rate at which the shells dissolve

- The lysocline occurs above the CCD, but is at or below the saturation horizon.

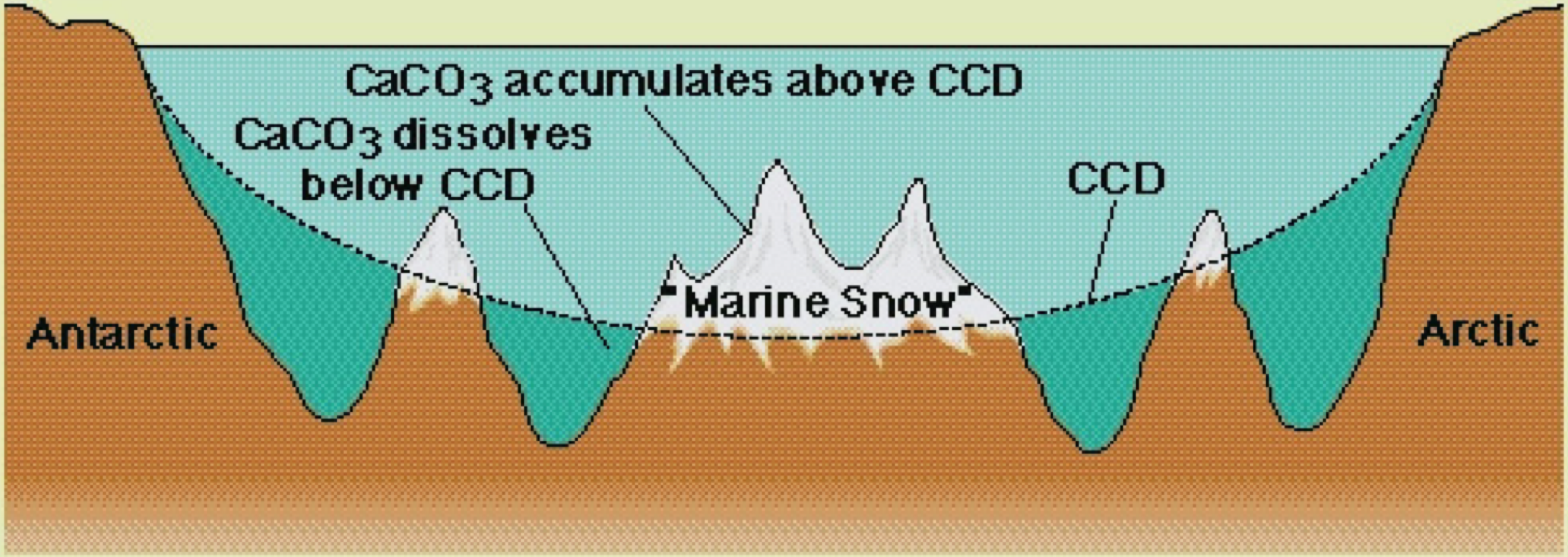
– Likelihood of dissolution of a shell depends on factors that control sinking rate and dissolution rate

– Both influenced by the size, density and shape of a shell

- Dissolution is also controlled by organic coatings and effects of trace ions on shell surfaces

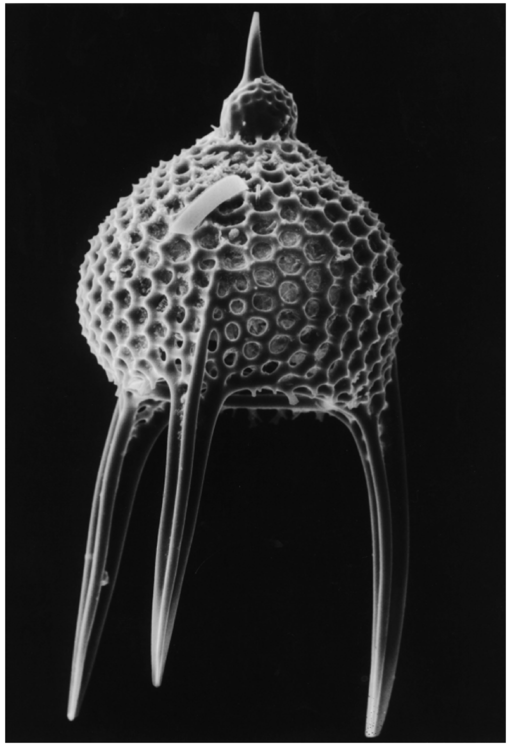


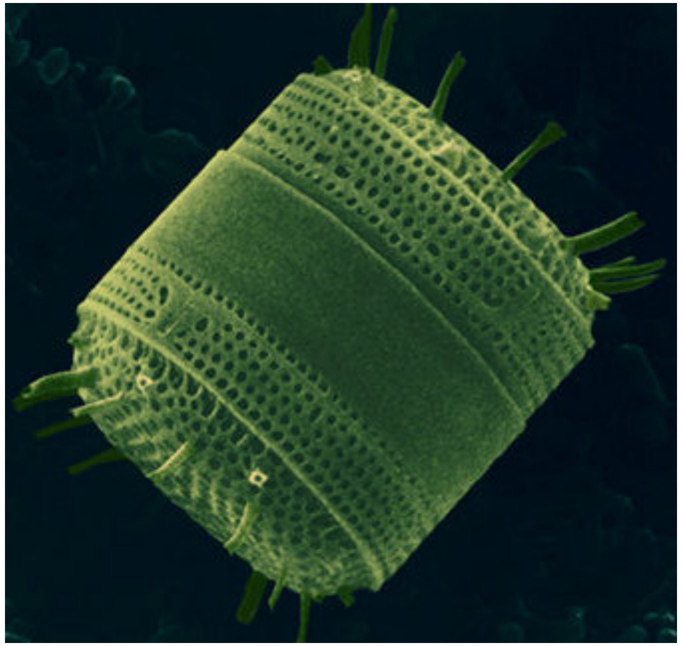
Calcium Carbonate Accumulation



Below the CCD, cold water holds more CO_2, which results in more carbonic acid, which dissolves $CaCO_3$ faster.

