

Ocean Formation & Sea Floor

ES 383

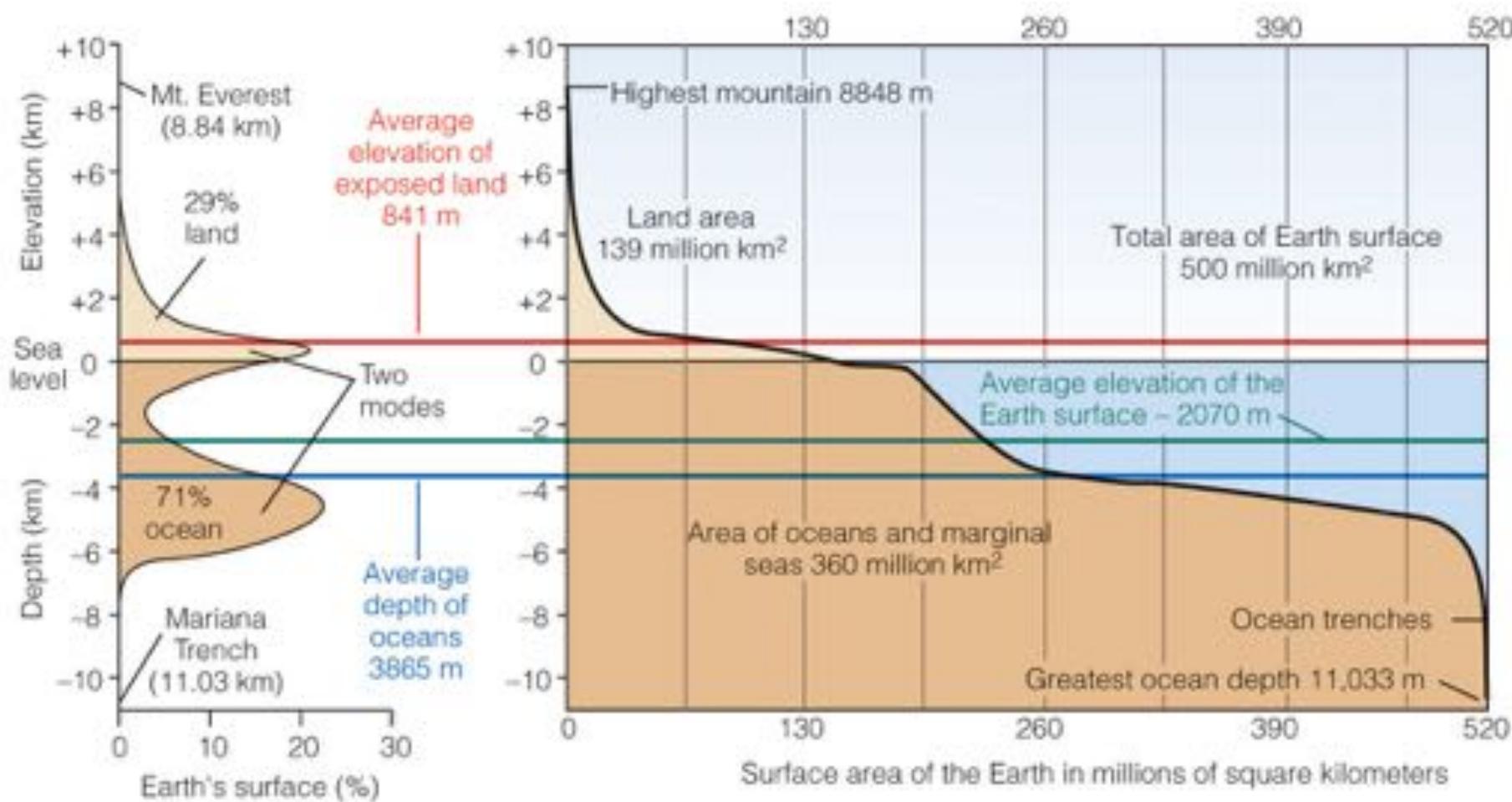
Colby at Bigelow, September 2019



Why do we have oceans?

