

Ocean Sediments

OCN 401

8 Nov 2018

Outline

Significance & terms

Origin & distribution of major types of marine sediments

Delivery - dissolution – destruction

mid-ocean ridges

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**

Superposition

sedimentary layers are deposited in a time sequence, the oldest at the bottom and the youngest at the top;

in the case of a strata, layers on top conform to the shape of the lower layers



Categories of Marine Sediments

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

The Origin of Marine Sediments

- **Volcanogenic particles** are derived from volcanic eruptions, range from boulders to dust
- **Lithogenous particles** are derived from pre-existing rocks by weathering (disruption of rocks by wind, temperature, water), deposited by wind or rivers
- **Glacially derived particles** are ground from rock beds by moving glaciers
- **Biogenic particles** are shells or skeletons of organisms that sink to the sea floor after the organisms death; made of silicate or carbonate

What Controls the Distribution of Various Kinds of Seafloor Sediments?

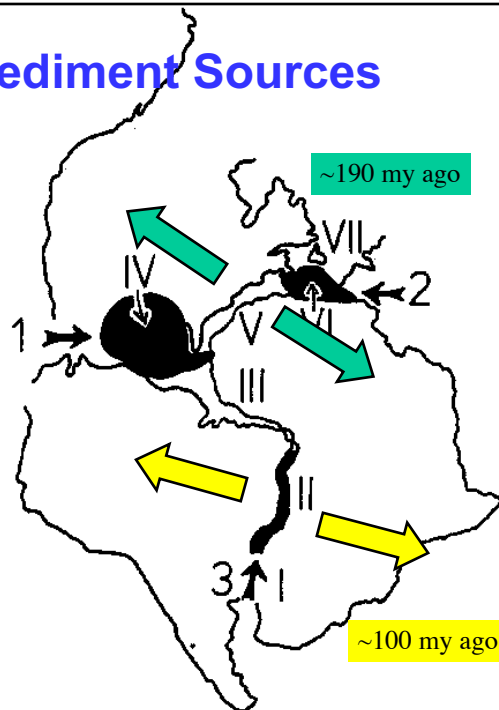
The answer is "the 3 D's":

- 1) **Delivery**: Without delivery of sediments into the ocean, they will of course never be found there.
- 2) **Dilution**: Many different types of sediment particles reach the seafloor. If too much of one type reaches a given place, or the rate of dilution is very high, the other types will become unimportant.
- 3) **Destruction**: Certain chemical, physical, and biological processes destroy sedimentary particles, removing them from the seafloor sediment.

Authigenic Sediment Sources

I. Evaporites:

- form when flux of freshwater out of a body of water exceeds flux of freshwater in;
- 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

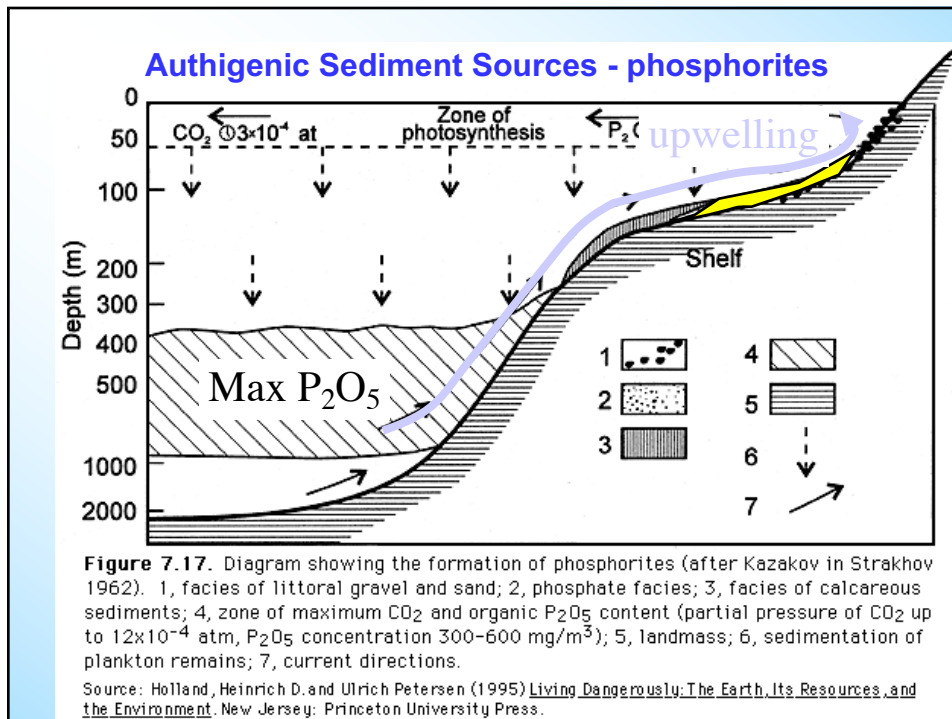


Authigenic Sediment Sources

II. Phosphorites:

- Sediments or sedimentary rocks rich in phosphate;
- Typically concentrated in coastal areas with:
 - (a) intensive upwelling,
 - (b) little or no terrigenous input

>20% phosphate content vs. <0.2% of typical sedimentary rock



Authigenic Sediment Sources - phosphorites

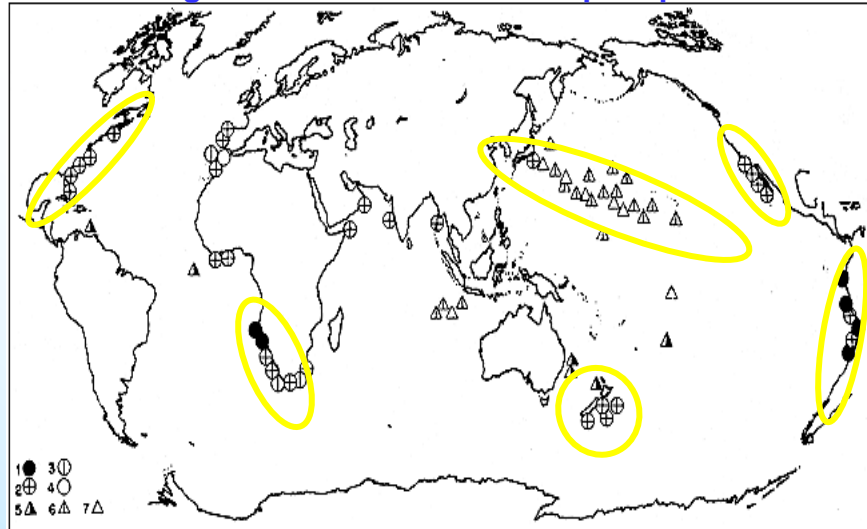


Figure 7.16. Location of phosphorites on the seafloor. 1-4, phosphorites on continental margins; 5-7, phosphorites on submerged mountains. Geological age: 1, Holocene; 2, 5, Neogene; 3, 6, Paleogene; 4, 7, Cretaceous. (From Bezrukov and Baturin 1979)

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

Terrigenous Sediment Sources

I. To the continental margins:

- Most clastics are left either along the margins of continents or are delivered to the abyssal plains.
- Transport of large sediment grains requires high energy (i.e., fast moving water).
- Very thick deposits - up to 10km beneath continental shelves.
- Sediments are funneled across continental margins through submarine canyons to deep sea fans.
- Sedimentation **rate** on deep sea fan: up to 1 km/my.

