

The World Ocean - I



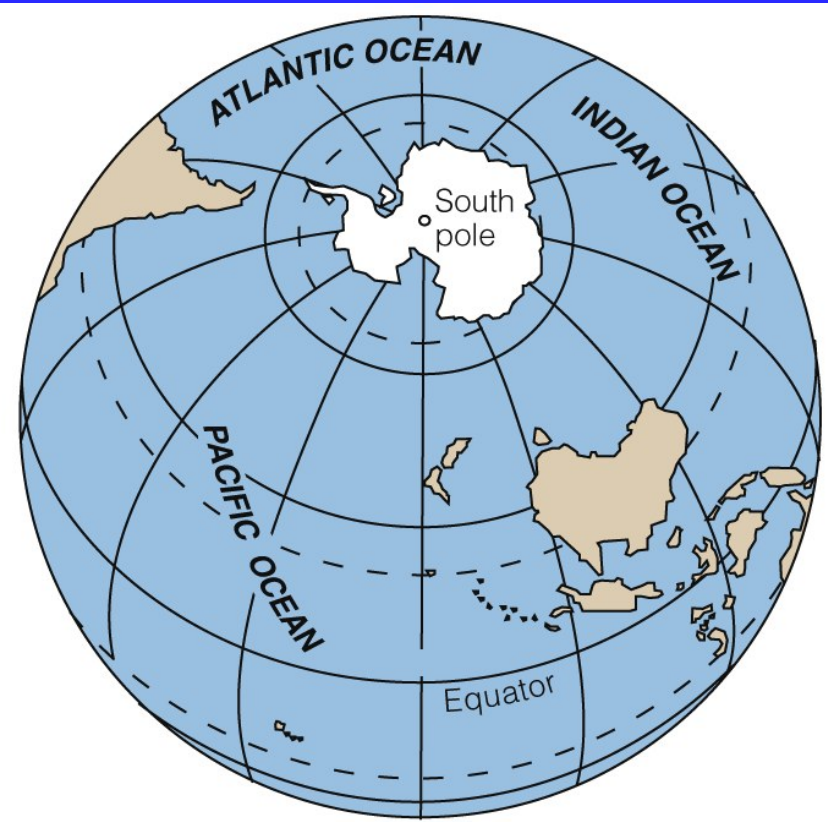
Ocean Basins and Ocean Water

- Seawater covers **70.8% of Earth's surface**
- **Land** comprising the remaining 29.2% is **unevenly distributed** between the northern and southern hemispheres
- **Most of the water is contained in three interconnected basins**; Pacific, Atlantic and Indian Oceans that, along with the Southern Ocean, make up the “**world ocean**”

Ocean Basins and Ocean Water



Land hemisphere
46.4% Land
53.6% Water



Water hemisphere
11.6% Land
88.4% Water

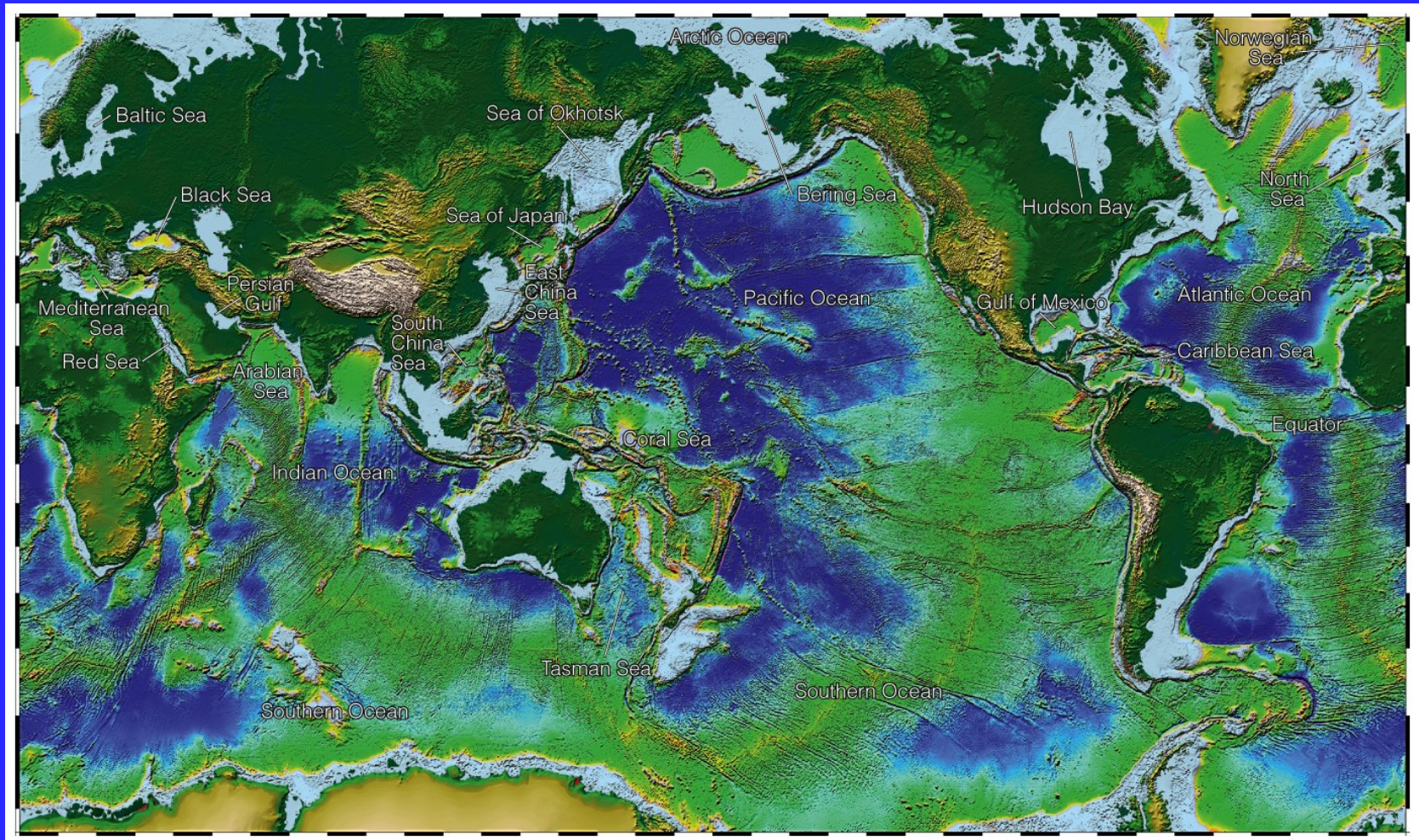
Ocean Basins and Ocean Water

- Before the 20th century, not much was known about the depth of the ocean
- Water depths were made with a weighted line lowered from a ship
 - Not very efficient!
- In the 1920s echo sounders began to be used, generating a pulse of sound that measured how long it took for the echo bouncing off the seafloor to return to the instrument

Ocean Basins and Ocean Water

- Thanks to echo sounders, the **topography of the seafloor** and depth of overlying water are **known in great detail** for most of the ocean basins
 - The **Mariana Trench** near Guam is the greatest ocean depth measured at **10,924 m**
- Recent **satellite measurements** reveal the average depth of the sea is 3970 m, and the average height of land above sea level is 840 m