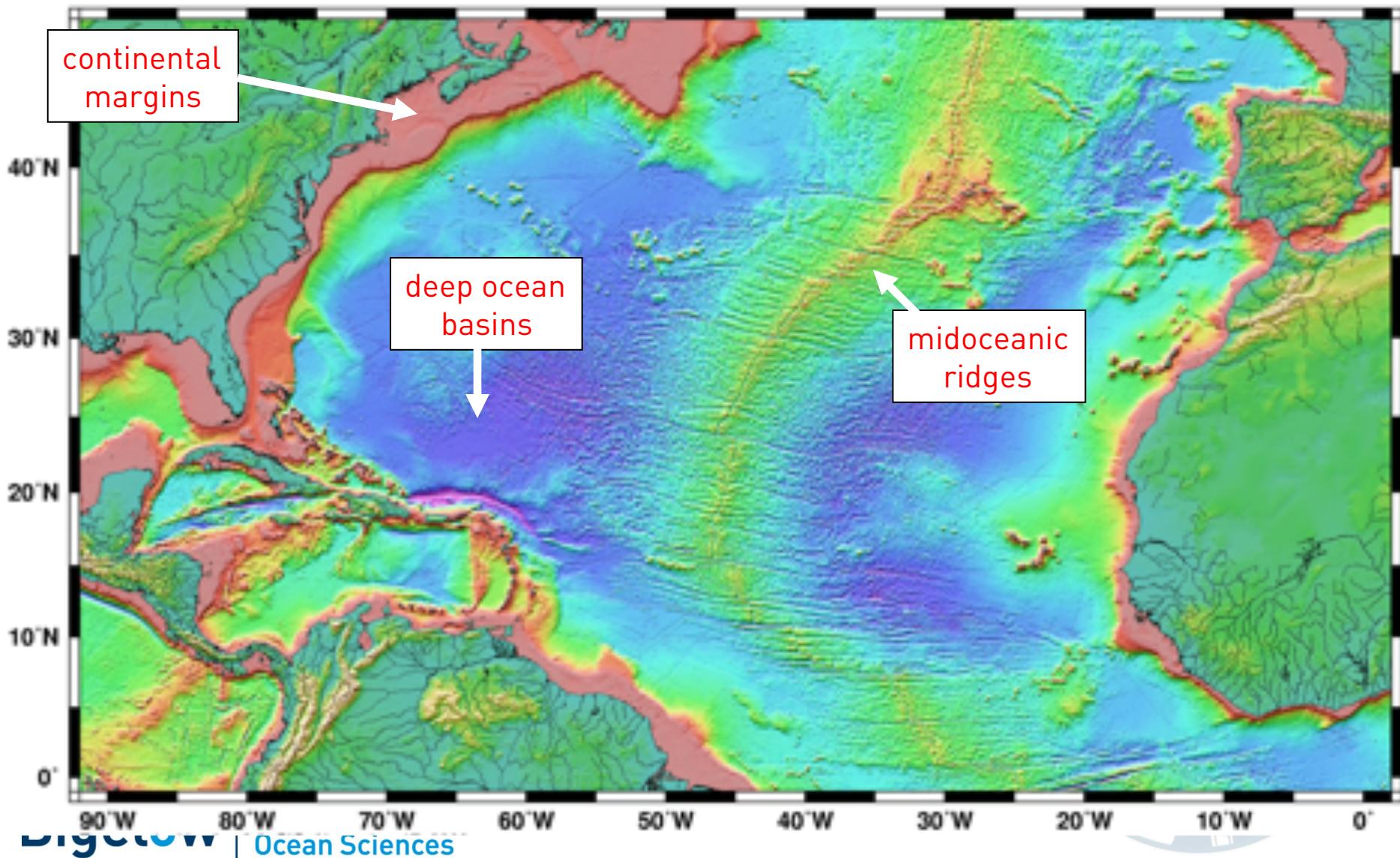


Why are there oceans and continents, and nothing in between?



The Physiography of the North Atlantic Ocean Floor

<http://topex.ucsd.edu>



Alfred Wegener

-Observed that the two sides of the Atlantic appear to fit together



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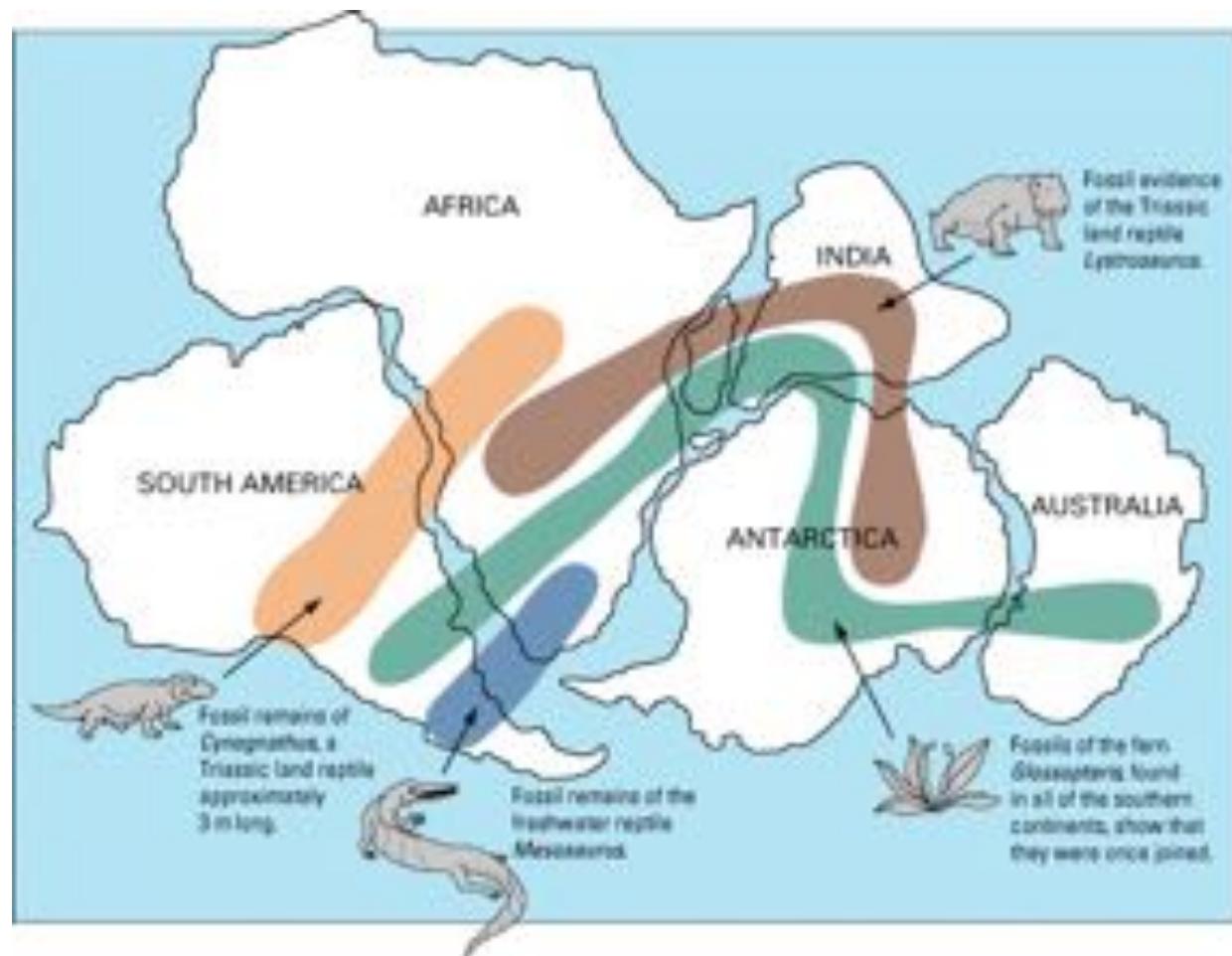
In particular: the edges of the continental shelves (not the coastlines)