Siliceous Oozes: (SiO_2) The dominant deep ocean sediment in high latitude regions, below the CCD and surface current divergences near the equator (where cold water is upwelling)





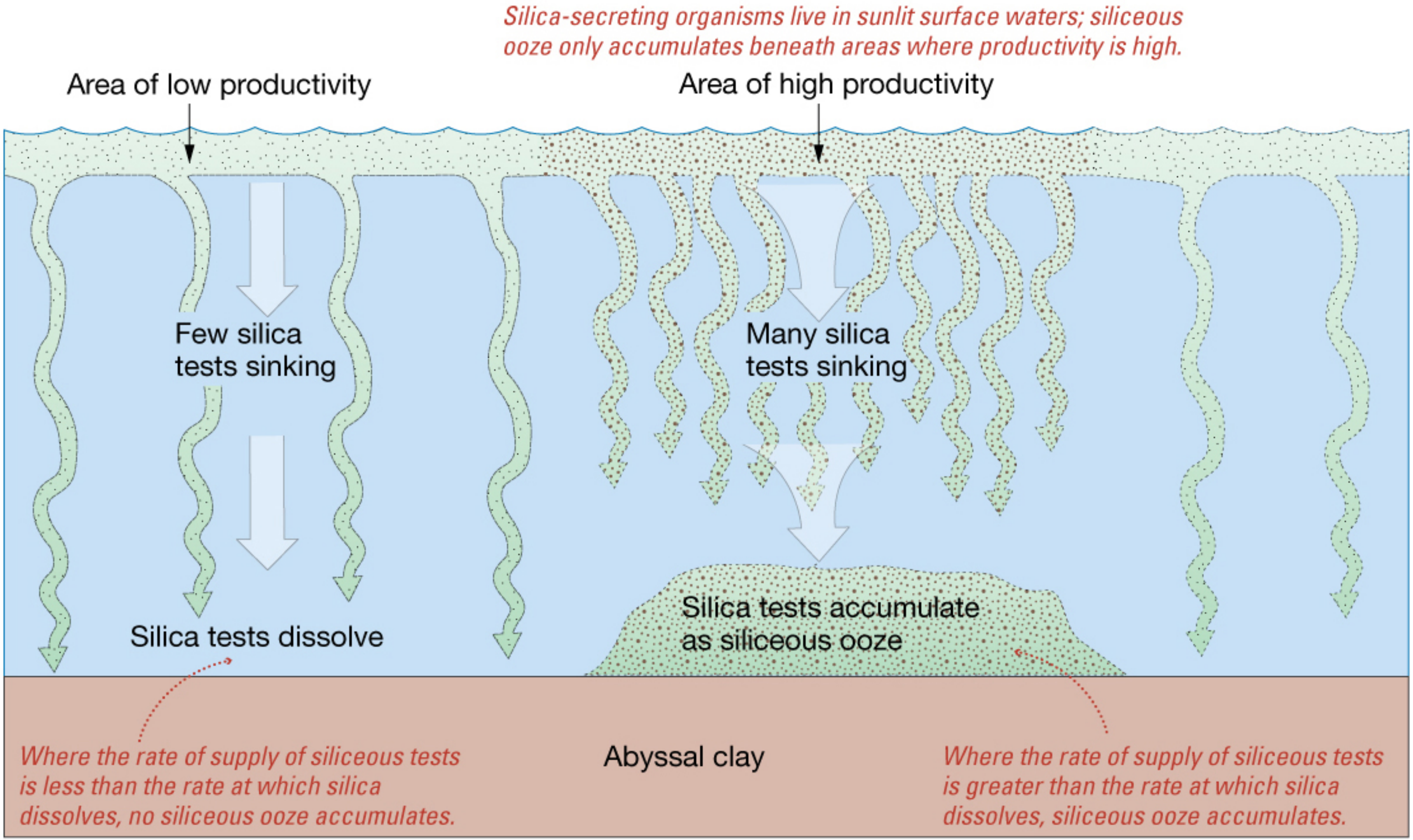
1. radiolarian- zooplankton

2. Diatom- phytoplankton

Concentrated in deepest waters! Do not dissolve below CCD…not $CaCO_3$!

Diatomaceous earth- sediment made up of mostly diatoms.

Siliceous ooze



Biogenous ooze turns to **rock**

When biogenous ooze hardens and lithifies, it can form:

a. **Diatomaceous earth** (if composed of diatom-rich ooze)
b. Chalk (if composed of coccolith-rich ooze)
c. Fossiliferous **limestone**

Distribution of biogenous ooze

Most biogenous ooze found as pelagic deposits at the bottom of the open ocean.

Factors affecting the distribution of biogenous ooze:

a. Productivity (Number of organisms in surface water above ocean floor)
b. Destruction (Skeletal or tests remains dissolve in seawater at depth)
c. Dilution (Deposition of other sediments decreases percentage of biogenous sediments)

Pelagic Sediments:

Sediments that come from open ocean water, not from land. Form in deep seas far from land.

Atlantic: over **3,000** feet thick

Pacific: over **1,600** feet thick

Oozes: Fine muds with **>30%** biological materials (pieces of living things).