Terrigenous Sediment Sources - continental margins

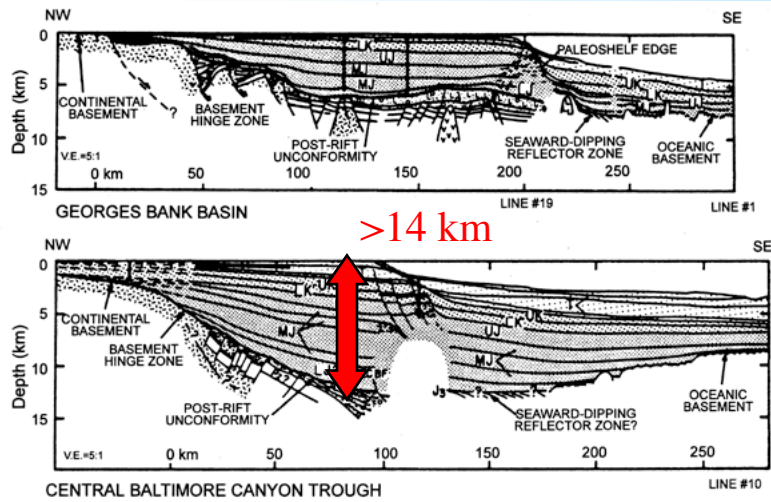
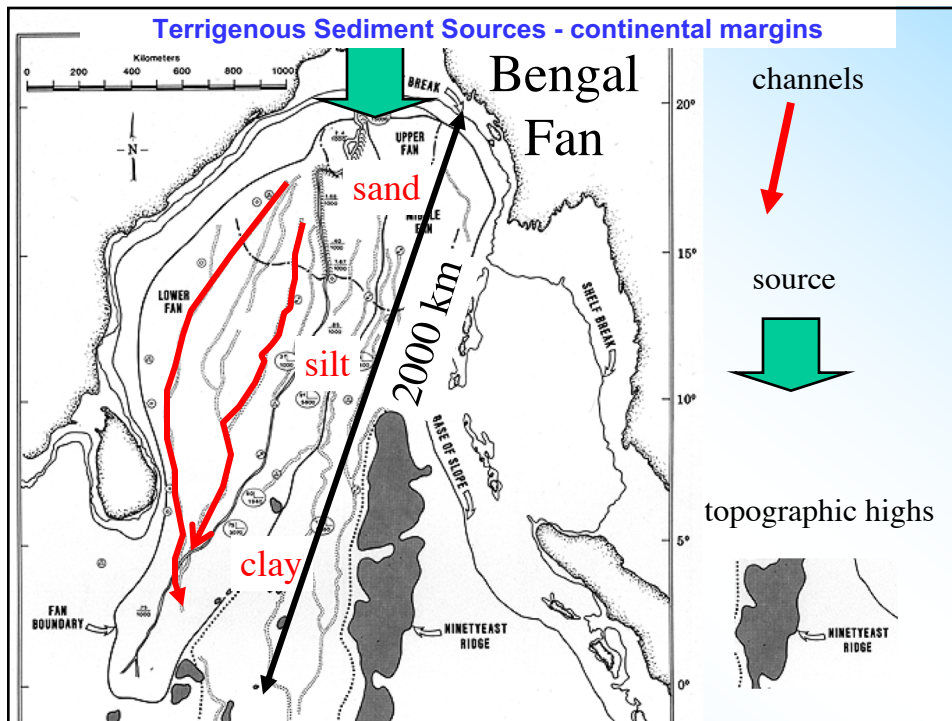


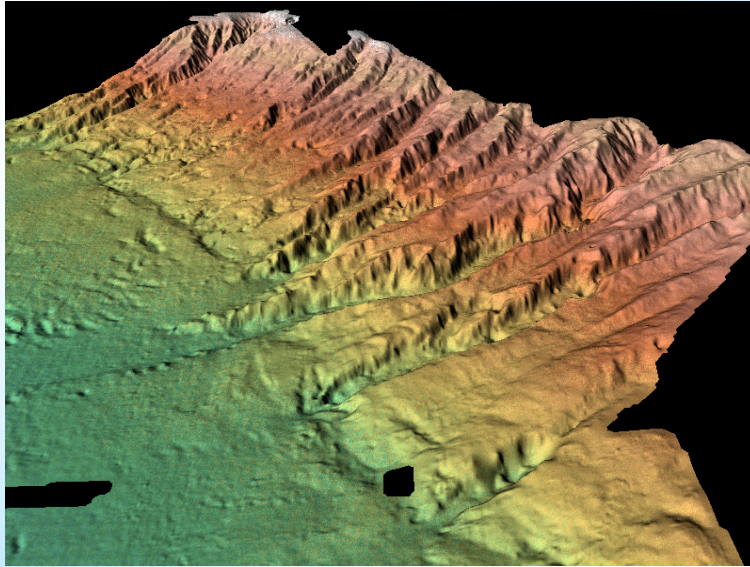
Figure 7.6. Cross sections across the Georges Bank Basin (upper) and the central Baltimore Canyon Trough (lower) (from Klitgord and Hutchinson 1985; Klitgord et al. 1988). ECBF = East Coast Boundary Fault; J3 = deepest Atlantic continental rise reflection (Sheridan 1989). T = Tertiary; UK = Upper Cretaceous; LK = Lower Cretaceous; UJ = Upper Jurassic; MJ = Middle Jurassic; LJ = Lower Jurassic.