Alfred Wegener

- Observed that the two sides of the Atlantic appear to fit together
- When lined up, geologic features line up:
 - mountain belts
 - fossils
 - belts of 200 million year-old rocks



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Gondwanaland affinities, USGS, <http://pubs.usgs.gov/gip/dynamic/continents.html>, Public Domain

Alfred Wegener

-Observed that the two sides of the Atlantic appear to fit together

- When lined up, geologic features line up:

mountain belts

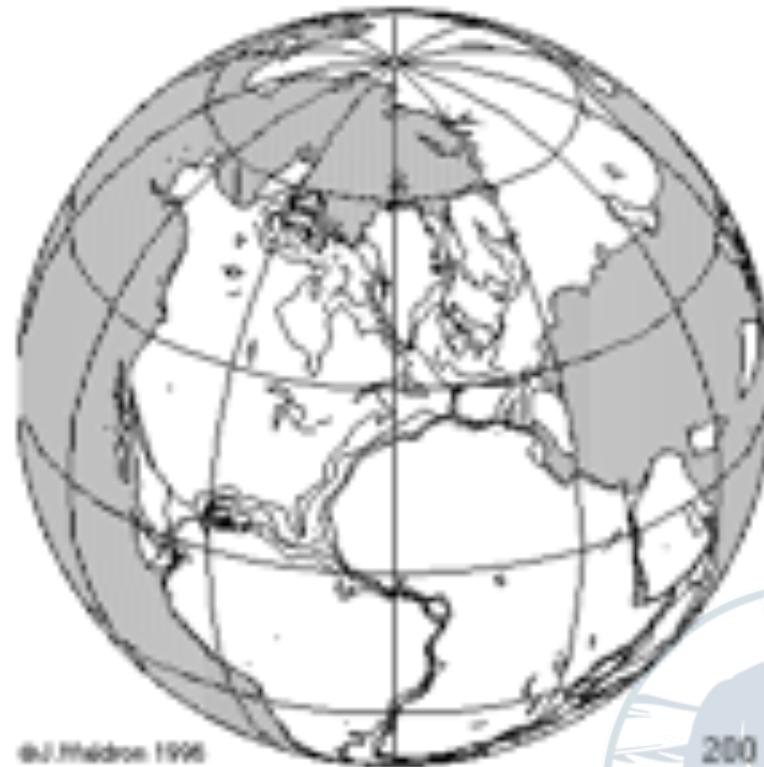
fossils

belts of 200 million year-old rocks

Proposed continental drift (1912)



© Story for sciences



(B.J. Holdren 1996)



How can continents “drift”?

Plate Tectonics

Unifying theory in geology

Explains:

- Locations and shapes of the oceans
- Locations and characteristics of earthquakes and volcanoes
- The age and composition of the sea floor
- The shape of the earth's surface

Theory has been accepted for ~ 60 years

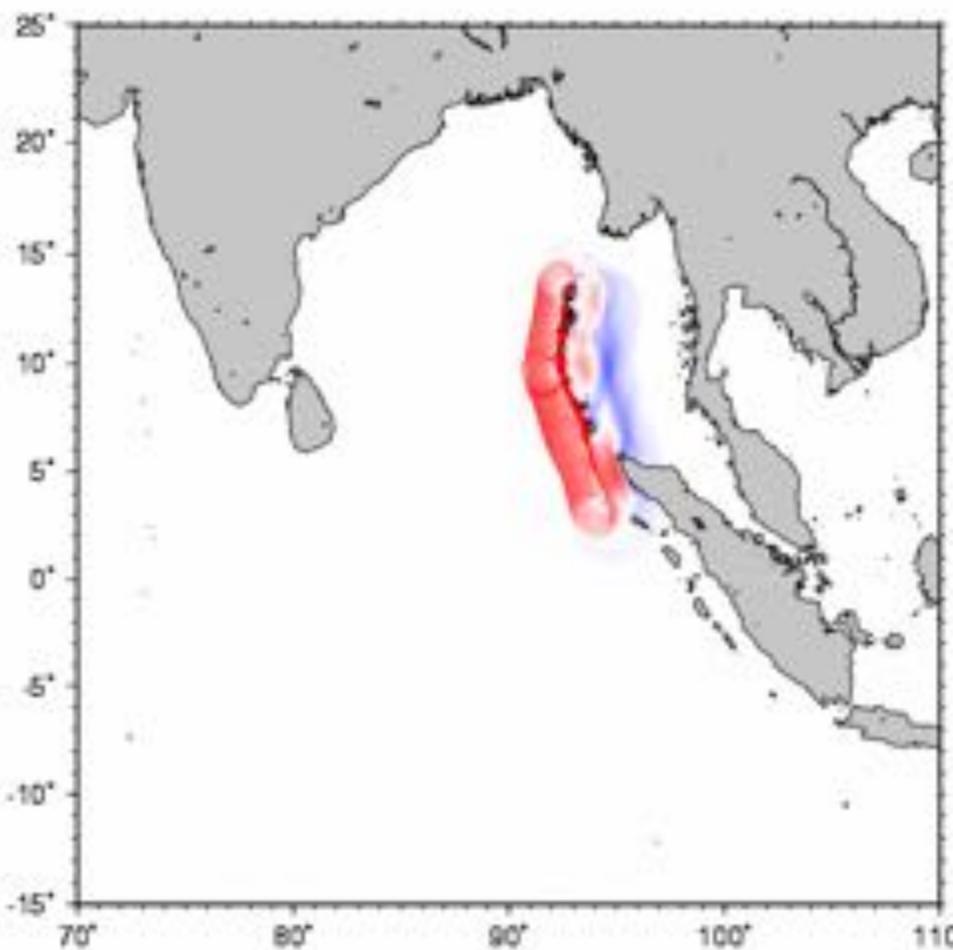
- compare to other unifying theories
- Evolution (1800s)
- Quantum physics (early 1900s)

What **evidence** gets us from Continental Drift to Plate Tectonics?