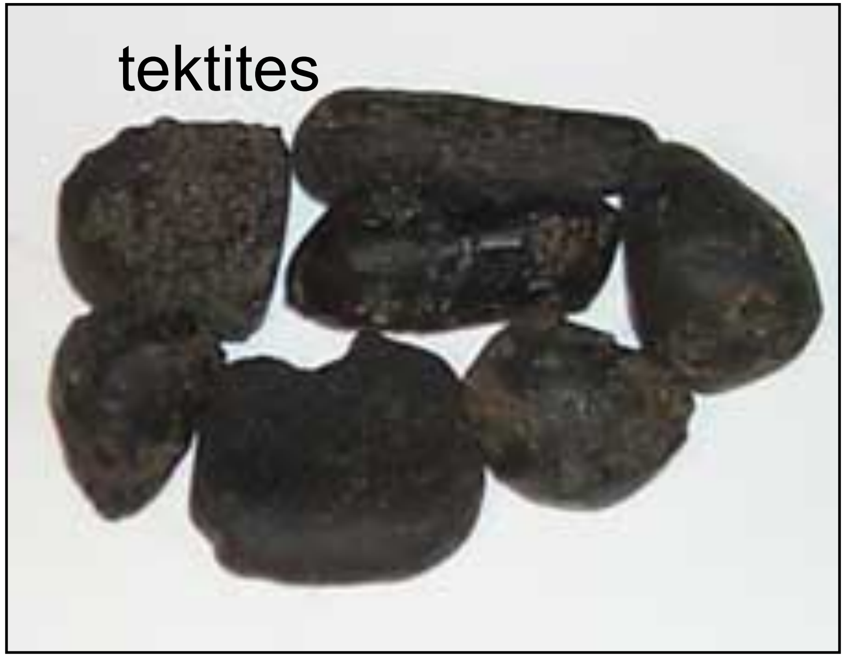
Clays: fine dust size particles containing **<30%** biological materials. Besides clay, contains pieces of living things (marine snow $CaCO_3$), micrometeorites, and volcanic dust.

Red Clays

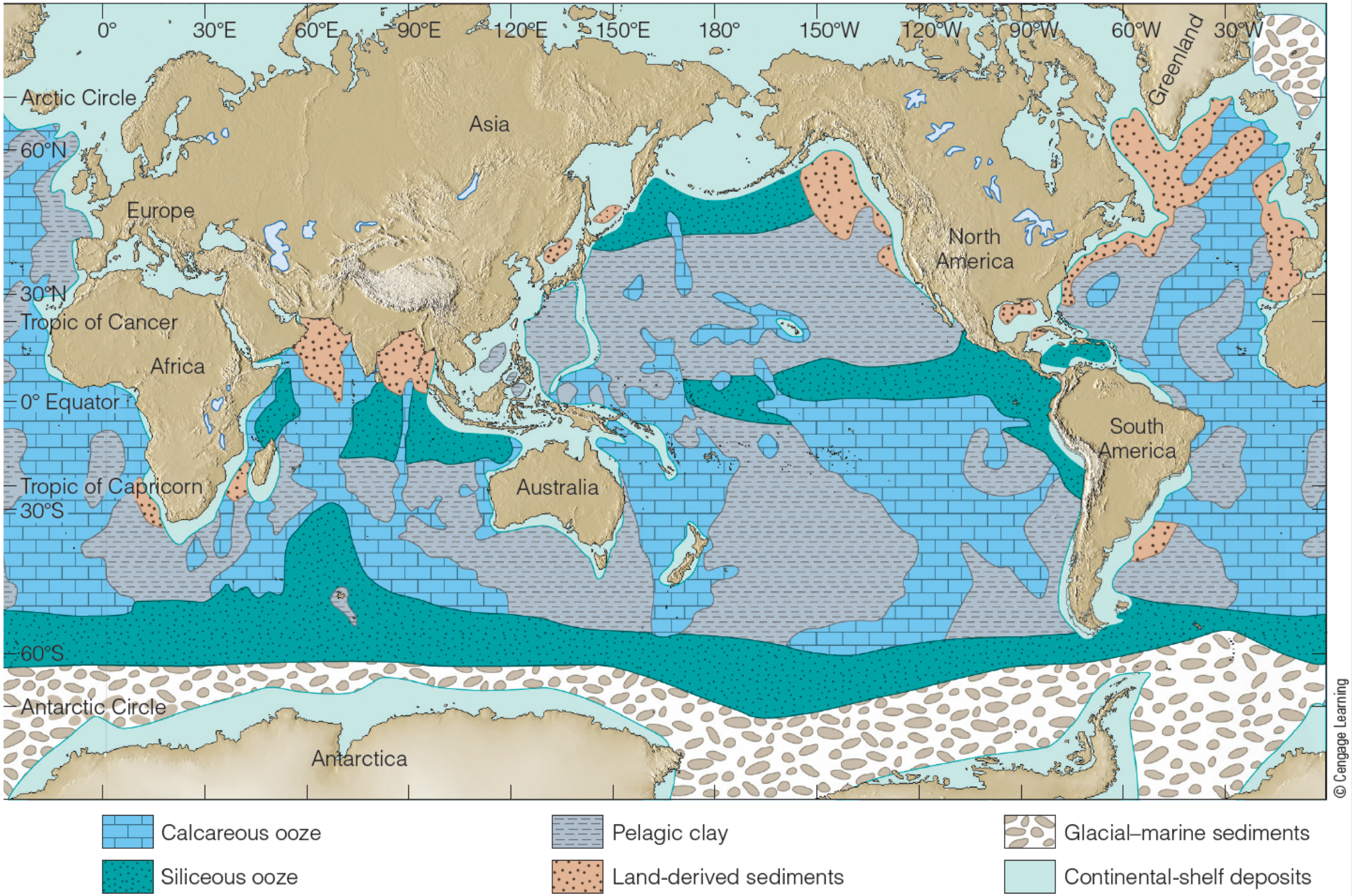
1. Red or brown sediment with **less than 30%** biogenic material.
2. Form in the **deepest calmest** areas of the ocean.
3. Tiny particles take **100 years** to descend.
4. It accumulates very slowly **0.2 cm/1000** years

Cosmogenous sediments:

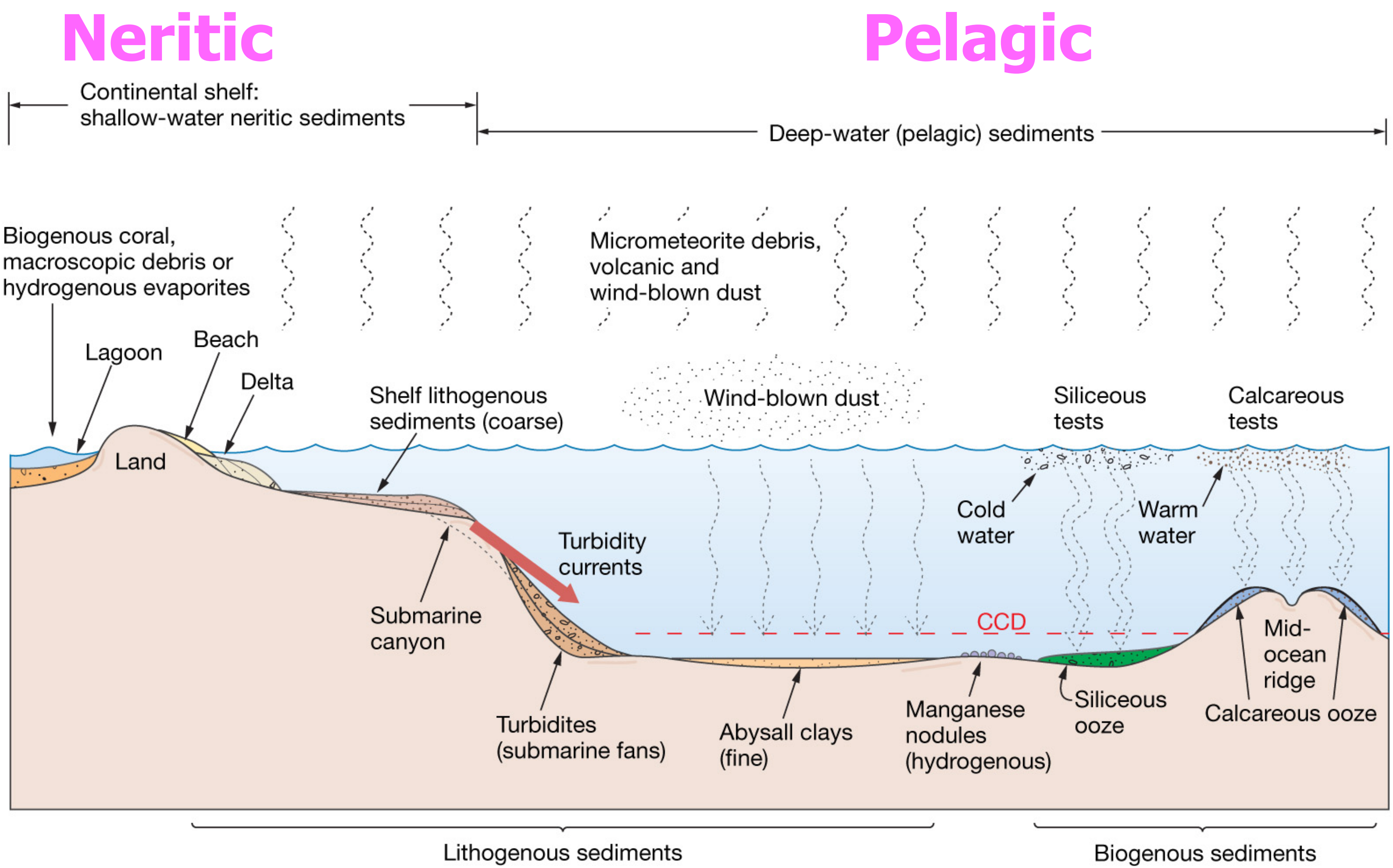
1. **Extraterrestrial** in origin
2. Two main types:
   - a. **Micro**scopic space dust
   - b. **Macro**scopic meteor debris
3. Forms an insignificant proportion of ocean sediment



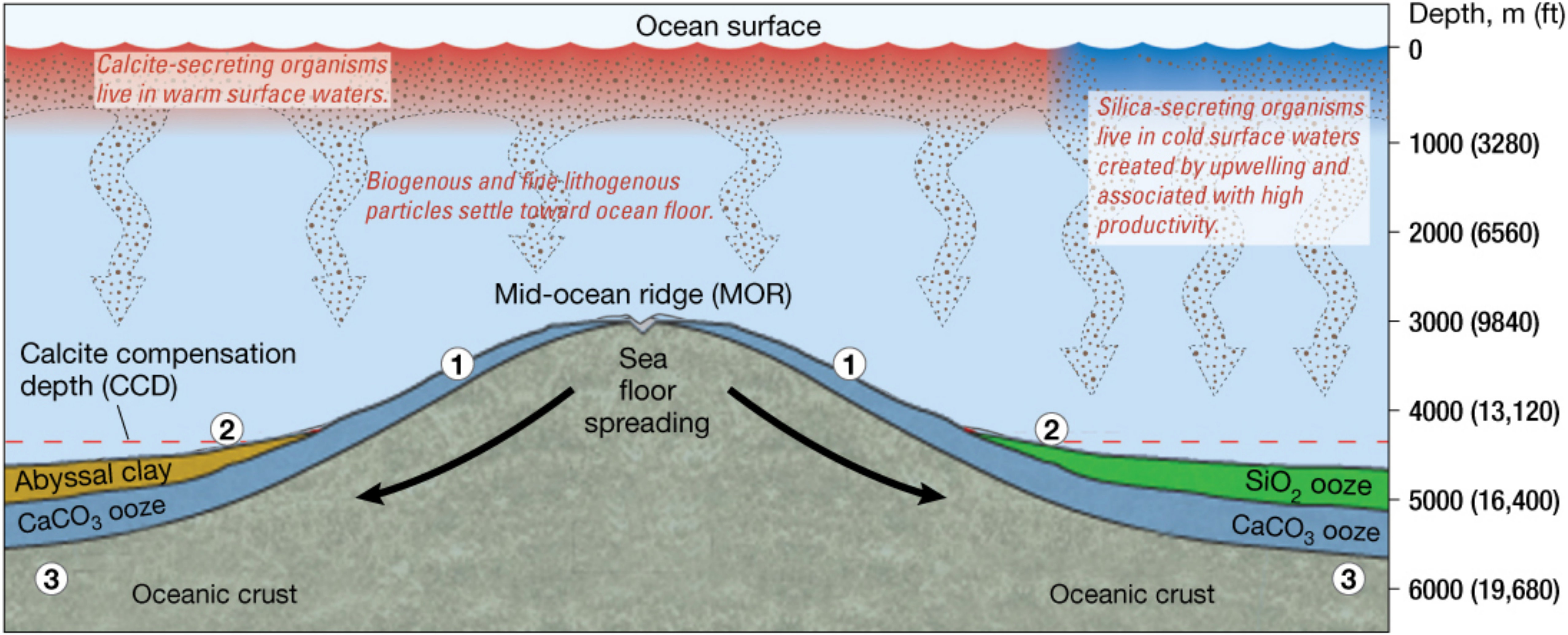
Ocean sediment deposits



Cross-section of the Ocean



Sea Floor Spreading and Sediment Accumulation



1 *Calcareous ooze deposited on the MOR above the CCD.*

2 *Calcareous ooze is covered and protected.*

3 *Sea floor spreading moves calcareous ooze beneath the CCD into deep water.*

Summary of Sedimen Map:

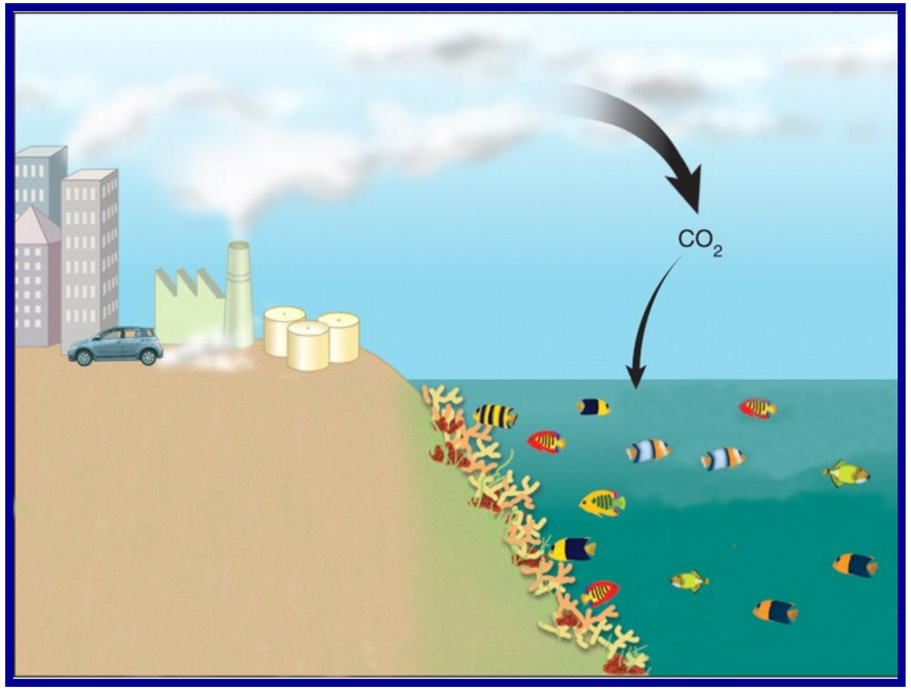
1. Red Clays occur in the deepest calmest parts of the ocean with low productivity.
2. Siliceous oozes occur in the deep oceans below CCD in areas with high productivity.
3. Calcareous oozes occur in areas of ocean with high productivity and above CCD level like plateaus, seamounts, m-o ridges.
4. Terrigenous sediments occur closer to continents along continental margins.
5. Manganeses nodules occur on abyssal plains and some plateaus (Blake).

Deep Ocean Characteristics

1. **Cold**
2. **Still**
3. **Stable**
4. **Dark**
5. **Essentially no productivity**
6. **Sparse Life**
7. **Extremely high pressure**
8. **Little food**
9. **Calcium and oxygen 'starved'**

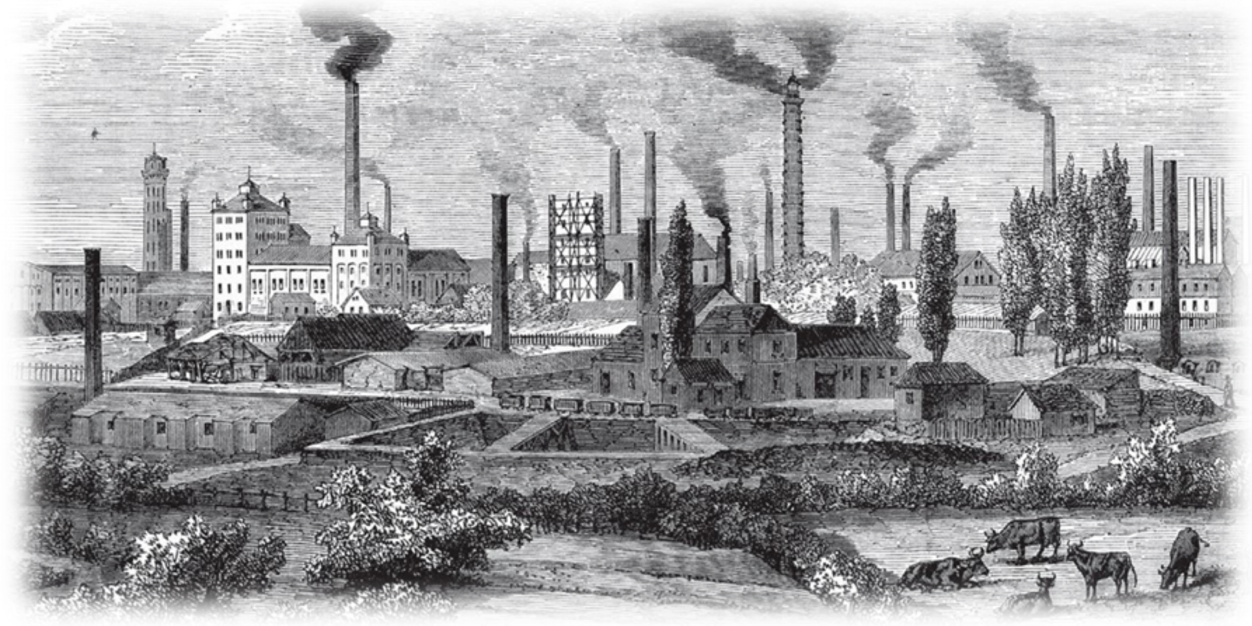
What is Ocean Acidification?