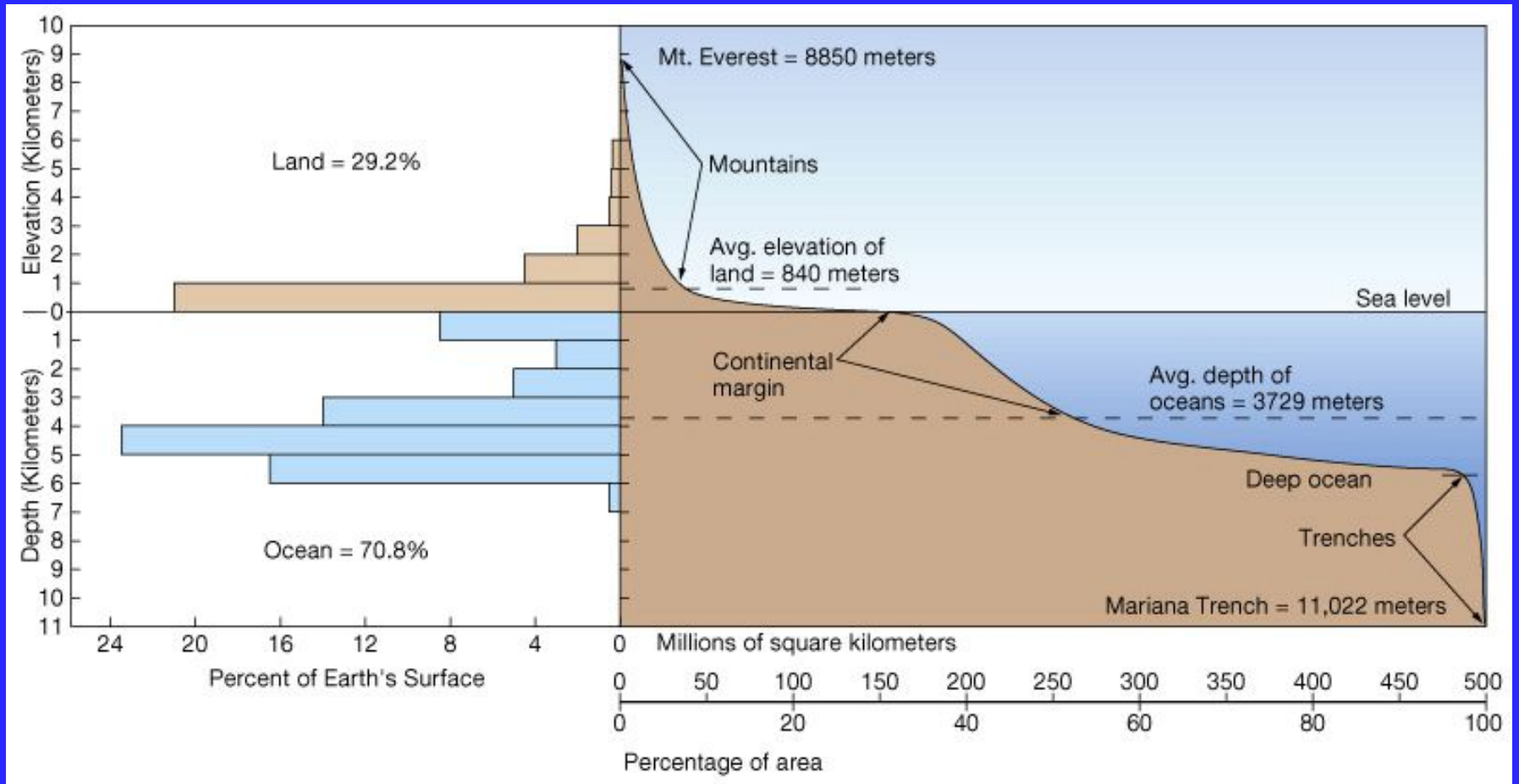
Ocean Basins and Ocean Water



Ocean Basins and Ocean Water

- As far back as the oldest sedimentary rocks, **more than 4 Ga, Earth has had liquid water** on its surface
 - Oxygen isotopes in zircons suggest that the **ocean** may be **4.4 billion** years old
- Where the water came from is still uncertain
 - **Carbonaceous chondrites** contain water as hydrous minerals, suggesting some water originated from accretion and volcanic steam
 - **Icy comets** bombarded early Earth, bringing with them frozen water

Hypsographic Curve

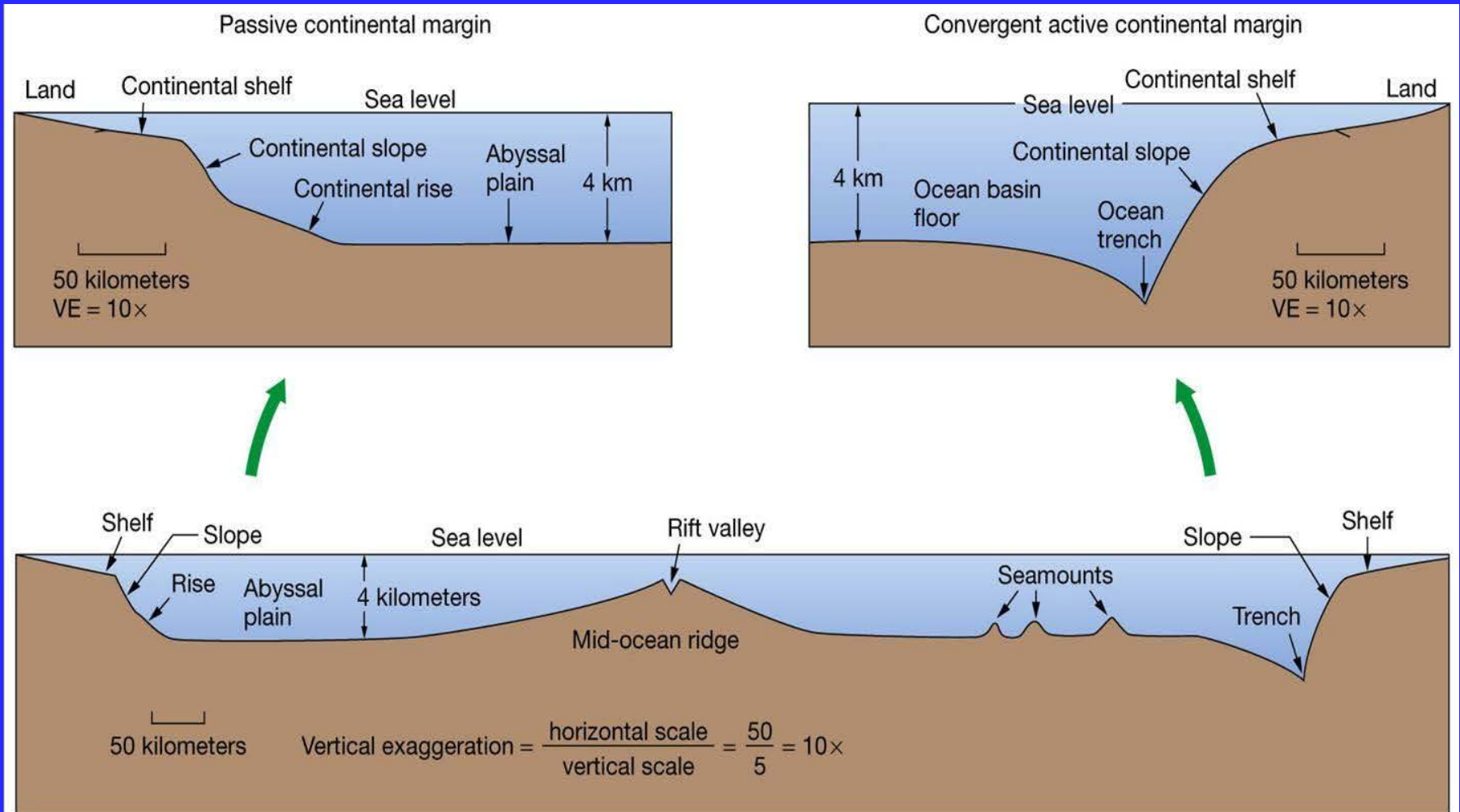


Distribution of different elevations (on land) and depths (at sea) on the earth.

Sealevel Changes

- **Eustatic** – due to changes in volume of water in the ocean basins. Growth and retreat of glaciers is the major process.
- **Noneustatic** – not due to changes in volume of water. For example, changes in rate of addition of magma to the ocean floor.
- **Relative sealevel change** – reference point is the land-sea margin
- **Absolute sealevel change** – the global change in sealevel. Answering this question is not as easy as it might seem.
- **Freeboard of continents** – throughout much of earth history the ocean basins are just full of water.

Seafloor cross-section and continental margins

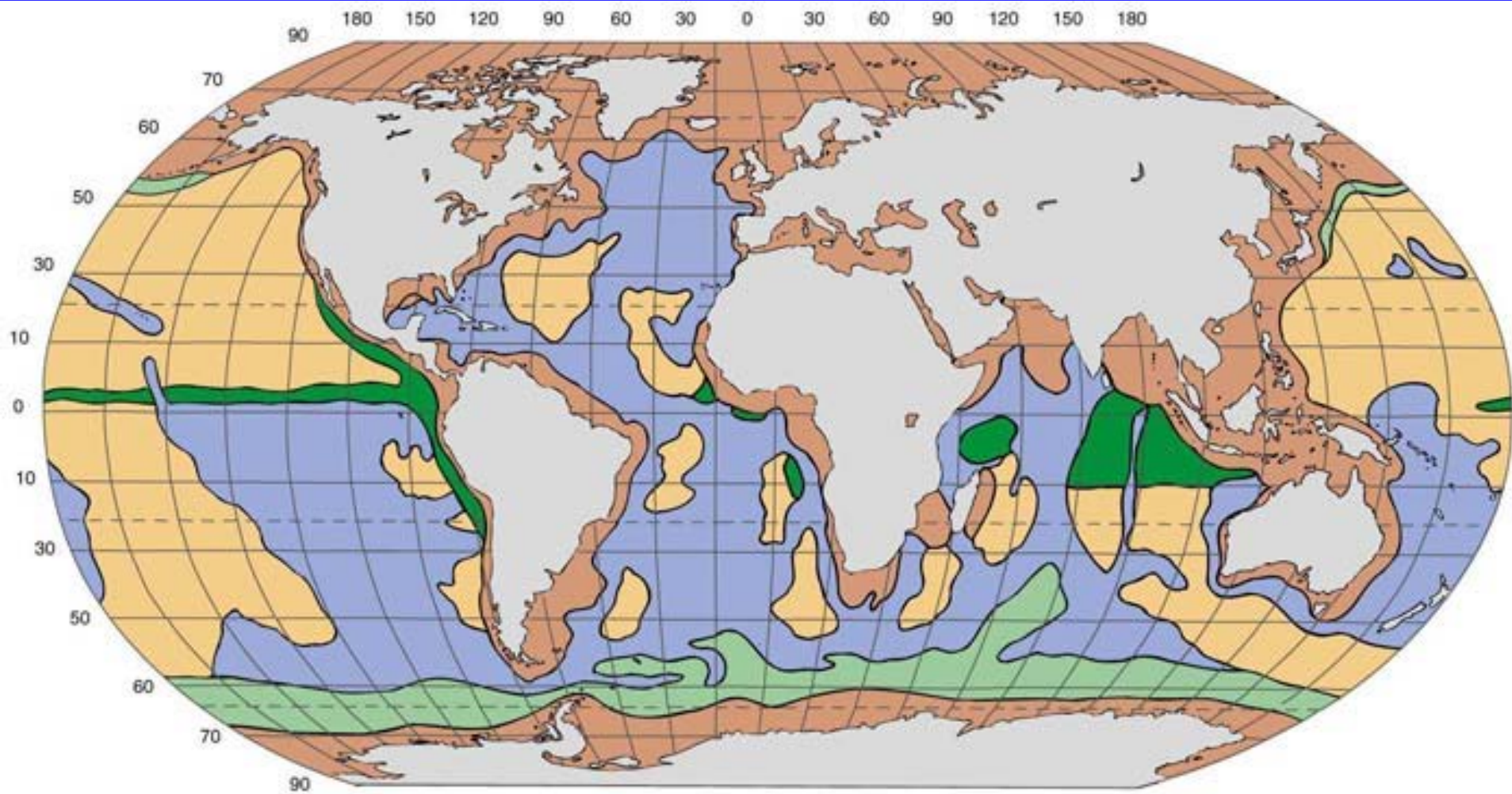


Origin and Distribution of Marine Sediments




What's all that squishy muck at the bottom of the ocean?