Evidence #1 Earthquakes

2004 Sumatra Earthquake 010 min

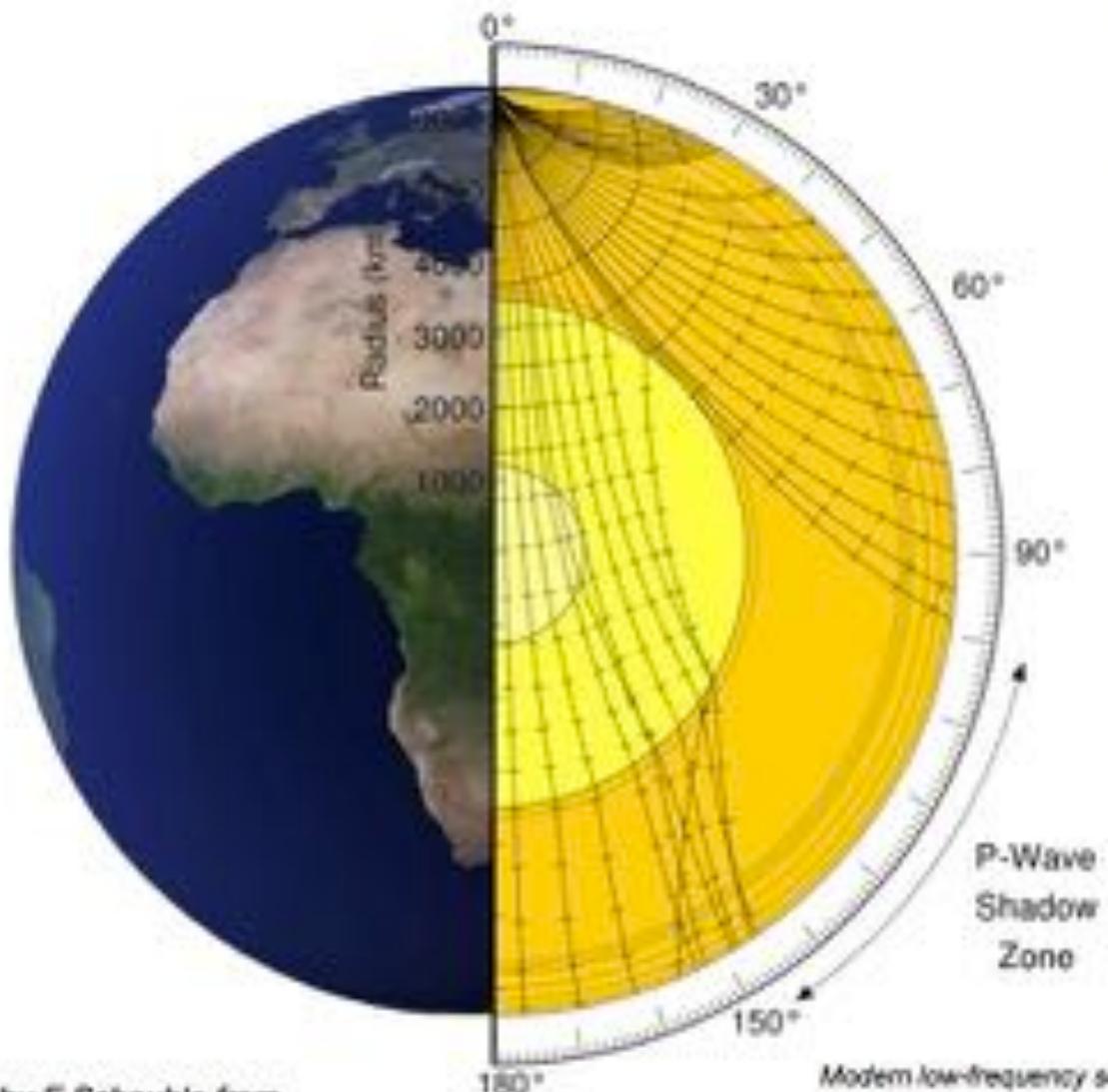


Sea level:
RISE
FALL

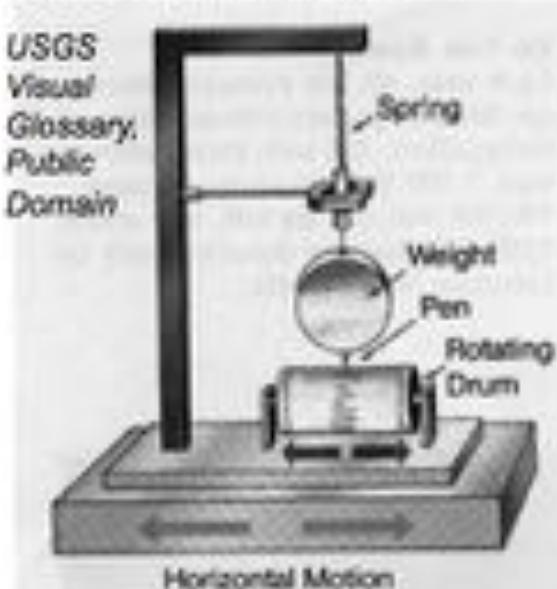


Courtesy: K. Satake, unpublished

Earthquake waves are detected with a seismometer



Modified by E.Schauble from
NASA, Wikimedia CC Images



Modern low-frequency seismometer;
viewed from above. wikimedia commons.
Hannes Grobe, CC A-SA 2.5