- International experts define <u>ocean acidification (OA) as a decrease in ocean pH over decades or more that is caused primarily by uptake of CO_2 from the atmosphere</u>.
- Because human activities are releasing CO_2 into the atmosphere very quickly, the ocean is taking up CO_2 faster today than it has in the past.
- This is <u>causing global ocean chemistry to change more quickly</u> than ocean systems can handle.



Ocean Acidification Trends

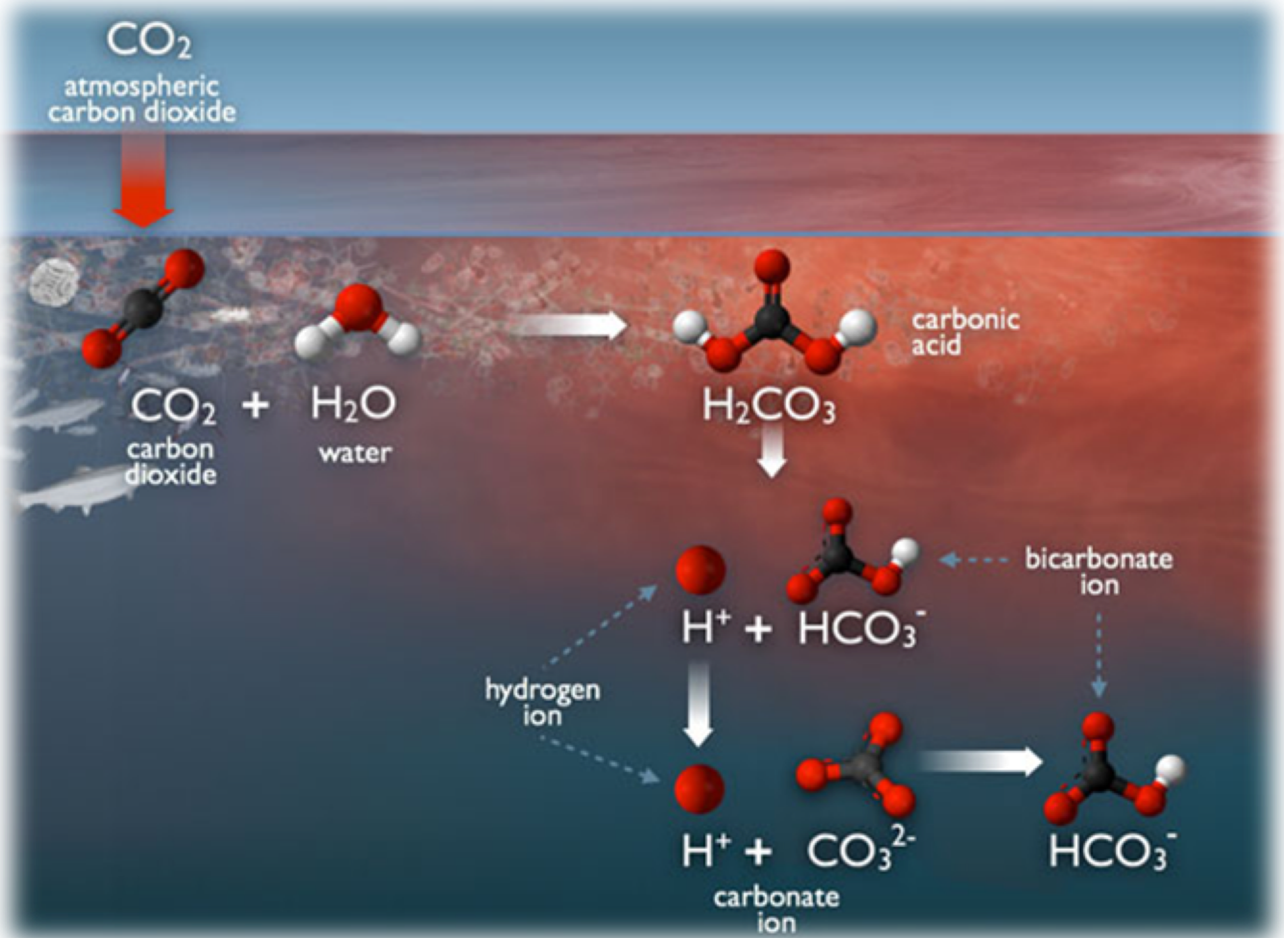
- Ocean acidification, related to the uptake of CO_2 at the ocean surface, causes a relatively slow, long-term increase in the acidity of the ocean, corresponding to a decrease in pH.
- Since the Industrial Revolution, the global average pH of the surface ocean has decreased by 0.11, which corresponds to approximately a 30% increase in the hydrogen ion concentration.



pH is the scale on which acidity is measured. The amount of hydrogen ions in a liquid determines how acidic the liquid is.

Ocean Acidification Chemistry

- As carbon dioxide (CO_2) dissolves into seawater it creates carbonic acid.
- Through a series of chemical reactions, carbonic acid releases hydrogen ions (H^+), which decreases seawater pH, and ***decreases the concentration of carbonate ions*** (CO_3^{2-}), which provide chemical building blocks for marine organisms' shells and skeletons.