What can we learn from it?



Neritic
Continental
(Lithogenous)





Abyssal
clay



Calcareous
ooze

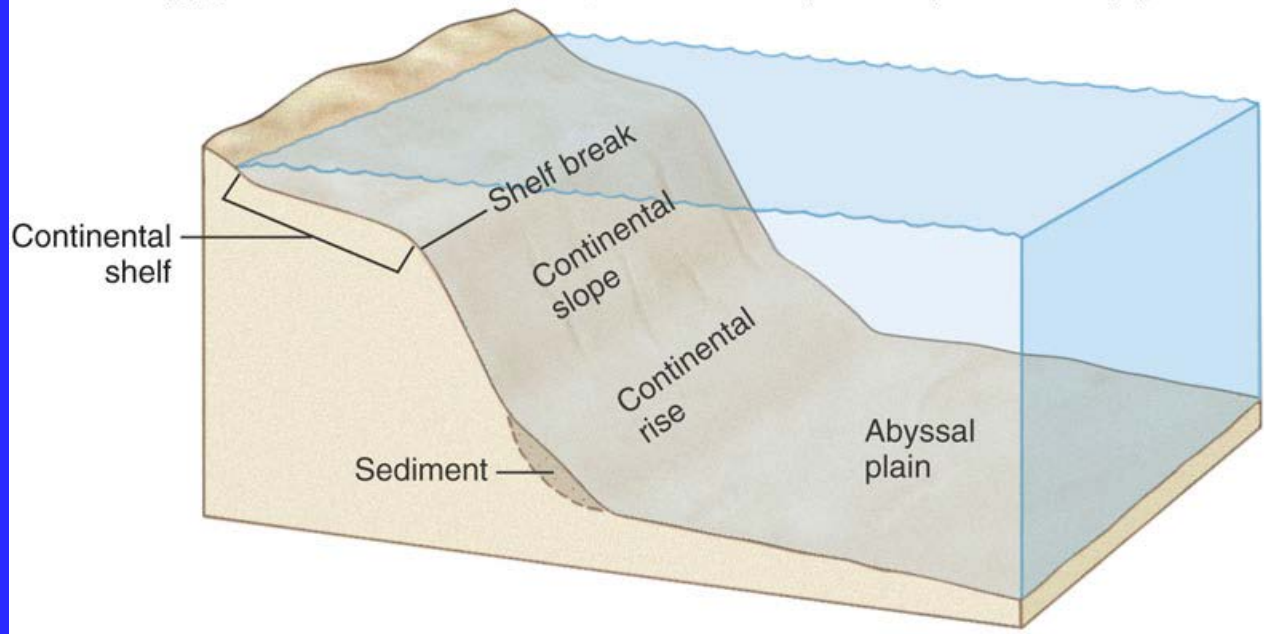


Siliceous ooze
Diatom Radiolarian

Continental Shelves

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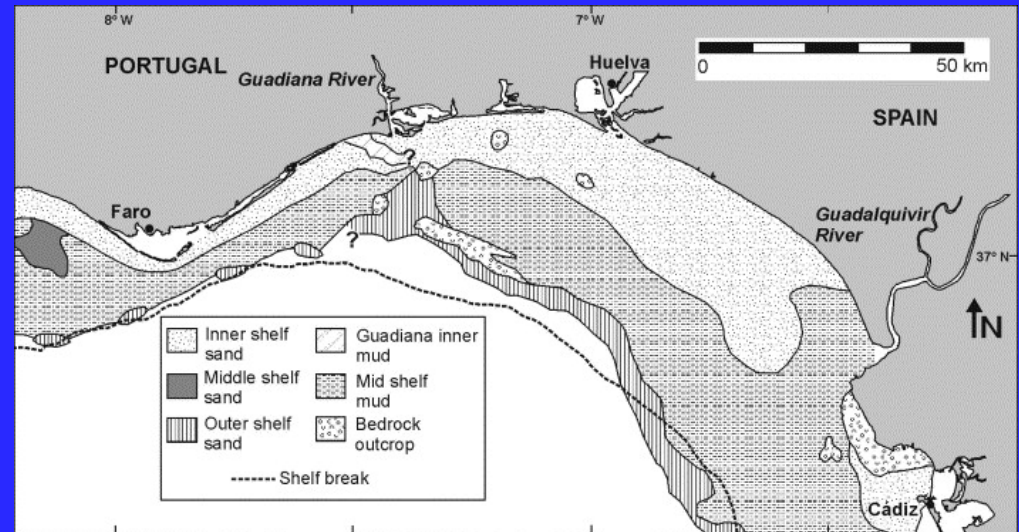
Processes affecting continental shelves

1. Glaciation
2. Sea-level change (± 130 m during continental glaciation)
3. Waves and currents
4. Sedimentation
5. Carbonate deposits
6. Faulting and volcanism

Sedimentation on the Continental Shelf

Theoretical distribution – coarse near shore to fine-grained further out. Stoke's Law in action.

Observed – coarse to fine to coarse.

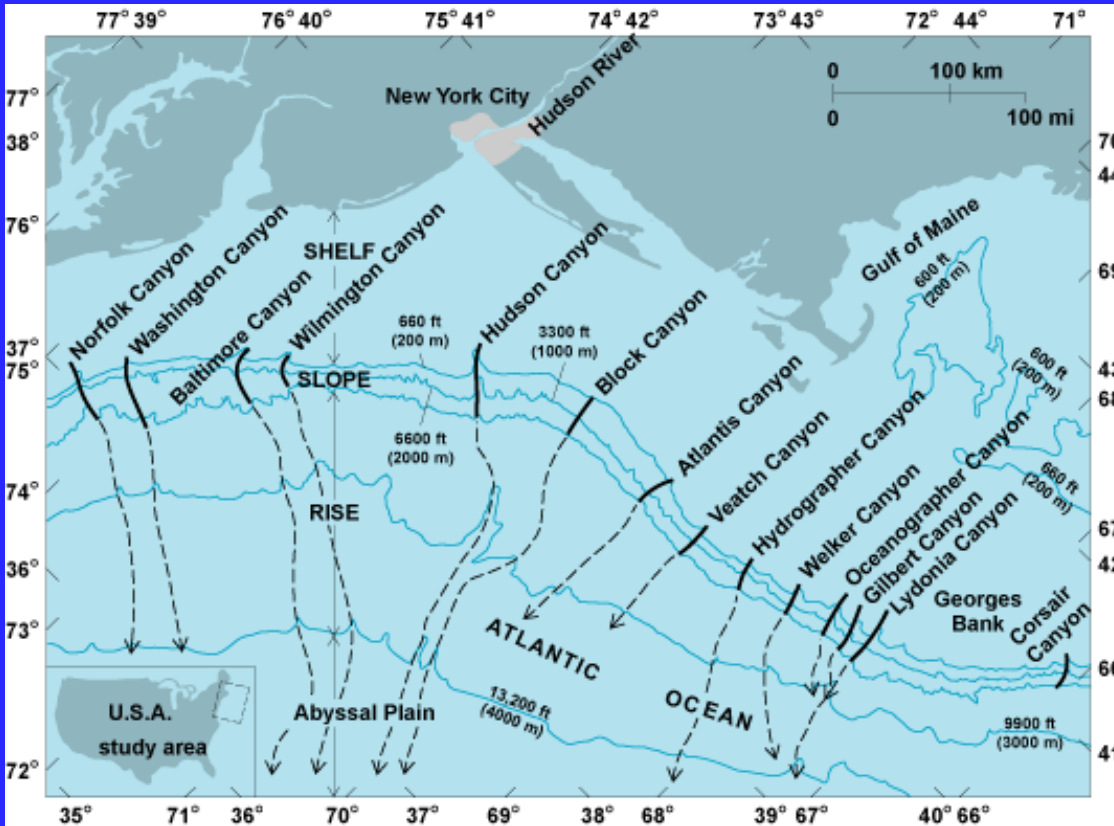


Holocene transgression – starts 10,000 years ago as continental glaciers formed during the maximum advance of the ice sheet begin to melt. Sea level rises ~125 m and continental margins are flooded.