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

Terrigenous Sediment Sources - continental margins



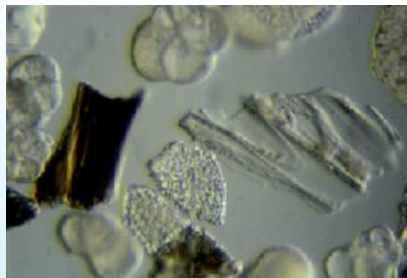
Terrigenous Sediment Sources - continental margins

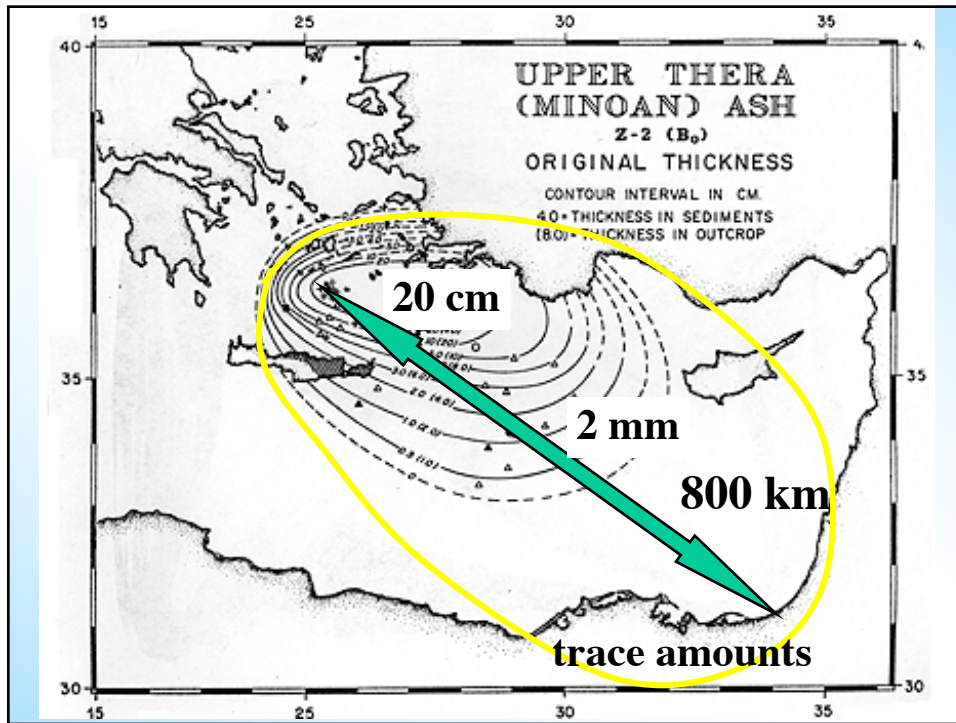


Terrigenous Sediment Sources

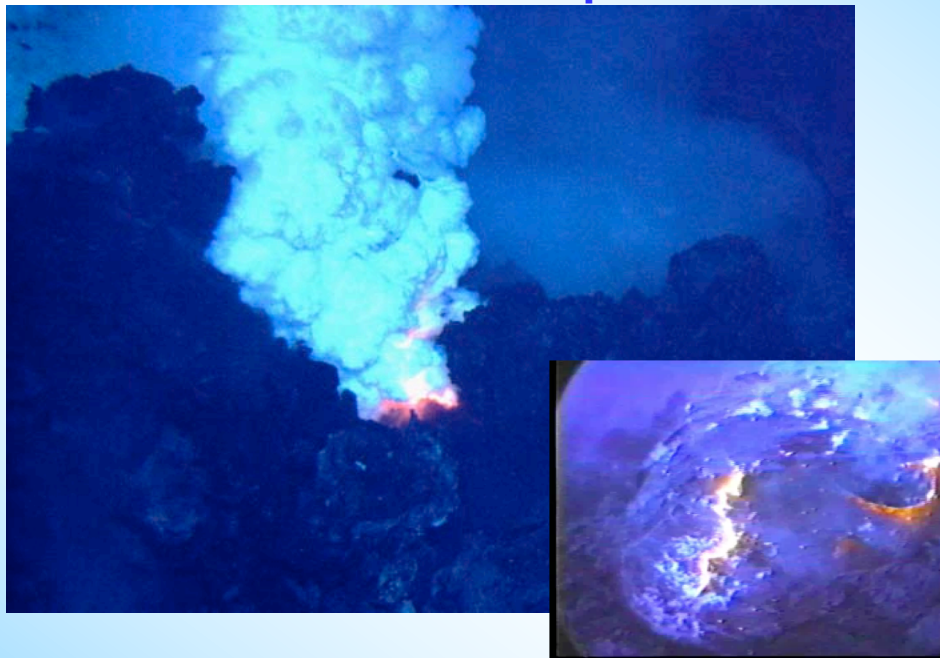
II. To the deep sea:

- 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





Subseafloor eruptions

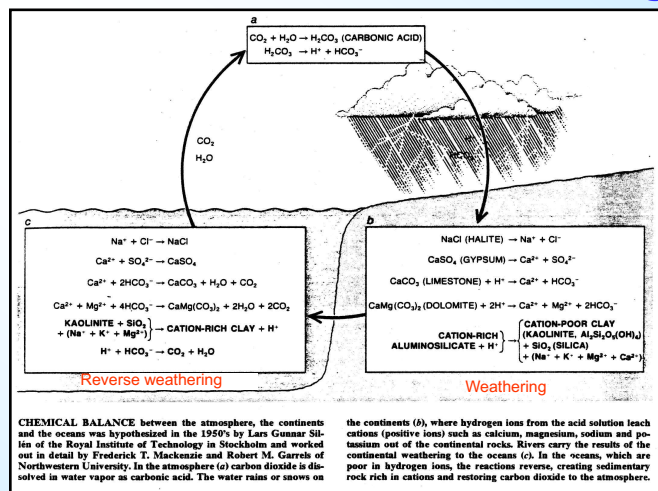


Terrigenous Sediment Sources

II. To the deep sea (continued):

- 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)

Review of reverse weathering

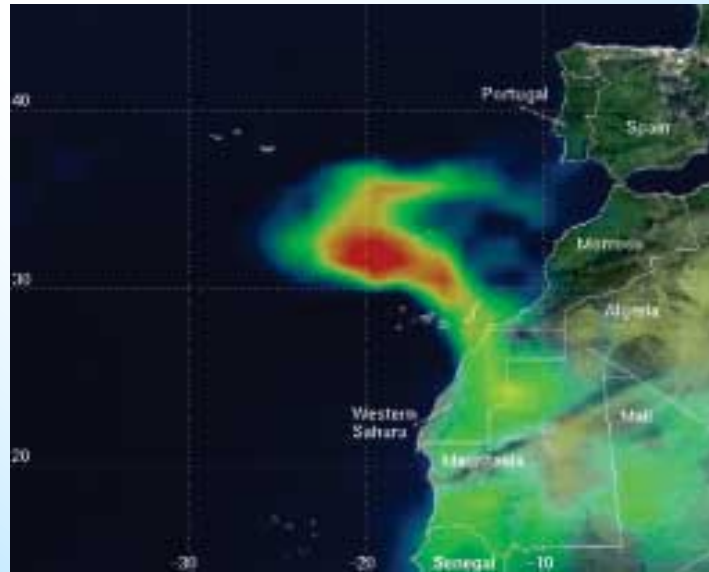


Silica + degraded aluminous clays + iron oxide + organic carbon + soluble cations + bicarbonate



New clay material + Carbon dioxide + water

Western Sahara Dust

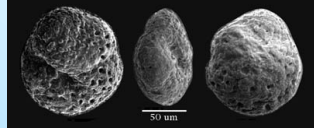
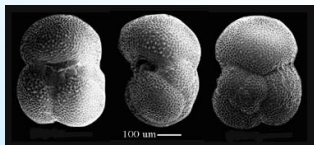


Biogenic Sediment Sources

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.
 - Calcium **carbonate** - mollusks, corals, foraminifera, coccoliths, some algae.
 - Hydrated **silica** - diatoms, radiolaria.