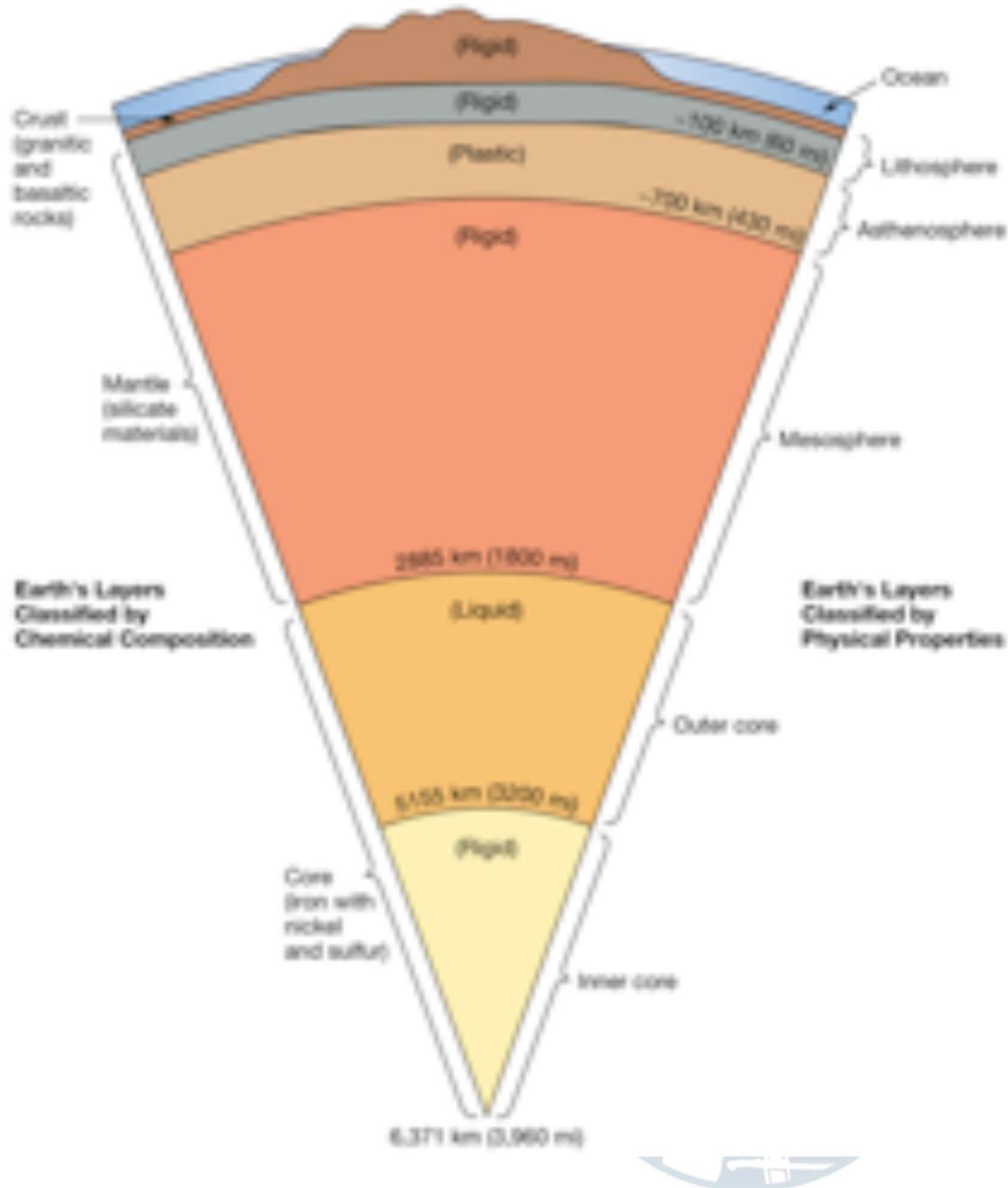


Can begin to build a picture of the interior of the earth.

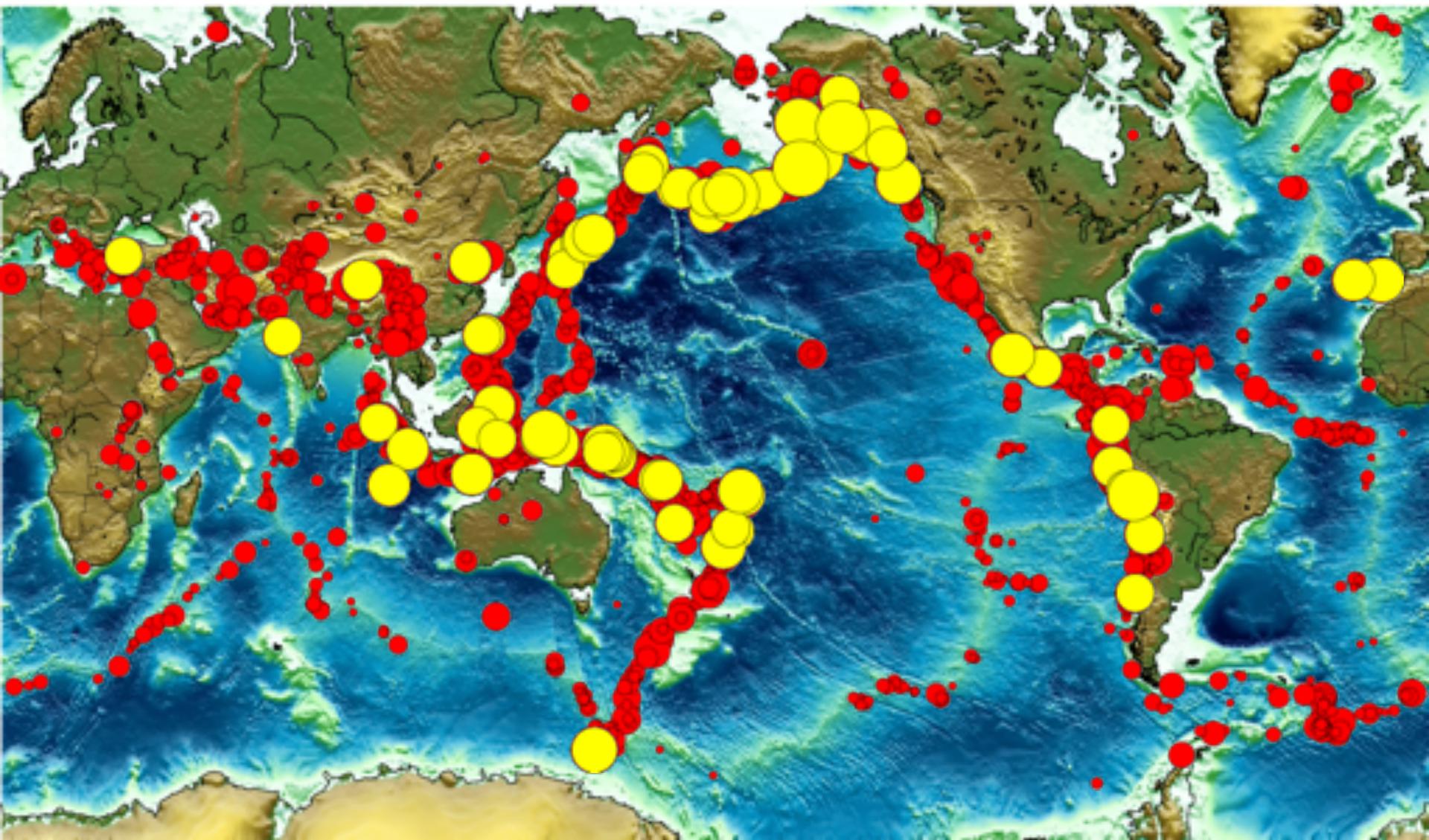
Earth consists of a series of concentric layers or spheres which differ in **chemistry** and **physical properties**.