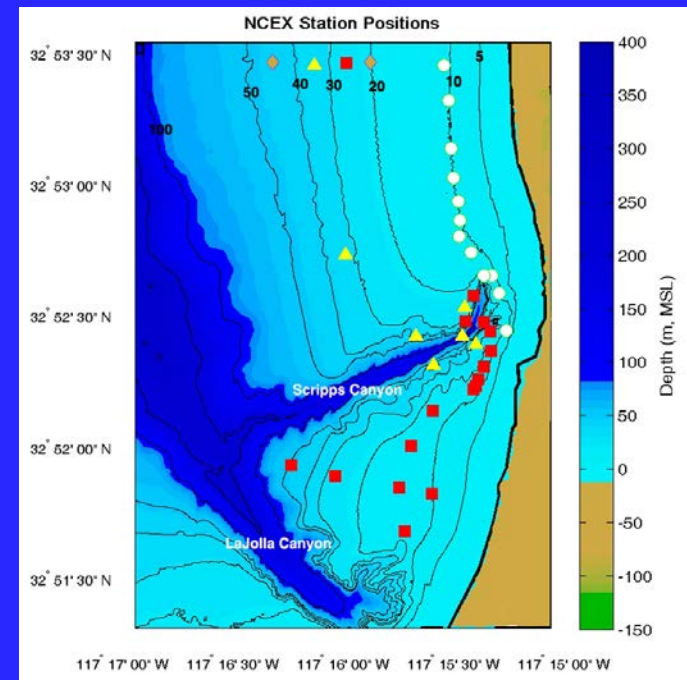
Sedimentary division of the shelf

- Inner shelf – zone of modern sedimentation
- Outer shelf – beyond the influence of modern sedimentation. Zone of **relict** sediment.

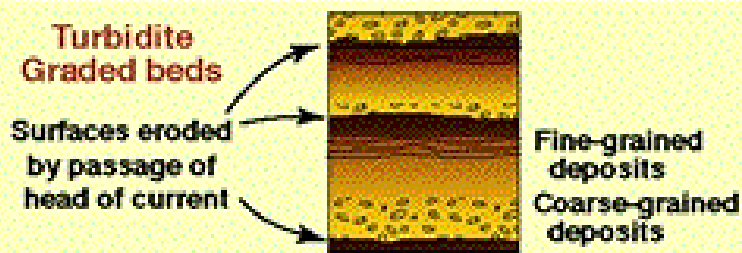
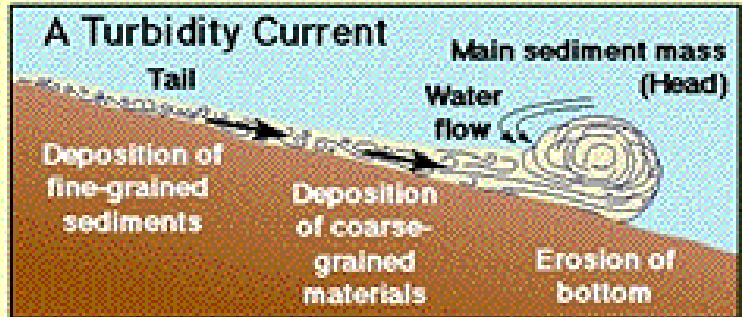
Submarine Canyons



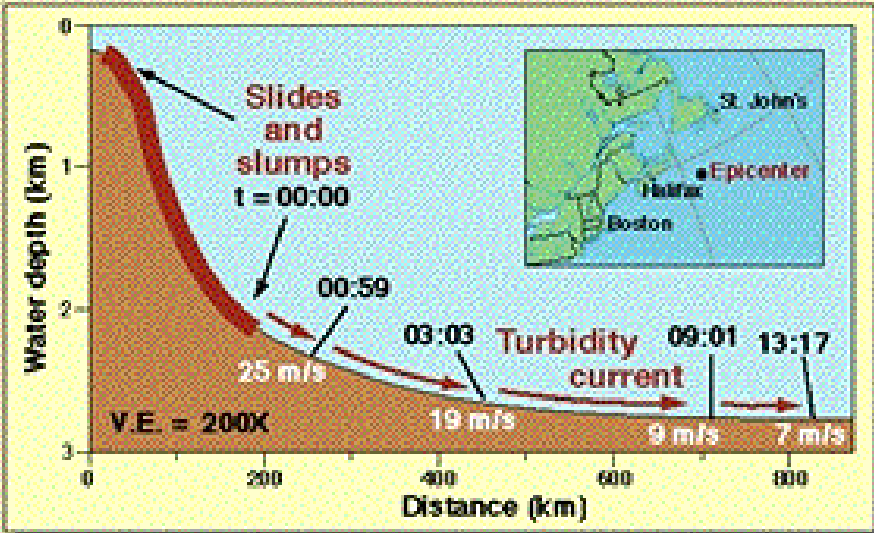
US Atlantic coast – passive continental margin



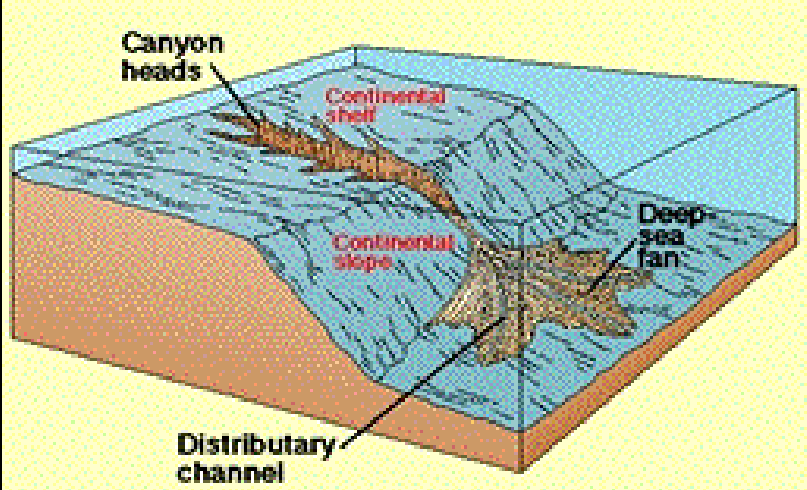
West coast of the US – active continental margin



The 1929 Grand Banks Earthquake



A Submarine Canyon-Fan System



Deep Ocean Sediments

Sources of sediments:

1. Terrigenous – land derived (from elevated land masses)
2. Biogenic – marine plant and animal materials. May include inorganic material but only that created by marine organisms.
3. Volcanic – submarine volcanic materials. Volcanic material added directly to the seafloor.
4. Hydrogenic – materials crystallized directly from seawater. For example, manganese nodules.
5. Cosmic – particles of extraterrestrial origin. Cosmic dust, meteoritic particles

Major components of deep sea sediments

1. **Detrital** – derived mainly from erosion of the continents. Mostly aluminosilicate minerals.

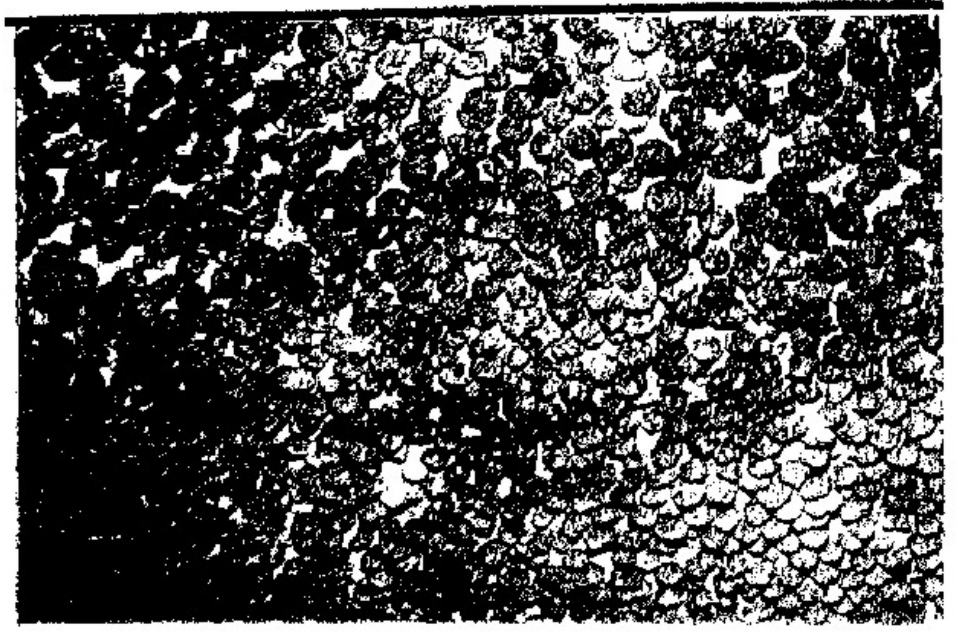
Mineral	Composition
Quartz	SiO_2
Orthoclase	KAlSi_3O_8
Plagioclase	$\text{NaAlSi}_3\text{O}_8 \rightarrow \text{CaAl}_2\text{Si}_2\text{O}_8$
Kaolinite	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$
Illite	$\text{KAlSi}_3\text{O}_{10}(\text{OH})_2$
Montmorillonite	$\text{Al}_2\text{Si}_4\text{O}_{10}(\text{OH})_2 \cdot x\text{H}_2\text{O}$
Chlorite	$\text{Mg}_5\text{Al}_5\text{Si}_3\text{O}_{10}(\text{OH})_8$

2. **Authigenic** – formed by spontaneous crystallization either on the seafloor or within the sediment column

Manganese nodules – concretions found on the deep seafloor that consist of layers of iron and manganese oxide around a core.