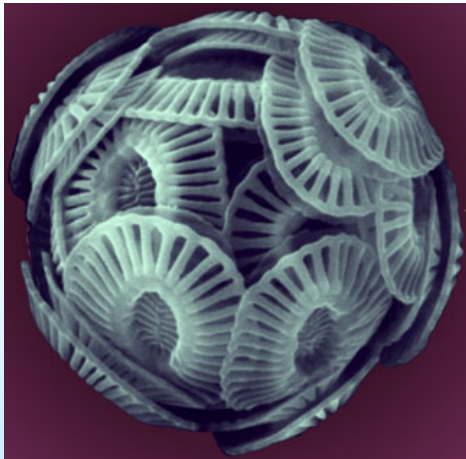
Biogenic Sediment Sources



Foraminifera: relatives of amoeba with calcite shell, which is composed of a series of chambers; 30 μm to 2 mm (most are 50-400 μm); bacteriovores; most abundant 40° N – 40° S

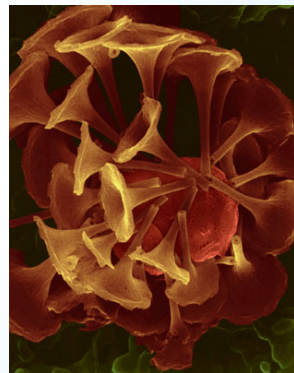
plaza.ufl.edu/mrosenme/Forams.htm

Biogenic Sediment Sources



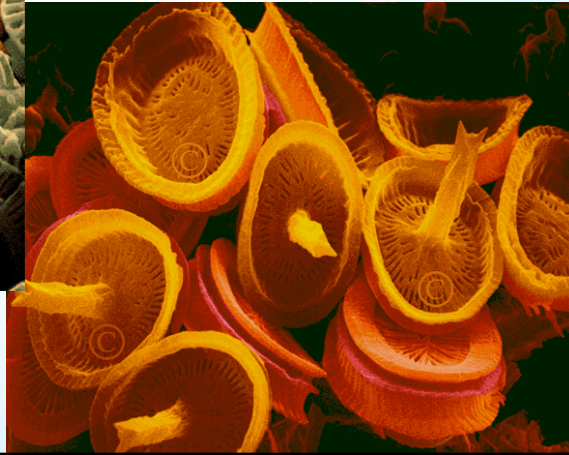
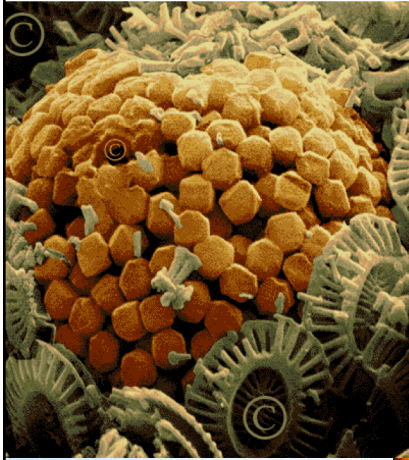
www.unf.edu/~gmead/ocbasins/marseds.htm

Coccolithophorids: single-celled flagellated algae, produce platelets called "coccoliths" that cover the cell for reasons that are poorly understood; very small (2-50 μm)



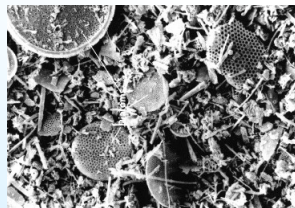
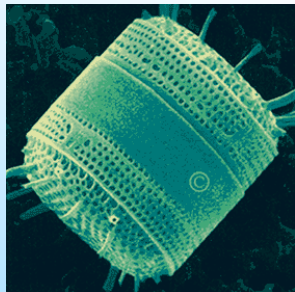
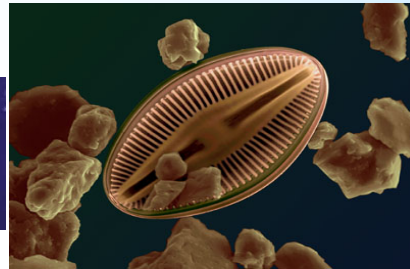
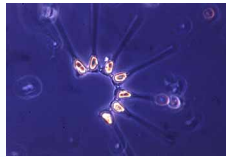
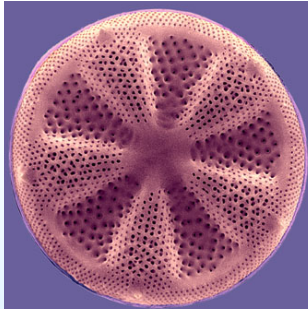
Biogenic Sediment Sources

More coccolithophorids:
crunchy, FeS centers?!



Biogenic Sediment Sources

Diatoms: unicellular microalgae
with cell walls made of silica;
2 μ m to 2 mm



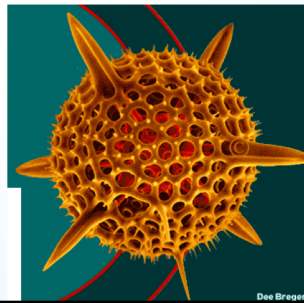
Biogenic Sediment Sources



www.microscopy-uk.org.uk

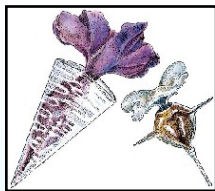
1 mm

Radiolaria: spherical, protozoans with silica capsule; 50 μm to several mm; feed on bacteria, small phyto- and zooplankton; cold water and deep-sea



Dee Breger

Biogenic Sediment Sources



www.jochemnet.de/flu/OCB3043_24.html



www.clipart.com

Pteropods: pelagic mollusk, suspension feeder; produce large mucous nets to capture prey; carbonate shells produce pteropod ooze on sea floor; generally 300 μm to 10 mm



www.oceans.gov.au/norfanz/Creature_feature2.htm

Biogenic Sediment Sources

Biogenic sediments (continued)

c. Conditions limiting sedimentation include biological productivity and dissolution

Surface waters are supersaturated in bicarbonate, but deeper water is undersaturated due to increasing pressure and acidity below 3.4 - 4.4km

Calcium carbonate dissolves below this depth, so no calcareous sediments can be deposited.

Distribution of Siliceous Sediments....