Note: rigid Lithosphere is only about 100 km thick (often much thinner)

~ skin on an apple

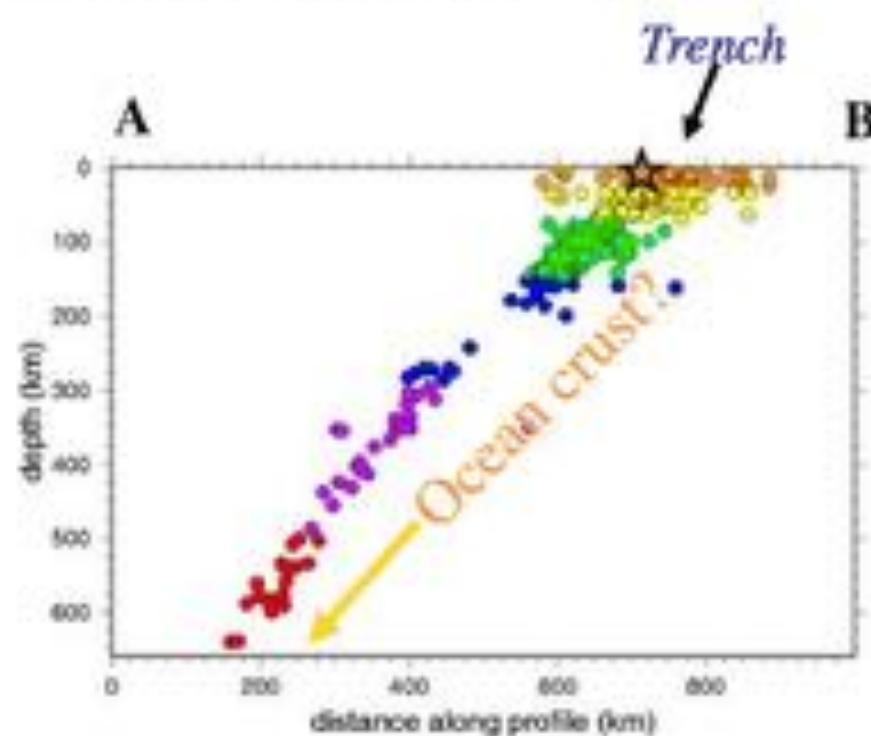
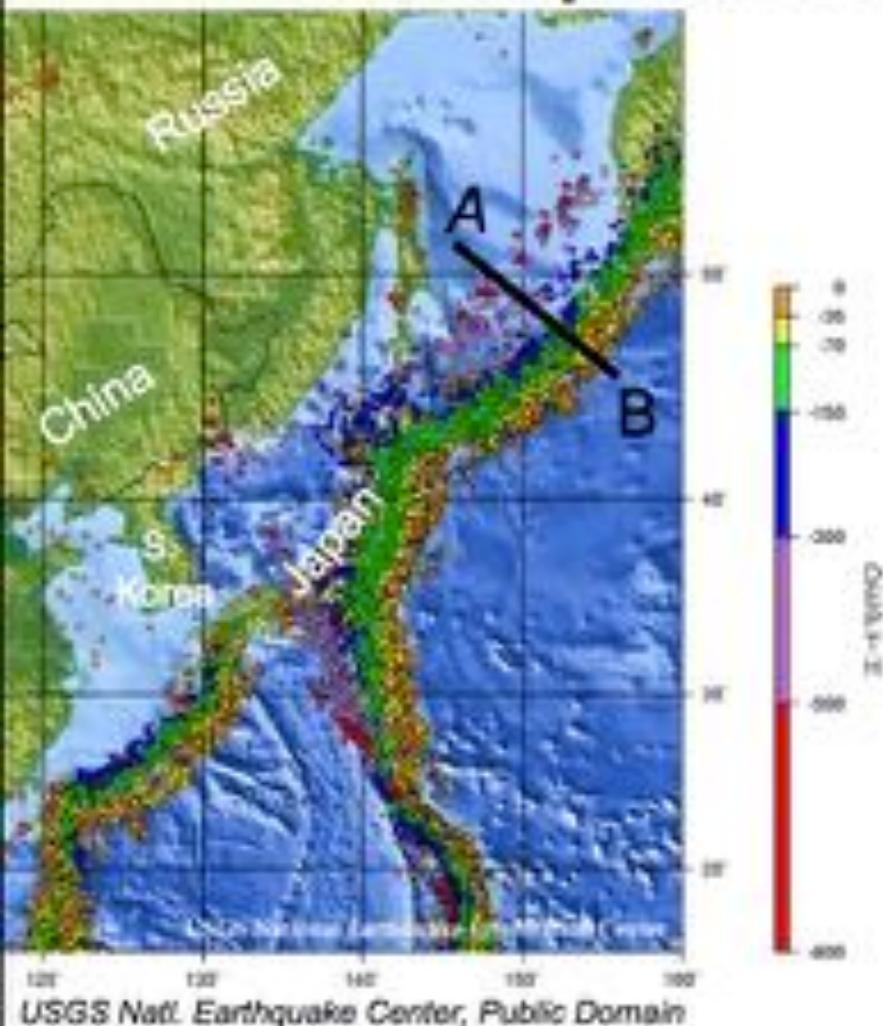