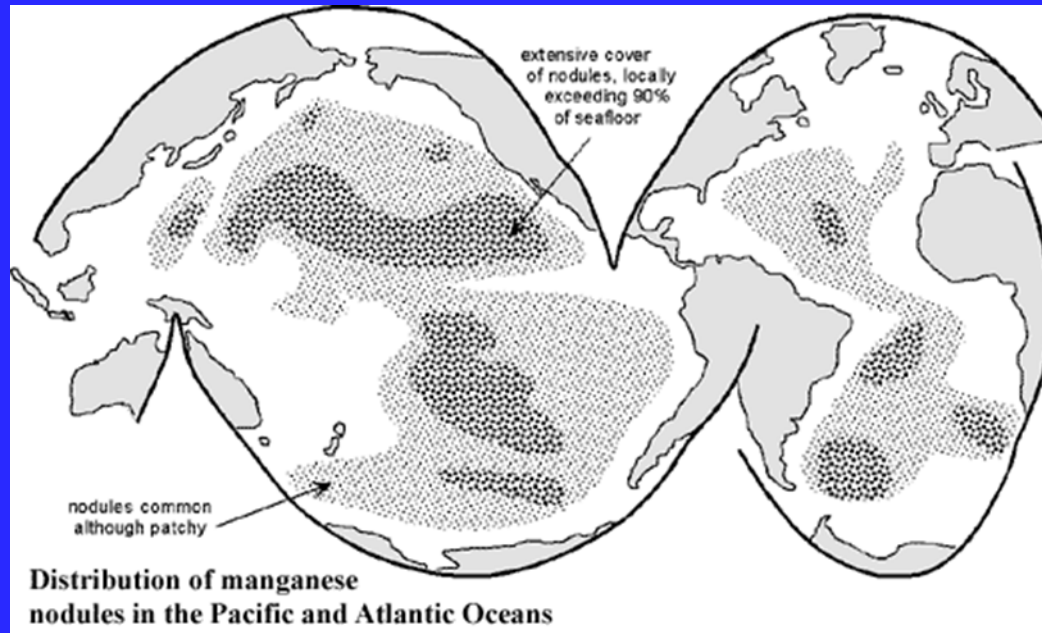


Figure 4-8 Photograph of a cross-sectional cut through a manganese nodule with two growth centers. The altered volcanic material at the centers nucleated the nodule's growth. Crude growth rings representing temporal changes in texture and composition can be seen. This nodule has a radius of 2 centimeters. At a growth rate of 2 mm/10⁶ yrs, it must have commenced about 10,000,000 years ago.



A field of closely spaced manganese nodules at the bottom of the Antarctic Ocean. The average diameter of the nodules is 6 cm.

Manganese nodules occur in fields located in the deepest part of the ocean basins.



Most nodules are found within one meter of the surface. Given their inferred slow growth rates, millions of years, and the rate of sediment accumulation on the deep seafloor (~ 0.1 cm/1000 years = 1 m/million years) why they are found so close to the surface is a puzzle. Also not understood is how they achieve a concentric growth pattern given that bottom currents are very weak and the nodules are not moved along the seafloor.

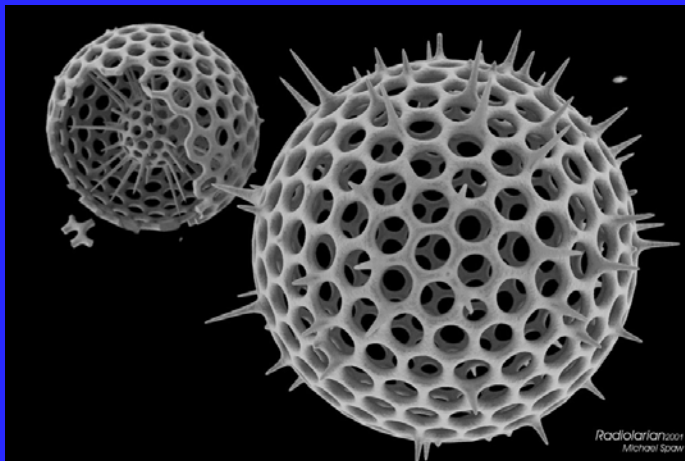
Major components of deep sea sediments

3. Biogenic – hard parts of organisms

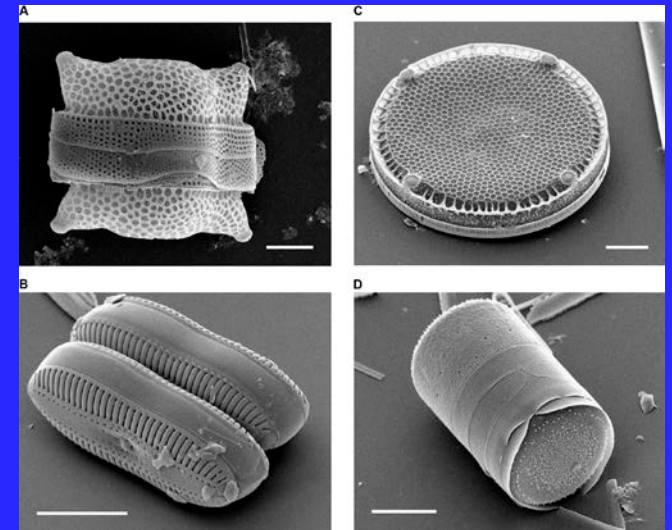
- a. Calcite or aragonite shells (polymorphs of CaCO_3).
Example – foraminifera
- b. Opal – $\text{SiO}_2 \cdot x\text{H}_2\text{O}$. Examples – diatoms (cold water), radiolaria (warm water).



Foraminifera



Diatoms



Radiolaria

Transport of terrigenous material to the open ocean

1. **Suspension** – sinking velocity of particle (as determined by Stoke's Law) less than upward velocity due to turbulence.

$$V = \frac{2}{9} \frac{g(\rho_s - \rho_f)r^2}{\mu}$$

for water (at 20°C), $\mu = 1.0 \times 10^{-3} \text{ Pa}\cdot\text{s}$

2. **Ice Rafting** – glacial marine deposits around areas of glaciation.
3. **Winds**
4. **Mudslides, landslides, turbidites**
5. **Marine algae anchored to rocks**
6. **Marine mammals (e.g. gastroliths)**

Biogenic Sediments

Opal ($\text{SiO}_2 \cdot x\text{H}_2\text{O}$)

1. The oceans are undersaturated in opal at all depths.
2. Various microscopic organisms make opaline shells.
3. Preservation of this shell material is a function of
 - a) Wall thickness
 - b) Surface/volume ratio
 - c) Organic coatings
4. Production is the key to the preservation of opal in deep sea sediments.
5. In the sediment column, opal is preserved because the pore waters become saturated in silica.

Calcite and aragonite (CaCO₃)

1. Production of CaCO₃ hard parts is more uniform than opal. Limiting factor is nutrient elements.
2. The upper part of the ocean is saturated in CaCO₃ (both aragonite and calcite).
3. Spontaneous precipitation takes place very slowly or not at all in the saturated part of the ocean. **Organisms are primarily responsible for the precipitation of CaCO₃.**
4. For calcite or aragonite in the ocean

$$\text{Degree of saturation} = D = \frac{([\text{Ca}^{2+}][\text{CO}_3^{2-}])_{\text{measured in seawater}}}{([\text{Ca}^{2+}][\text{CO}_3^{2-}])_{\text{saturated seawater}}}$$