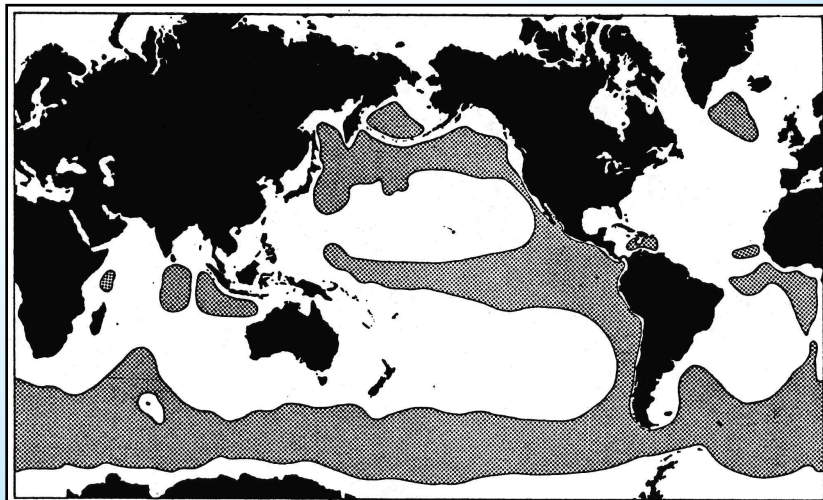
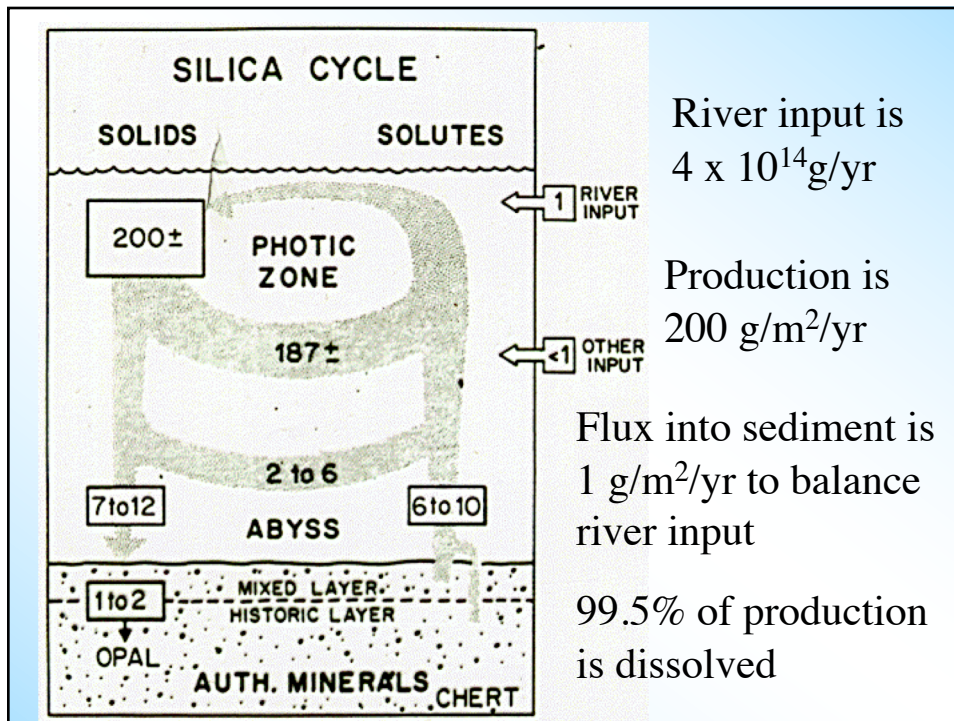
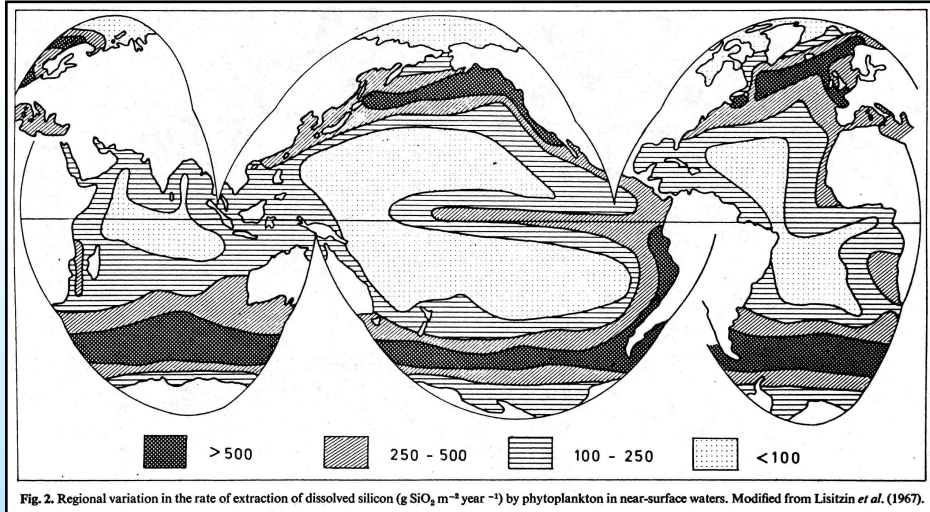


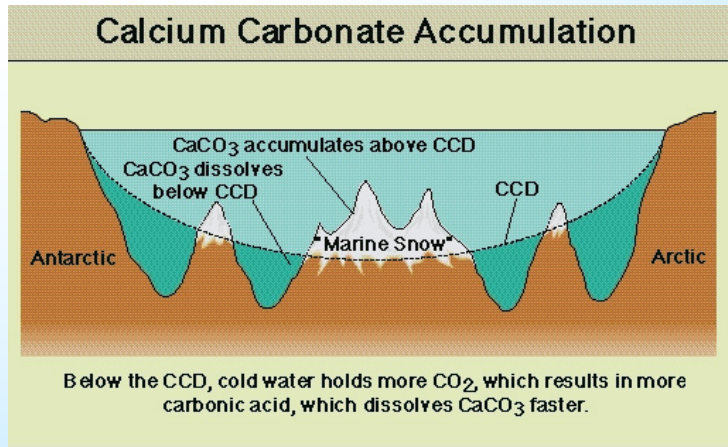
FIG. 24.5. Distribution of siliceous fossils (stippled) in ocean sediments. (Based largely on Berger, 1974, and Luyendyk and Davies, 1974).

Davis & Gorsline, 1976

....is Largely Controlled by Delivery



In Contrast, Carbonate Sediments are Generally Controlled by Sediment Depth



faculty.uvi.edu/users/sratchf/SSEA_ocean/files/origins/origins20.htm

CCD = Carbonate Compensation Depth, the depth at which there is an abrupt decrease in the sediment carbonate content

First, a review of the CO₂ system...

Why is it important to understand the CO₂ system?