World Seismicity



Most “Great” earthquakes are subduction mega-thrust events
Many large earthquakes occur along subduction zones

Earthquakes near Trenches



USGS Natl. Earthquake Center, Public Domain

Star shows location of magnitude 8.3 Kurile Eq. 11/15/2006

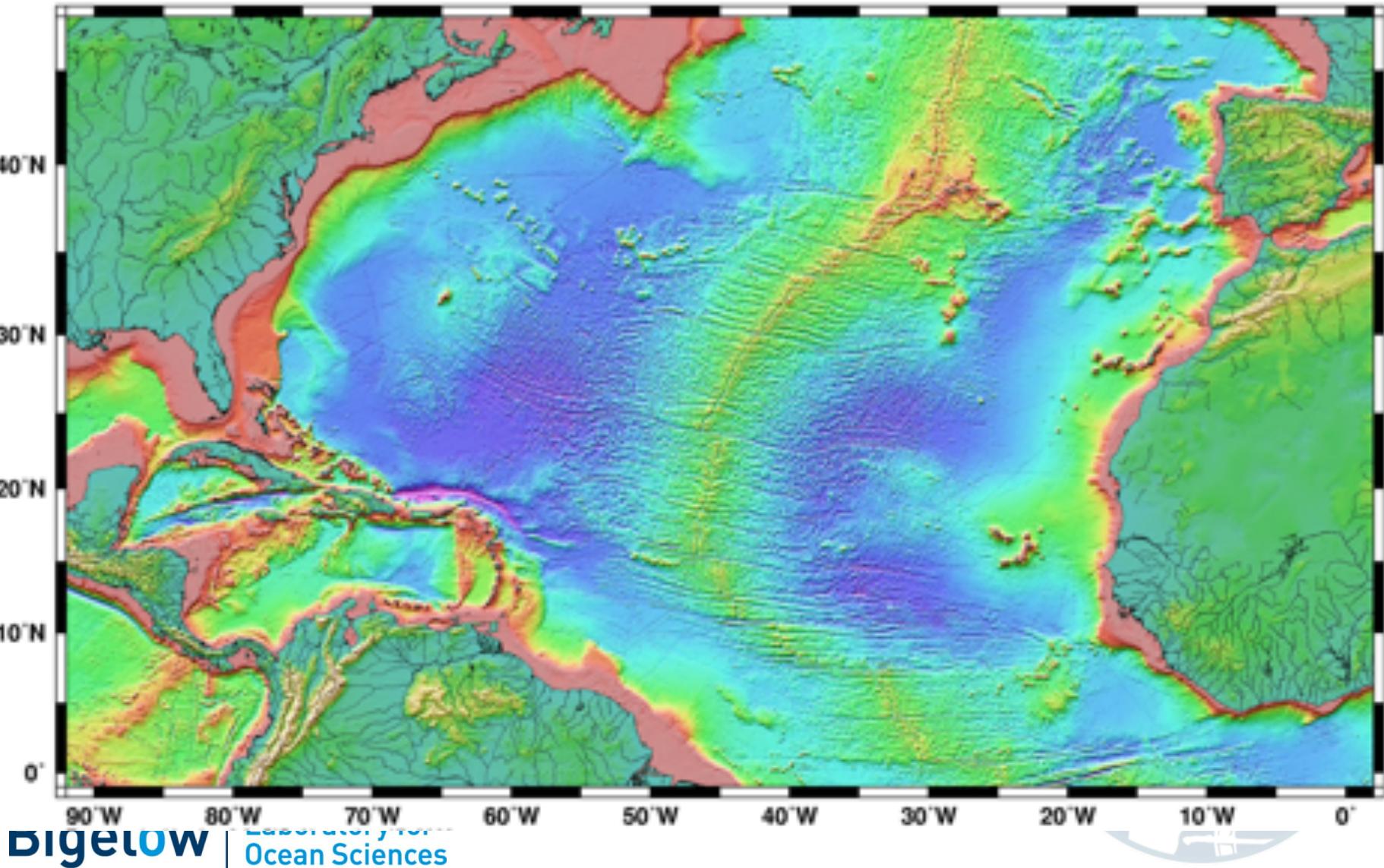
Observation 4: At trenches (e.g., NE. of Japan) earthquakes get deeper with distance. Earthquakes happen in rocks that are cold & break rather than flow. Deep earthquakes suggest a slab of cold material that was recently at the Earth's surface.