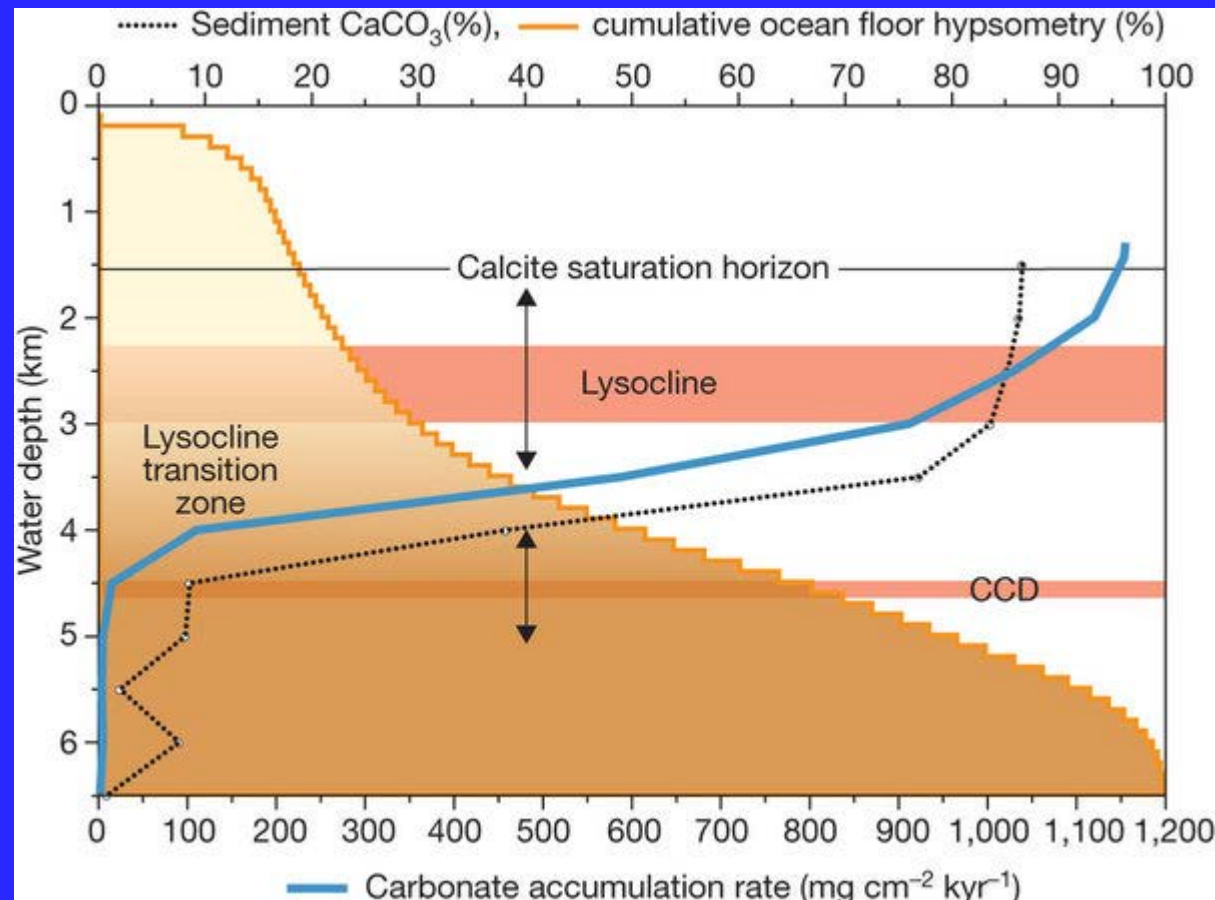
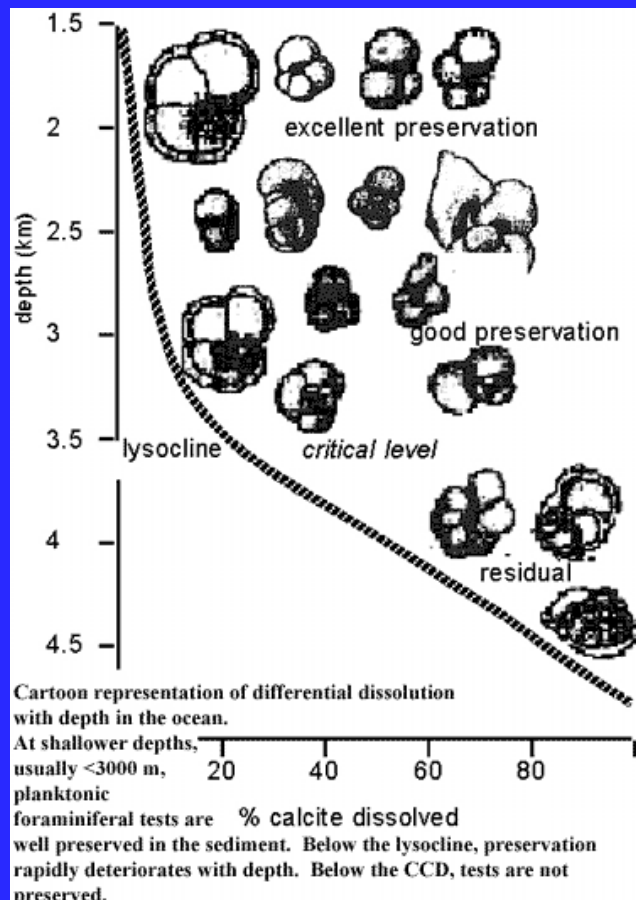
since Ca^{2+} is more or less constant in seawater

$$D = \frac{[\text{CO}_3^{2-}]_{\text{measured}}}{[\text{CO}_3^{2-}]_{\text{saturated seawater}}}$$

5. Solubility of calcite and aragonite $f(T,P)$. 100 Atm \equiv 1000 m depth

		Saturation $[\text{CO}_3^{2-}]$ 10^{-6} moles/liter	
T($^{\circ}\text{C}$)	P(Atm)	Calcite	Aragonite
24	1	53	90
2	1	72	110
2	250	97	144
2	500	130	190

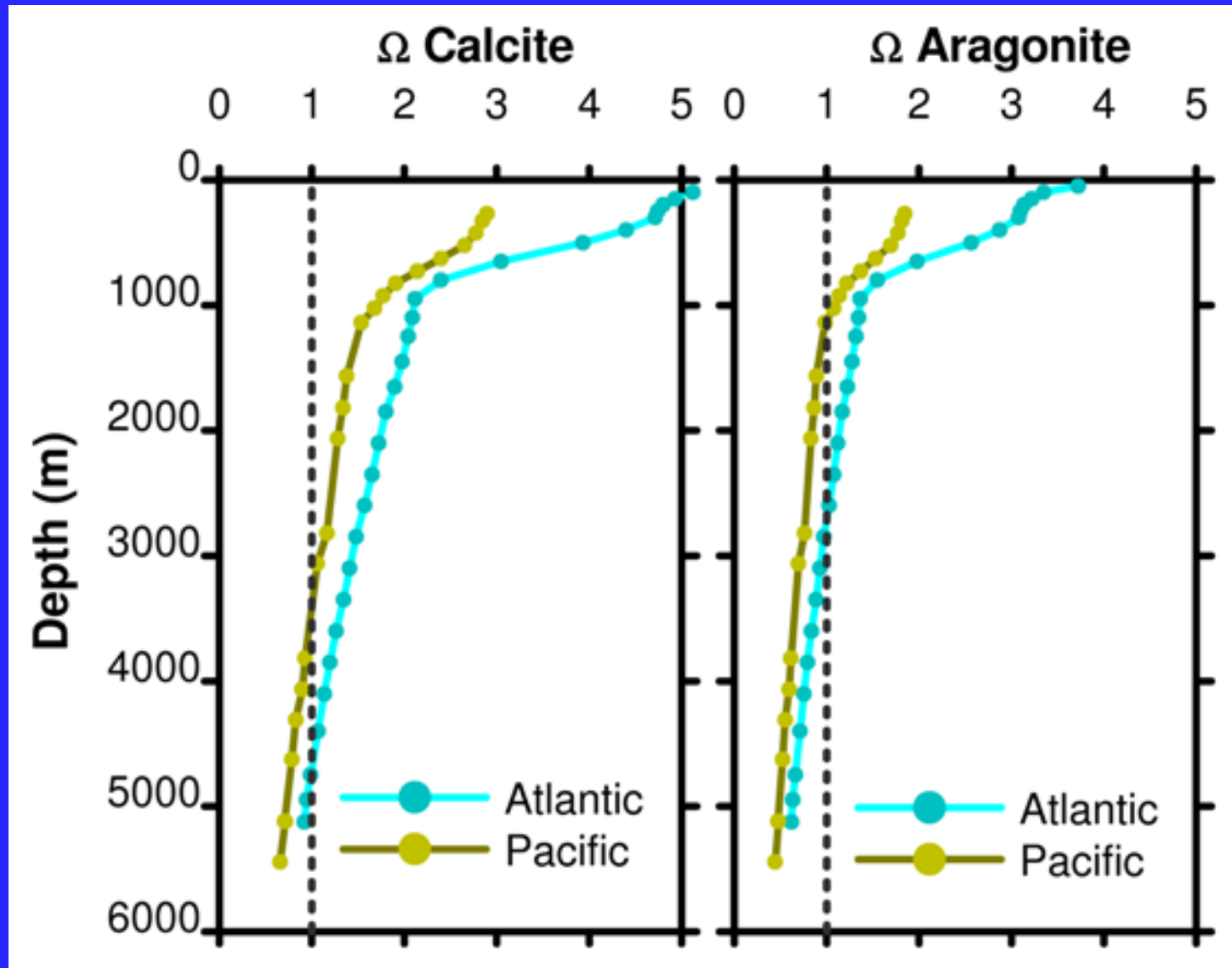
6. **Saturation horizon** – depth at which ocean becomes undersaturated in carbonate.
7. **Lysocline** – region of rapidly changing carbonate saturation.
8. **Carbonate compensation depth (CCD)** – depth below which carbonates are not found in the seafloor sediments.