- CO₂ is the raw material used to build **organic matter**
- CO₂ controls the **pH** of the oceans
- CO₂ controls the fraction of inbound radiation that remains trapped in the atmosphere (**greenhouse effect**), which controls planetary climate
- Distribution of CO₂ species affects preservation of **CaCO₃** deposited on the sea floor

CO₂ Speciation

- CO₂(g) reacts extensively upon contact with H₂O
- Major dissolved forms:
 - CO_{2(aq)} (*aqueous carbon dioxide*)
 - HCO₃⁻ (*bicarbonate ion*)
 - CO₃⁻² (*carbonate ion*)
- Species interconvert readily
- Changes to one part of CO₂ system lead to redistribution of all CO₂ species
- Reactions not always intuitive!

Equations for CO₂ Speciation

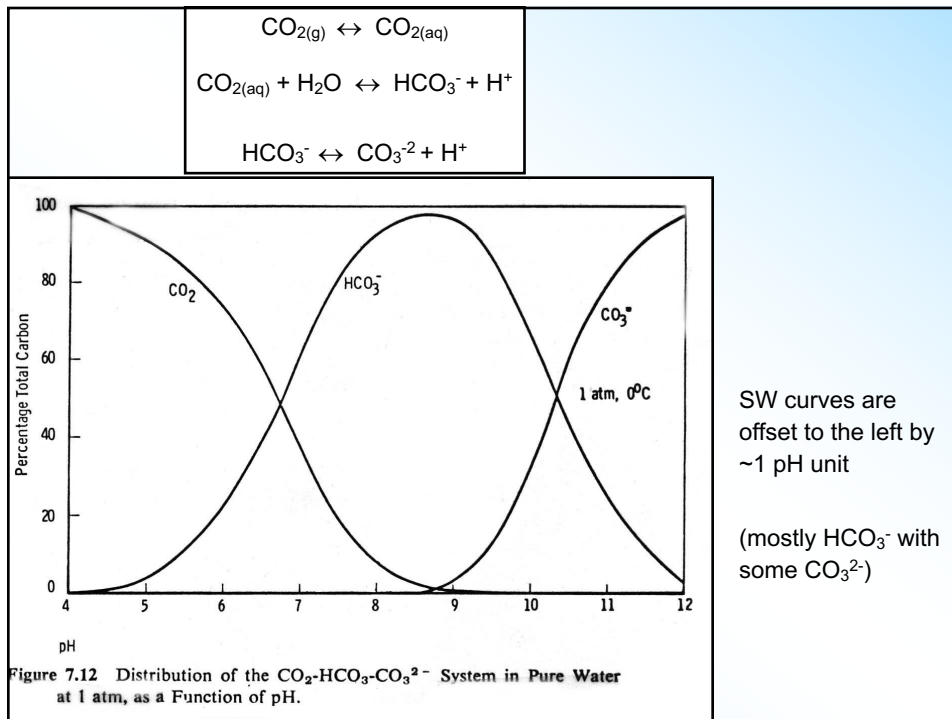
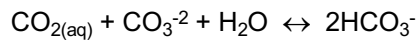
The equilibrium of gaseous and aqueous carbon dioxide:



Subsequent hydration and dissociation reactions:



Hint: when pH is between 7.5 and 8.5:



Total CO₂ (ΣCO₂)

$$\text{Total CO}_2 = [\text{CO}_{2(\text{aq})}] + [\text{H}_2\text{CO}_3] + [\text{HCO}_3^-] + [\text{CO}_3^{2-}]$$

- At seawater pH, >99% of CO₂ species are HCO₃⁻ and CO₃⁻², so we can simplify:

$$\text{Total CO}_2 = [\text{HCO}_3^-] + [\text{CO}_3^{2-}]$$

- This is also known as **dissolved inorganic carbon (DIC)** or **total inorganic carbon (TIC)**

Vertical ΣCO₂ Profiles

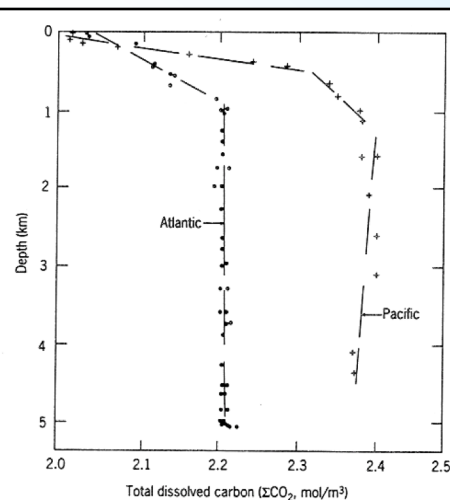


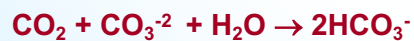
FIGURE 15.4. Variation of total dissolved inorganic carbon concentrations with depth in the Atlantic (36°N 68°W) and in the Pacific (28°N 122°W). Source: From *Chemical Oceanography*, W. S. Broecker, copyright © 1974 by Harcourt, Brace and Jovanovich, Publishers, Orlando, FL, p. 39. Data from Dr. R. Weiss, Scripps Institute of Oceanography, La Jolla, CA. Reprinted by permission.

Oceanic CO₂ and Biogenic Particle Production

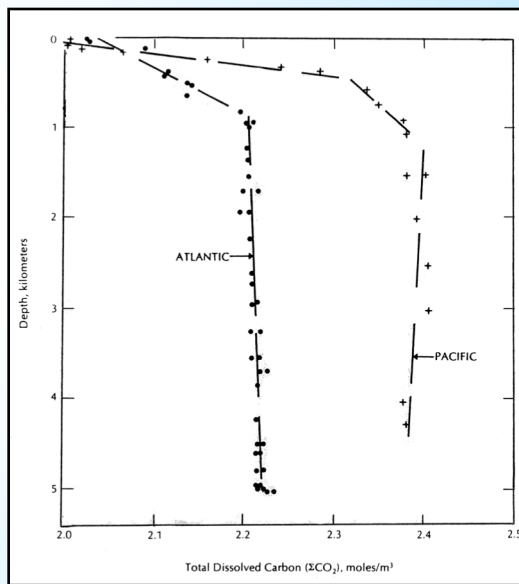
- Surface ocean often under- or over-saturated wrt atmospheric CO₂ due to primary production and mixing
- Primary production removes atmospheric CO₂ via organic C to deep waters -- most is remineralized in water column
- Sedimentary CaCO₃ sink is 4x greater than organic carbon sink

Calcite Dissolution

- Remineralization of organic matter in the water column produces CO₂ that reacts with CO₃⁻²



- Higher ΣCO_2 at depth
- Lower CO₃⁻² at depth
- In the deep ocean, the decrease in [CO₃⁻²] from this reaction has a big effect on CaCO₃ solubility