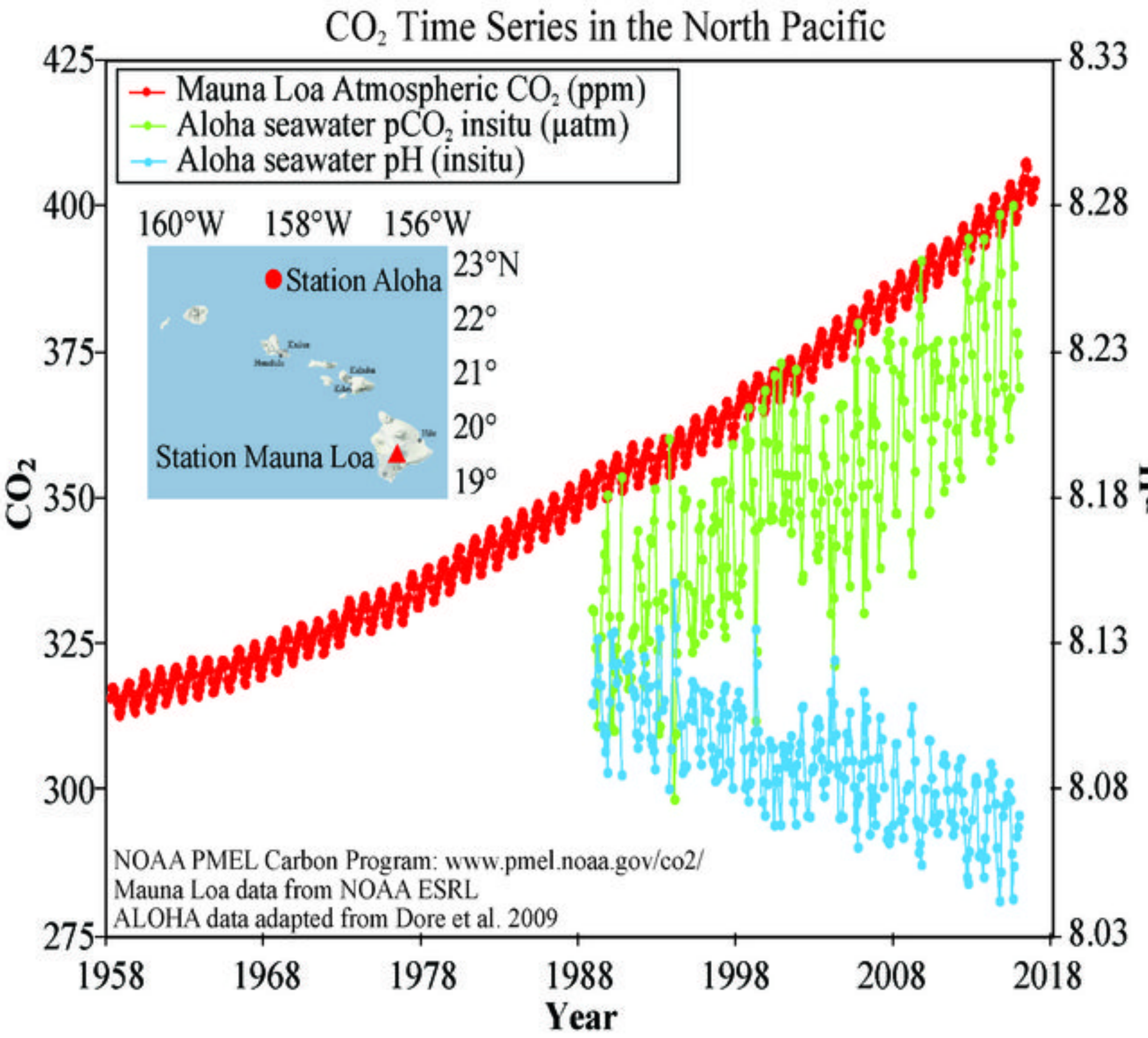


Carbonic acid reduces Ocean pH

Concentration of Carbonate ion decreases

Ocean Absorption of CO2

- The <u>ocean absorbs about a quarter of the CO_2</u> we release into the atmosphere every year, so as atmospheric CO_2 levels increase, so do the levels in the ocean.
- Initially, many scientists focused on the benefits of the ocean removing this greenhouse gas from the atmosphere. However, decades of ocean observations now show that there is also a downside — the <u>CO_2 absorbed by the ocean is changing the chemistry of the seawater.</u>



Data: Mauna Loa (ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_mm_mlo.txt) ALOHA (http://hahana.soest.hawaii.edu/hot/products/HOT_surface_CO2.txt)
Ref: J.E. Dore et al, 2009. Physical and biogeochemical modulation of ocean acidification in the central North Pacific. *Proc Natl Acad Sci USA* **106**:12235-12240.

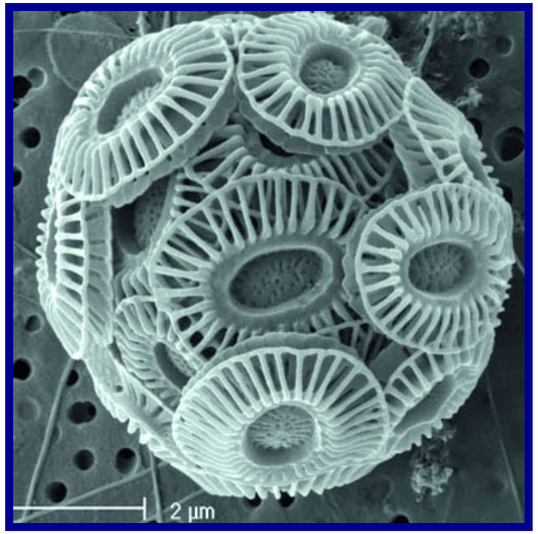
Why be concerned with a small change in pH?

- Many organisms are very sensitive to seemingly small changes in pH.
- Many marine organisms are very sensitive to either direct or indirect effects of the change in acidity (or H^+ concentration) in the marine environment.
- Fundamental physiological processes such as respiration, calcification (shell/skeleton building), photosynthesis, and reproduction respond to the magnitude of changes in CO_2 concentrations in seawater.

•As the ocean acidifies, organisms such as corals, snails, and calcifying plankton will not be able to make their shells and grow.

•Zooplankton (Pteropod)

•Coral



•Phytoplankton (Coccolithophore)

Some Issues with lower pH

- Calcium carbonate minerals are the building blocks for the skeletons and shells of many marine organisms.
- In areas where most life now congregates in the ocean, the seawater is supersaturated with respect to calcium carbonate minerals. This means there are abundant building blocks for calcifying organisms to build their skeletons and shells.
- However, continued ocean acidification is causing many parts of the ocean to become under-saturated with these minerals, which is likely to affect the ability of some organisms to produce and maintain their shells.
- Carbonate ions are an important building block of structures such as sea shells and coral skeletons.
- Decreases in carbonate ions can make building and maintaining shells and other calcium carbonate structures difficult for calcifying organisms such as oysters, clams, sea urchins, shallow water corals, deep sea corals, and calcareous plankton.