8. Throughout the ocean red clay (alumino-silicate debris) is raining down at an average rate of $0.3 \text{ g/cm}^2 \cdot 1000 \text{ yrs}$ and CaCO_3 at a rate of $1.0 \text{ g/cm}^2 \cdot 1000 \text{ yrs}$. If a particular location is above the saturation horizon the sediment is 3 parts clay to 10 parts carbonate ooze. Below the saturation horizon the sediment is dominantly composed of red clay.
9. 60% of the Atlantic seafloor is above the saturation horizon and carbonate ooze is the dominant sediment. 15% of the Pacific seafloor is above the saturation horizon and red clay is the dominant sediment type.
10. Location of the saturation horizon compared to the CCD

	Aragonite		Calcite	
	Calc.	CCD	Calc.	CCD
Atlantic	200-400 m	~300 m	400-3500 m	3500 m
Pacific	2000 m	2500 m	4500 m	5000 m

Calcite and Aragonite Saturation in Ocean



Variations of sediment types due to seafloor spreading

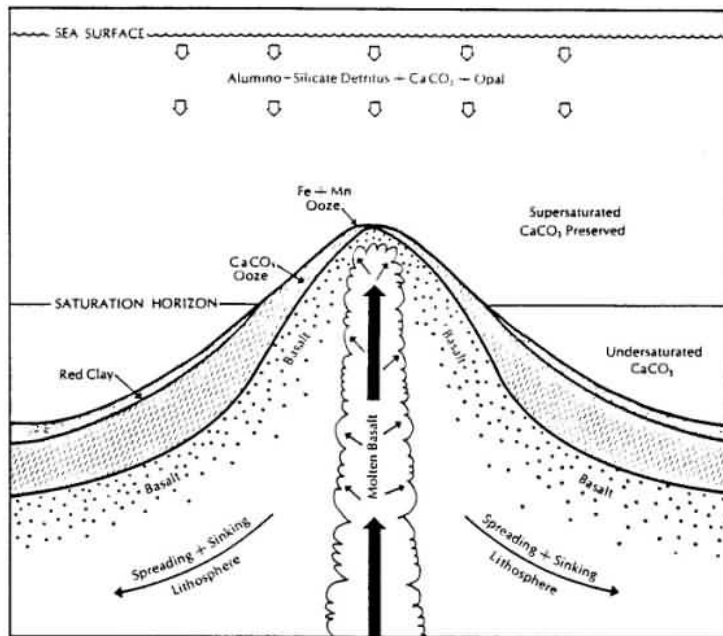


Figure 2-8 Sequence of sediment types accumulated by the great lithospheric plates as they move away from the crests of mid-ocean rises. The first sediment to be deposited is iron (Fe) + manganese (Mn) oxide, a product of volcanism. When a point a few kilometers away from the crest is reached, the sediment no longer receives volcanic products and is dominated by CaCO_3 falling from the surface. At a point several hundred kilometers from the crest, the plate subsides below the saturation horizon for calcite and CaCO_3 no longer accumulates. Beyond this point, continental detritus and perhaps opal dominate the sediment. A core bored through sediment capped with red clay would encounter buried CaCO_3 and then a thin layer of Fe + Mn-rich sediment before entering the underlying basalt (hard rock).

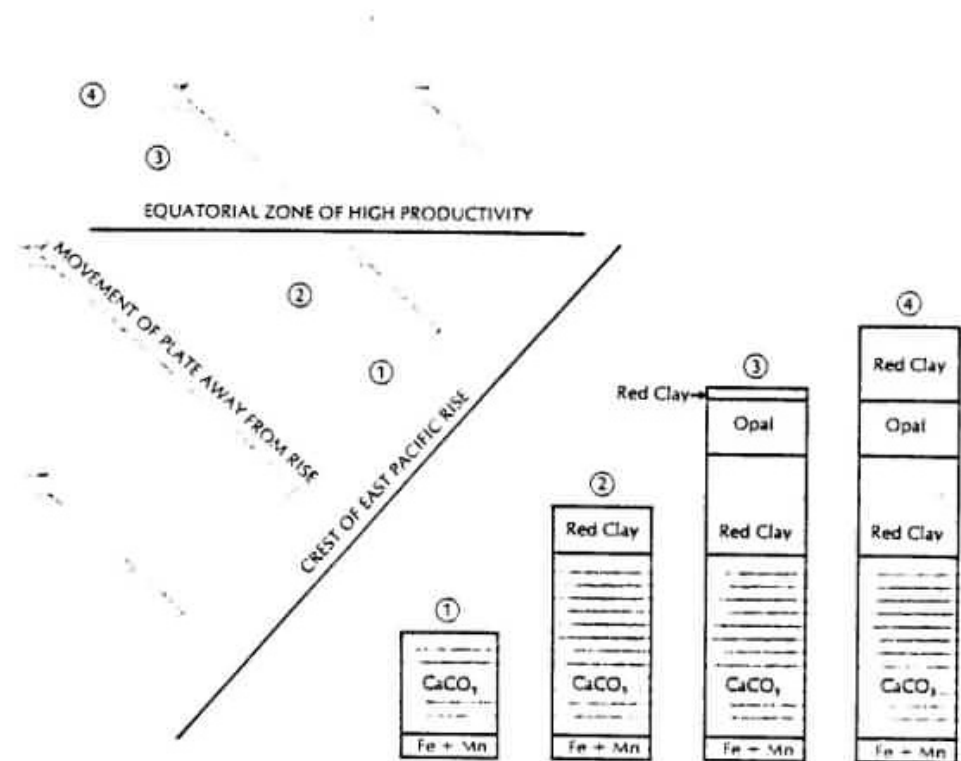
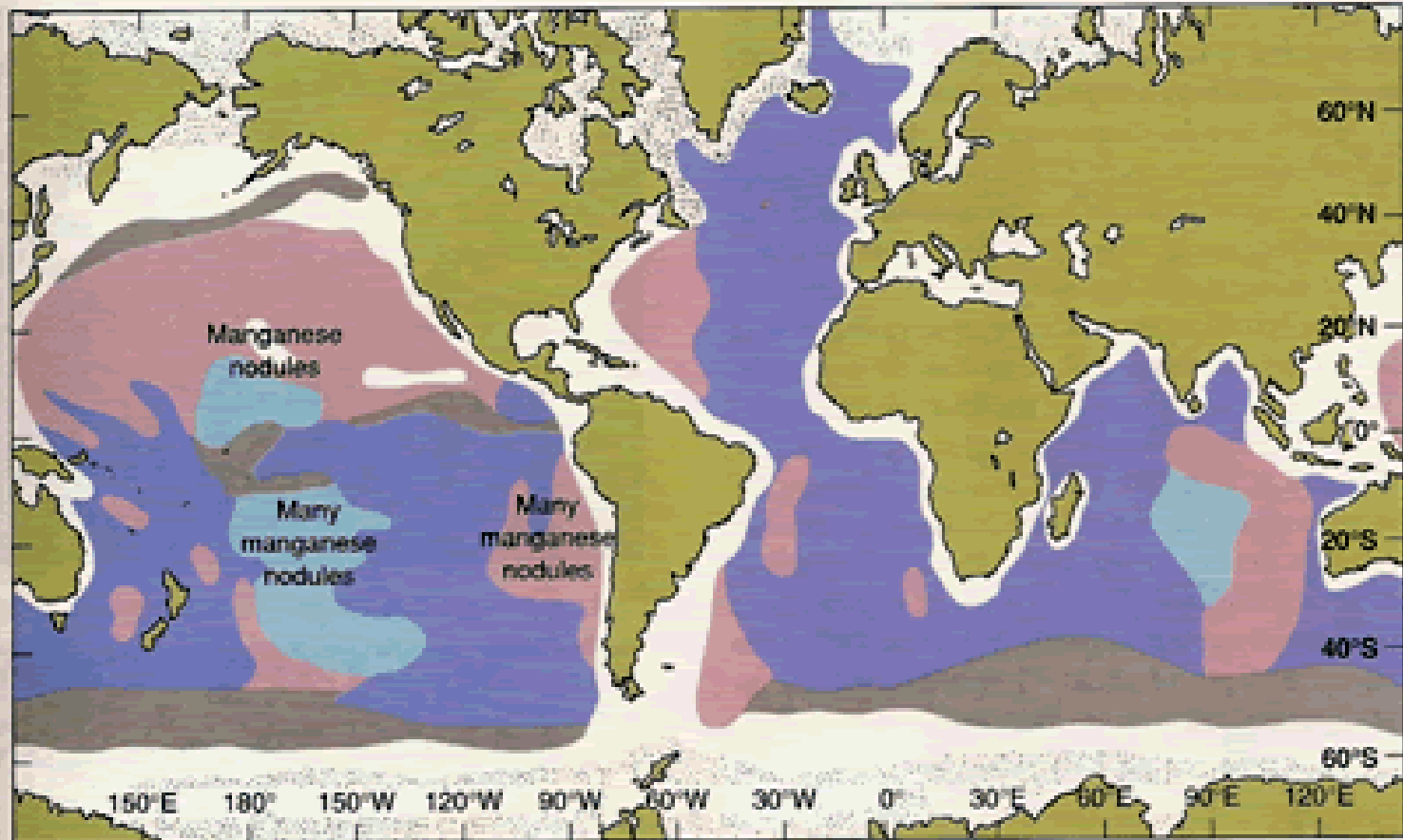


Figure 2-9 Sequence of sediments accumulating on a plate which crosses the high productivity equatorial belt in its movement away from a ridge crest. The numbers relate the map locations to the corresponding sedimentary sequences found in borings made at these points.