Saturation State of SW



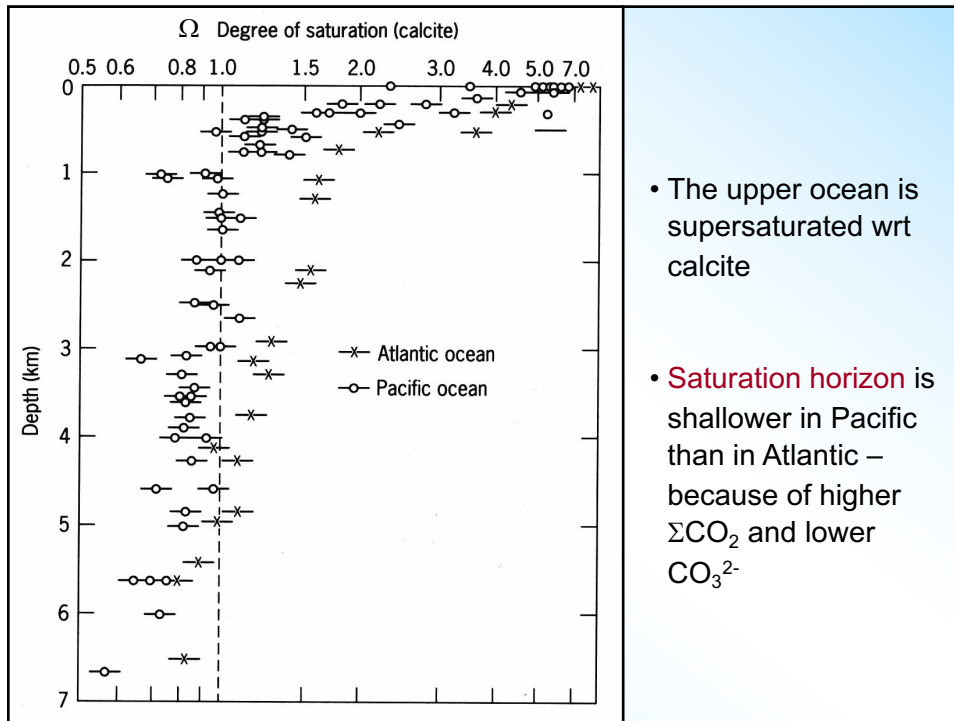
- The saturation state of SW with respect to **calcium carbonate** (calcite, aragonite, etc.) determines whether these phases will dissolve or not
- Define the *saturation state of SW with respect to calcite* (CaCO_3) as:

$$\Omega = \frac{[\text{Ca}^{2+}][\text{CO}_3^{2-}]_{\text{Seawater}}}{[\text{Ca}^{2+}][\text{CO}_3^{2-}]_{\text{Calcite-saturated seawater}}}$$

- Ca^{2+} concentrations don't vary much in the ocean
- Depth at which $\Omega = 1$ is called the **saturation horizon**

Interpretation of Ω Values

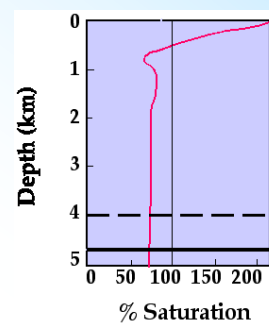
Ω	Description	CaCO_3 Transformations
<1	Undersaturated	Net dissolution
1	Saturated	Equilibrium
>1	Supersaturated	Net precipitation



Carbonate Compensation Depth

Factors affecting CCD:

- Temperature
- Depth
- $[\text{CO}_2]$
- pH
- Carbonate supply
- Terrigenous supply



Depth of the lysocline (dotted line) and the CCD (solid line) in the Equatorial Pacific, along with amount of water column carbonate saturation

The Shallower CCD in the Pacific Has a Dramatic Effect on Sediment Distribution....

TABLE 29.4.
Relative areas of World Ocean covered by pelagic sediments (in percent)*

	Atlantic	Pacific	Indian	Total extent
Foram ooze	65.1	36.2	54.3	47.1
Pteropod ooze	2.4	0.14	—	0.6
Diatom ooze	6.7	10.1	19.9	11.6
Radiolarian ooze	—	4.6	0.5	2.6
Oxypelite ("red clay")	25.8	49.1	25.3	38.1
Relative size of ocean (%)	23.0	53.4	23.6	100.0

* Data from Sverdrup *et al.* (1942). Pacific pteropod ooze area from Bezrukov (1970). Area of deep sea floor = 268.1×10^6 km².

Berger, 1976

Effects on Sediment

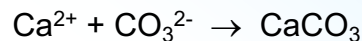
- **Saturation Horizon** is where " Ω " = 1
- **Lysocline** is where dissolution effects first appear in carbonate grains
 - Since degree of saturation decreases with depth, dissolution rates should increase with depth
- **Carbonate Compensation Depth (CCD)** is where the deposition rate of carbonate is equal to the dissolution rate (*i.e.*, no net accumulation of carbonates on the seafloor)

Kinetic Considerations

- CaCO_3 should not be preserved in sediments below the saturation horizon
- Yet, calcareous shells do persist... Why?
- Main factors: slow dissolution rates relative to rates of sinking (in water) and burial (in sediment)
 - 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

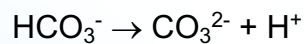
CaCO₃ Precipitation

A tricky subject when discussing “CO₂”
(or, more properly, p_{CO2})

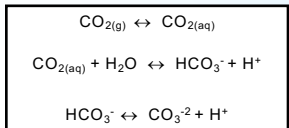
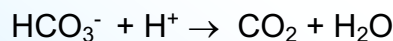


Does this reduce the CO₂ (p_{CO2}) level of the seawater?

No! Lost CO₃²⁻ will be replaced:

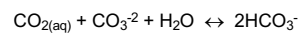


But this H⁺ release causes:



Thus, CaCO₃ precipitation causes a decrease in Total CO₂, but an increase in p_{CO2}

Hint: when pH is between 7.5 and 8.5:



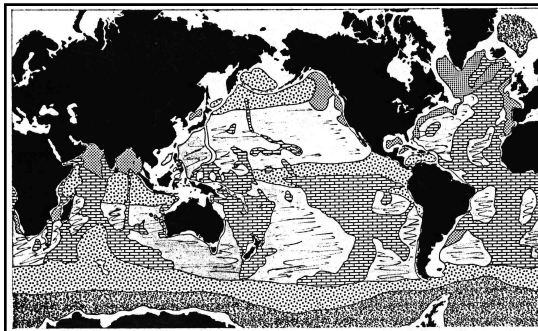
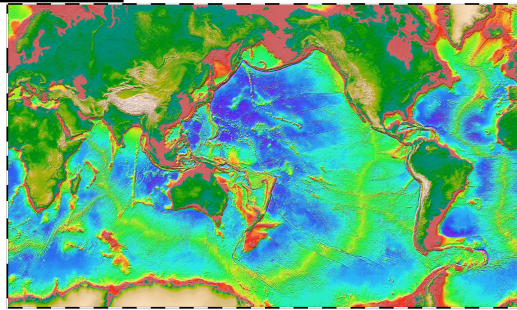


FIG. 24.7. Distribution of the principal types of sediment on the floors of the oceans. (Based on data from many sources.)