Food Web - Fish

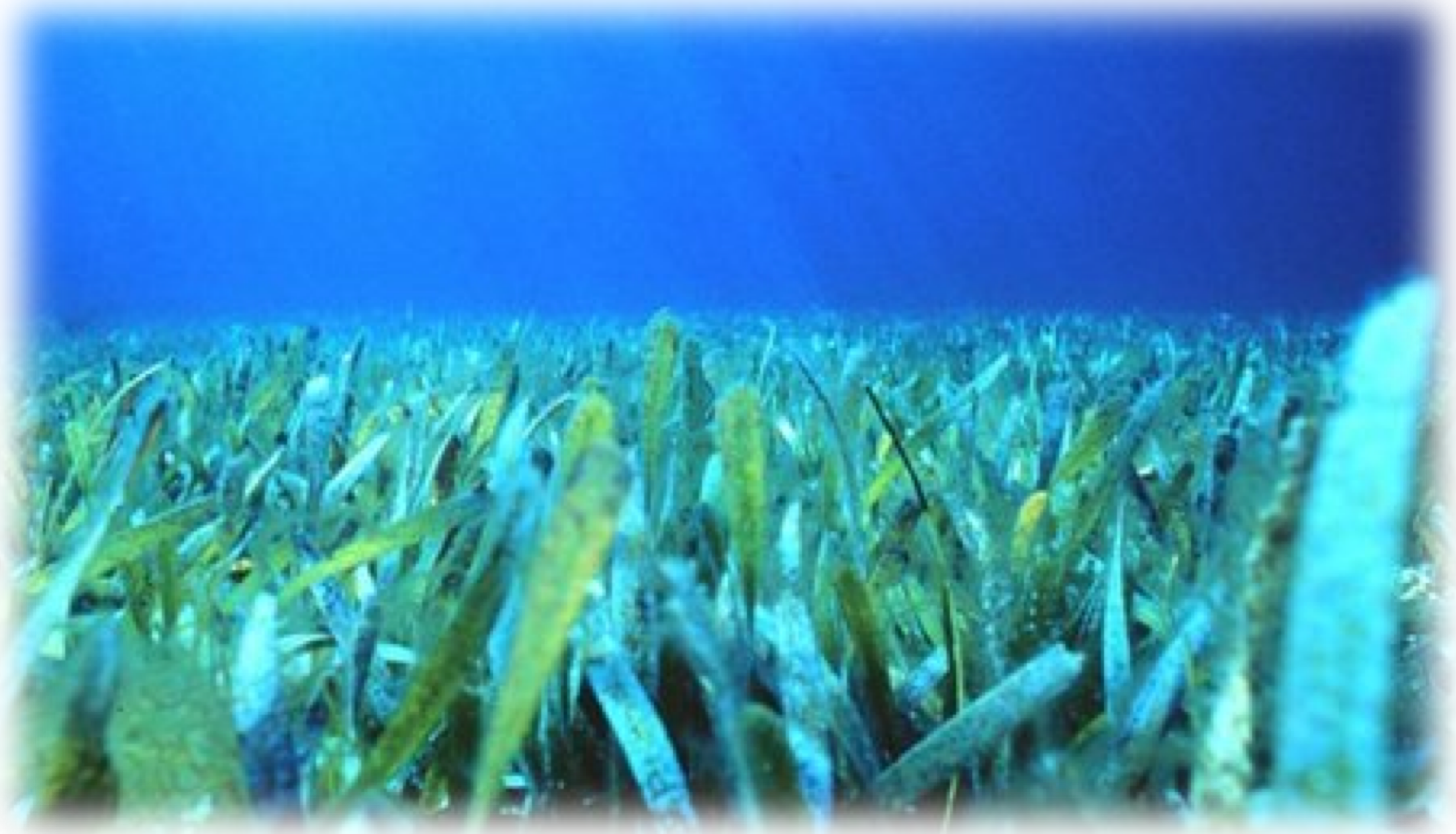
- The ability of certain fish, like pollock, to detect predators is decreased in more acidic waters. Recent studies have shown that decreased pH levels also affect the ability of larval clownfish to locate suitable habitat.
- When subjected to lower pH levels, the larval clownfish lost their chemosensory ability to distinguish between their favored and protective anemone habitat among the reefs and unfavorable habitats like mangroves.
- Additionally, greater acidity impairs their ability to distinguish between the "smell" of their own species and that of predators. These two factors create an increased risk of predation.
- When these organisms are at risk, the entire food web may also be at risk.

(Run Time ~ 4:26)

[A Climate Calamity in The Gulf of Maine Part 2: Acid in the Gulf]

Is there any advantage to higher CO2 levels in our oceans?

- While some species will be harmed by ocean acidification, <u>photosynthetic algae and seagrasses may benefit from higher CO_2 conditions in the ocean</u>, as they require CO_2 to live just like plants on land.



Our Oceans' Futures

- Estimates of future carbon dioxide levels, based on "business as usual" emission scenarios, indicate that <u>by the end of this century the surface waters of the ocean could be nearly 150% more acidic, resulting in a pH that the oceans haven't experienced for more than 20 million years.</u>
- Ocean acidification is currently affecting the entire world's oceans, including coastal estuaries and waterways.
- Today, more than a billion people worldwide rely on food from the ocean as their primary source of protein.
  - Approximately 20% of the world's population derives at least 1/5 of its animal protein intake from fish.
  - Many jobs and economies in the U.S. and around the world depend on the fish and shellfish that live in the ocean.

What is Next?

It is currently impossible to predict exactly how ocean acidification impacts will cascade throughout the marine food chain and affect the overall structure of marine ecosystems. With the pace of ocean acidification accelerating, scientists, resource managers, and policymakers recognize the urgent need to strengthen the science as a basis for sound decision making and action.

CO_2 sequestration is required.