Distribution of marine sediments - review



Terrigenous sediment

Red clay

Siliceous ooze

Calcareous ooze

Hydrogenous sediment

Ice-rafted sediments

Stratigraphic Markers

- 1) **Magnetic reversals** – determine magnetic signatures of sediment core as a function of depth and correlate reversals with the magnetic time scale (last reversal ~700,000 years before present)
- 2) **Faunal changes** – key horizons which can be traced across the ocean basins
- 3) **Climate changes** – useful for the last 200,000 years
 - Changes in CaCO_3 content – reflects changes in ocean temperature
 - $^{18}\text{O}/^{16}\text{O}$ ratio changes in CaCO_3 from foram shells ($^{18}\text{O}/^{16}\text{O} \downarrow$ as $T \uparrow$)
 - Faunal changes in response to changing surface T
 - Coarse fraction changes

Determination of Absolute Ages

- 1) **Radiocarbon dating** – present to about 40,000 (120,000 by AMS) years

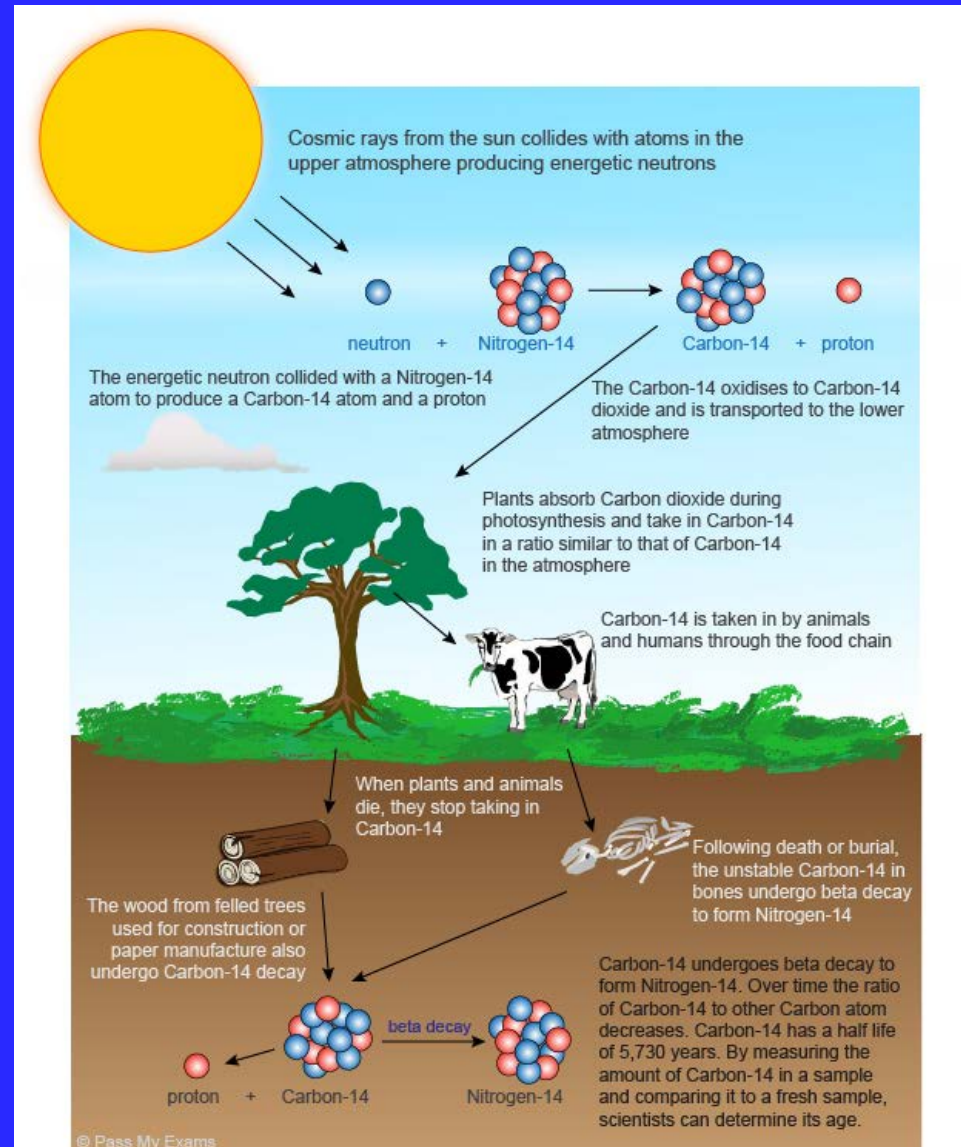


$$t_{1/2} = 5700 \text{ years}$$

Secular equilibrium achieved so ${}^{14}\text{C}/\text{C}$ ratio in seawater is constant.

$$\left(\frac{{}^{14}\text{C}}{\text{C}}\right)_{\text{today}} = \left(\frac{{}^{14}\text{C}}{\text{C}}\right)_{\text{initial}} \times e^{-\lambda t}$$

$$t = 8200 \ln \frac{\left(\frac{{}^{14}\text{C}}{\text{C}}\right)_{\text{initial}}}{\left(\frac{{}^{14}\text{C}}{\text{C}}\right)_{\text{today}}}$$



2) U-series disequilibrium dating

- Th-230 in the U-238 series
- Pa-231 in the U-235 series
- U is very soluble and has a long residence time in the ocean ~1,000,000 years
- Secular equilibrium is achieved
- Th and Pa are very reactive in seawater and are scavenged by particles in a couple of months.

Table 3-4. Uranium Isotope Decay Series Showing the Decay Products of the Naturally Occurring Isotopes of Uranium

	Uranium-238 Series, Includes ^{234}U Series					Uranium-235 Series					
Np											
U	^{238}U 4.5E9		^{234}U 2.5E5y					^{235}U 7.1E8 y			
Pa		^{234}Pa 1.2 m						^{231}Pa 3.3E4 y			
Th	^{234}Th 24 d		^{230}Th 8E4y					^{231}Th 25.5 h		^{227}Th 18.7 d	
Ac								^{227}Ac 21.8 y			
Ra			^{226}Ra 1600 y							^{223}Ra 11.4 d	
Fr								^{223}Fr 21.8 m			
Rn			^{222}Rn 3.82 d							^{219}Rn 4.0 s	
At				^{218}At 2s						^{215}At 1E-4s	
Po			^{218}Po 3.05 m		^{214}Po 1.6E-4s		^{210}Po 138 d			^{215}Po 1.8E-5	^{211}Po 0.5 s
Bi				^{214}Bi 19.7 m		^{210}Bi 5.0 d				^{211}Bi 2.15 m	
Pb			^{214}Pb 26.8 m		^{210}Pb 22.3y		^{206}Pb stable			^{211}Pb 36.1 m	^{207}Pb stable
Tl				^{210}Tl 1.3 m		^{206}Tl 4.2 m				^{207}Tl 4.79 m	

↓ alpha decay; ↗ beta decay; half life (d = days; m = minutes; s = seconds; y = years)

Source: NCRP 1975

- f) Activity at any depth compared to the activity at the surface yields the age of the sediment by the relationship

$$A_{\text{today}} = A_{\text{initial}} e^{-\lambda t} \quad \text{or} \quad t = \frac{1}{\lambda} \ln \frac{A_{\text{initial}}}{A_{\text{today}}}$$

- g) Age equations:

$$\text{Th-230: } t_{1/2} = 75,000 \text{ years} \quad t = 108,202 \ln \frac{A_{\text{initial}}}{A_{\text{today}}}$$

$$\text{Pa-231: } t_{1/2} = 32,500 \text{ years} \quad t = 46,888 \ln \frac{A_{\text{initial}}}{A_{\text{today}}}$$

h) If the sedimentation rate is constant then a plot of log (activity) versus depth yields a straight line.

3. **K-Ar dating** – used to date volcanic rocks. Can be used to date ash layers if present.

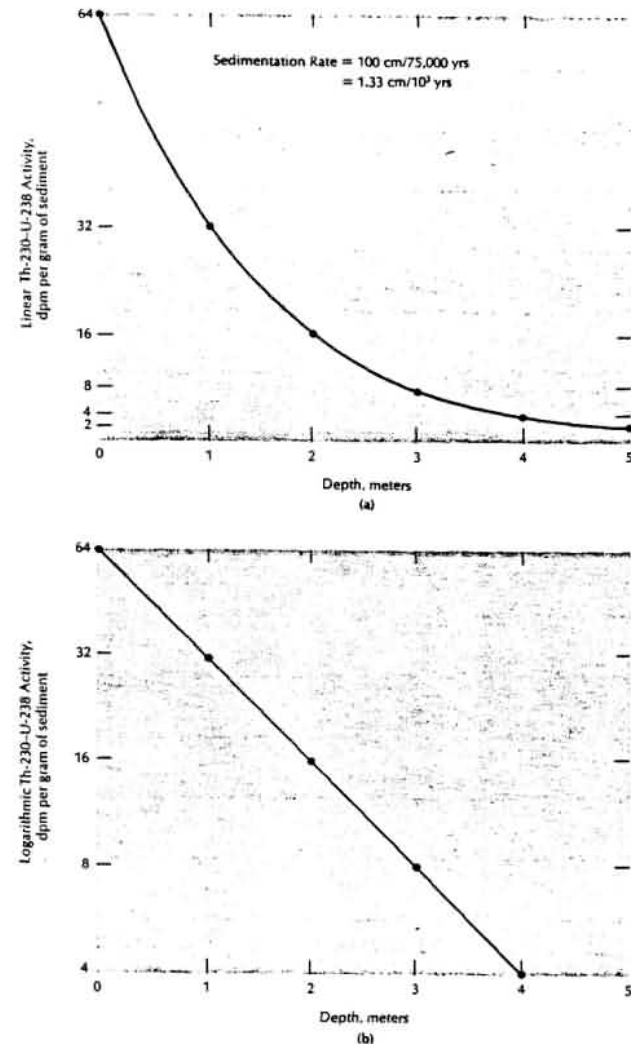


Figure 3-9 The distribution with depth of excess Th-230 in an ideal core with a constant sedimentation rate of 1.33 cm/10³ yrs and a constant rate of Th-230 influx. In such a core, the amount of excess Th-230 shows a drop by a factor of 2 for each interval of 100 centimeters penetrated. (This thickness of sediment is deposited in one half-life of Th-230.) (a) employs a linear scale for the Th-230 content; (b) employs a logarithmic scale. (Note that the points in (b) fall along a straight line.)