....Which is Reflected in the Distribution of the Principal Types of Sediment on the Seafloor



Comparison of Silica vs. Calcite Dissolution in the Ocean

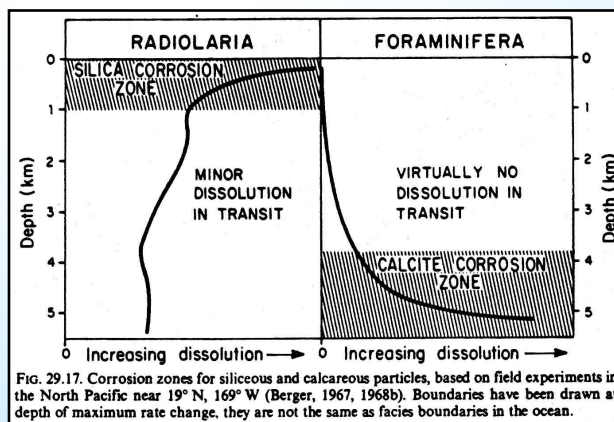
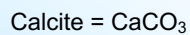


FIG. 29.17. Corrosion zones for siliceous and calcareous particles, based on field experiments in the North Pacific near 19° N, 169° W (Berger, 1967, 1968b). Boundaries have been drawn at depth of maximum rate change, they are not the same as facies boundaries in the ocean.

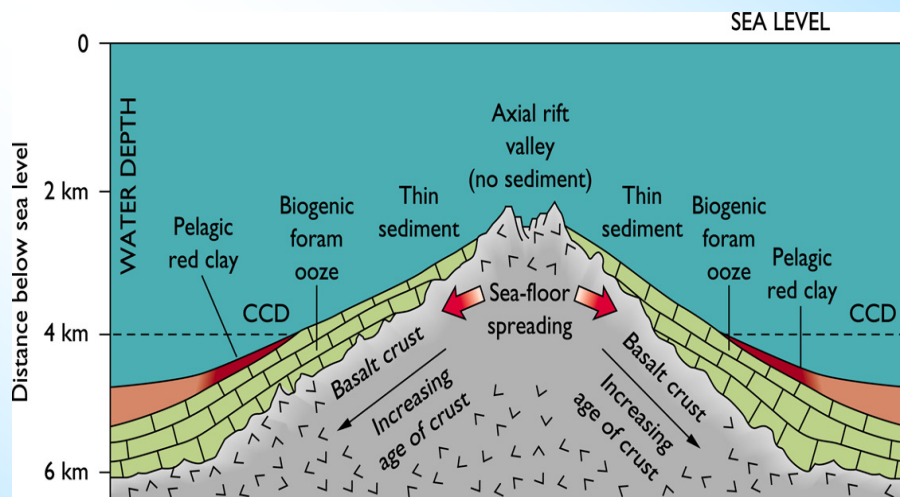
Berger, 1976



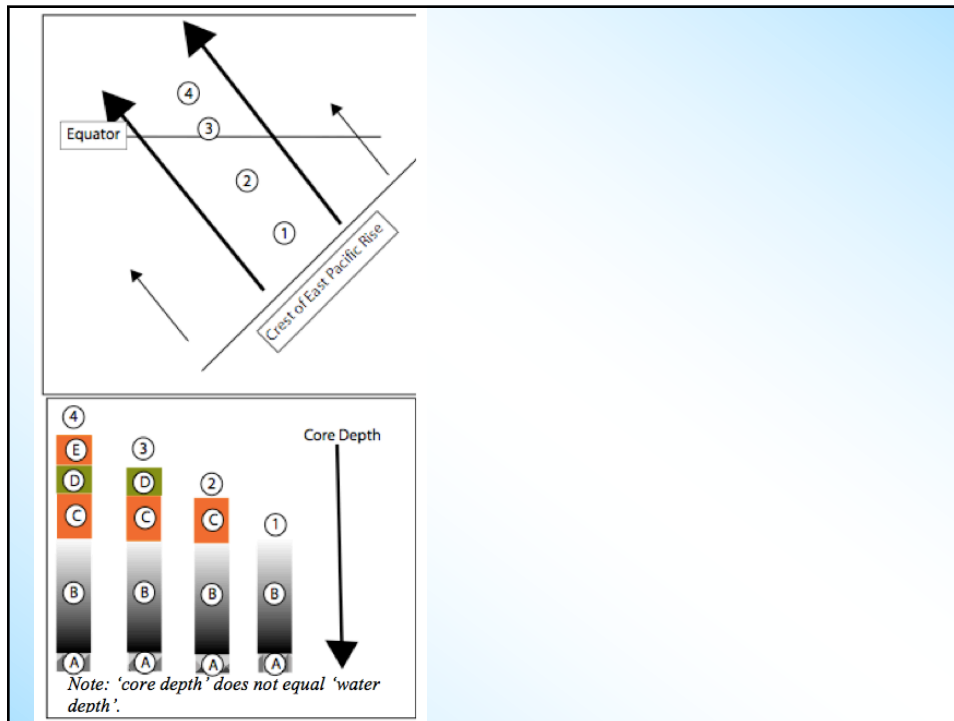
To recap some definitions...

- **Saturation Horizon** is where $\Omega = 1$
- **Lysocline** is where dissolution effects first appear in carbonate grains
 - Since degree of saturation decreases with depth, dissolution rates should increase with depth... (*Libes has this wrong*)
- **Carbonate Compensation Depth (CCD)** is where the depositional rate of carbonate is equal to the dissolution rate (i.e., no net accumulation)
- The lysocline occurs above the CCD, but is at or below the saturation horizon because of
 - Kinetic effects
 - Protection by organic matter on particulates
 - Inhibitory effect of dissolved species like phosphate which have mid-depth maxima

Sediment Distributions are Related to Mid-Ocean Spreading

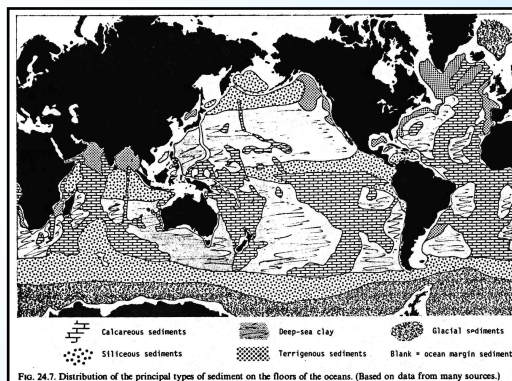


Compare with figures: “Sediment Deposition Rates”
“Deep-Sea Sediment Distribution”



Distribution Summary of the Principal Types of Sediment on the Seafloor

- Thick terrigenous layers in aprons around continents;
- Biogenic in equatorial band & along western continental boundaries... WHY?
- Authigenic and eolian sediments across vast areas of deep ocean floor covered by sediments of ~100s meters
- Volcanic tephra within 1000km of islands arcs and volcanic belts
- Thin sediment at active spreading centers



Davis & Gorsline, 1976