Evidence #2

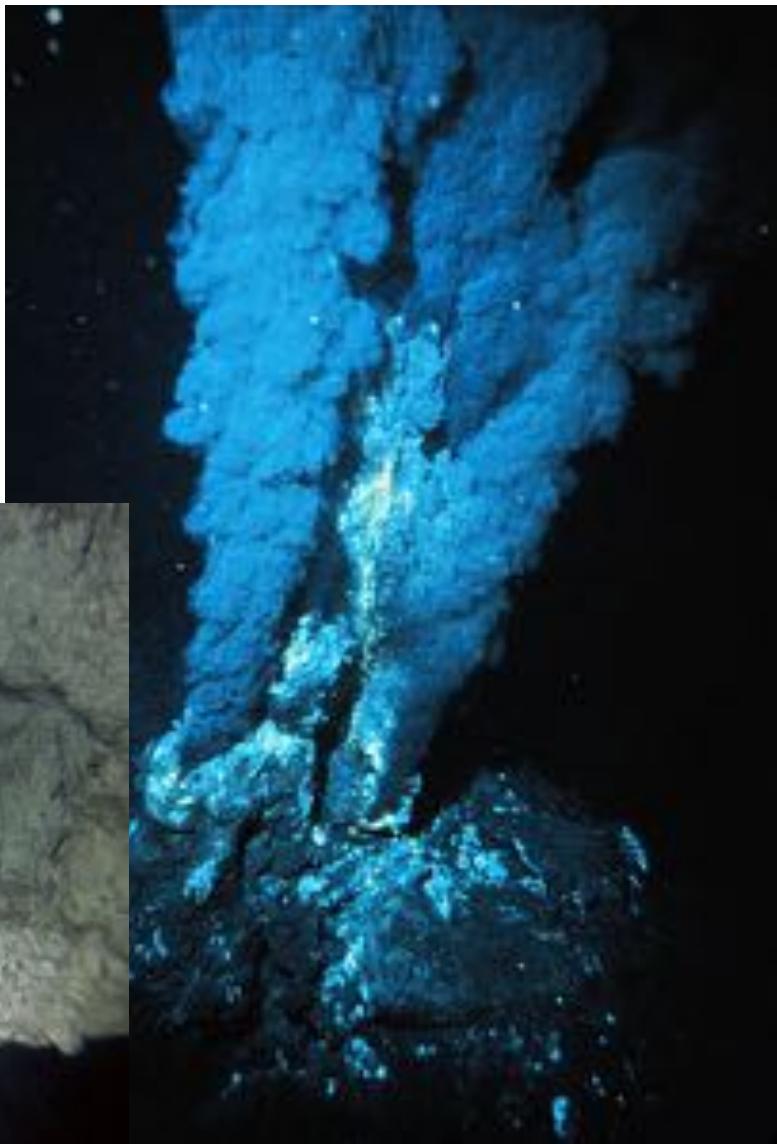
Magnetic record

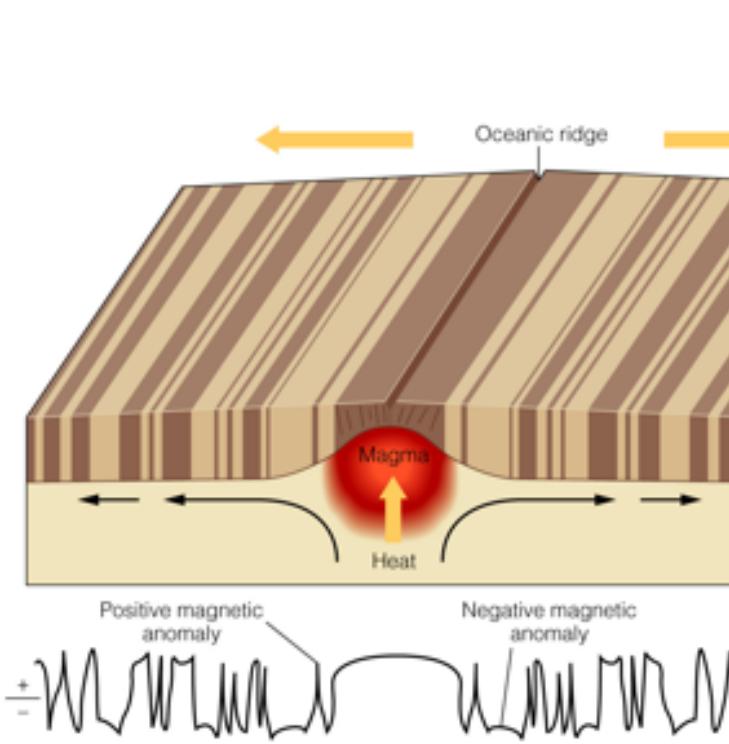


What's happening at the Mid-Atlantic Ridge?

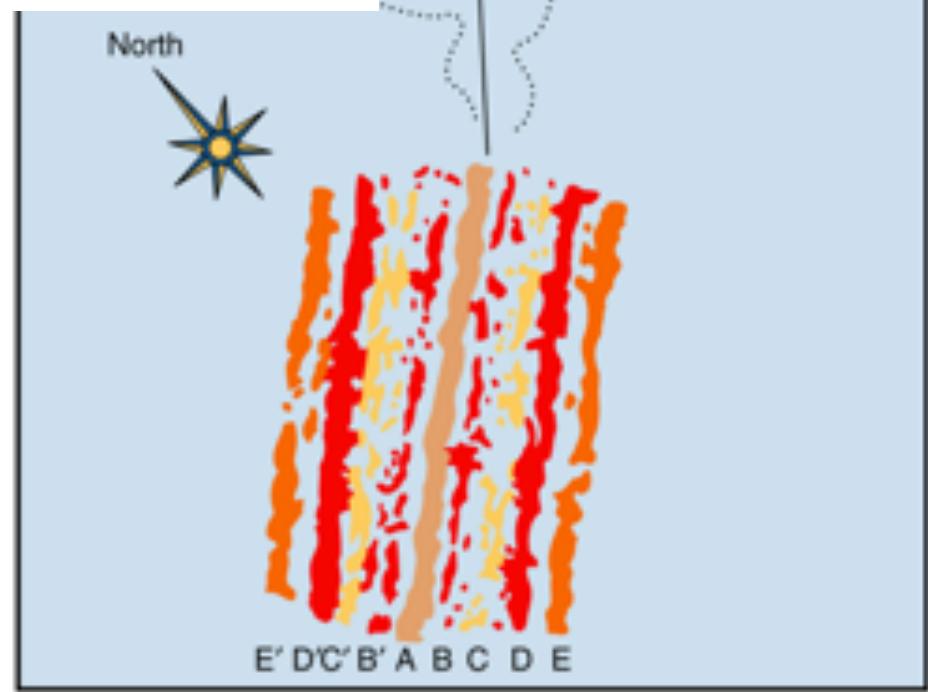
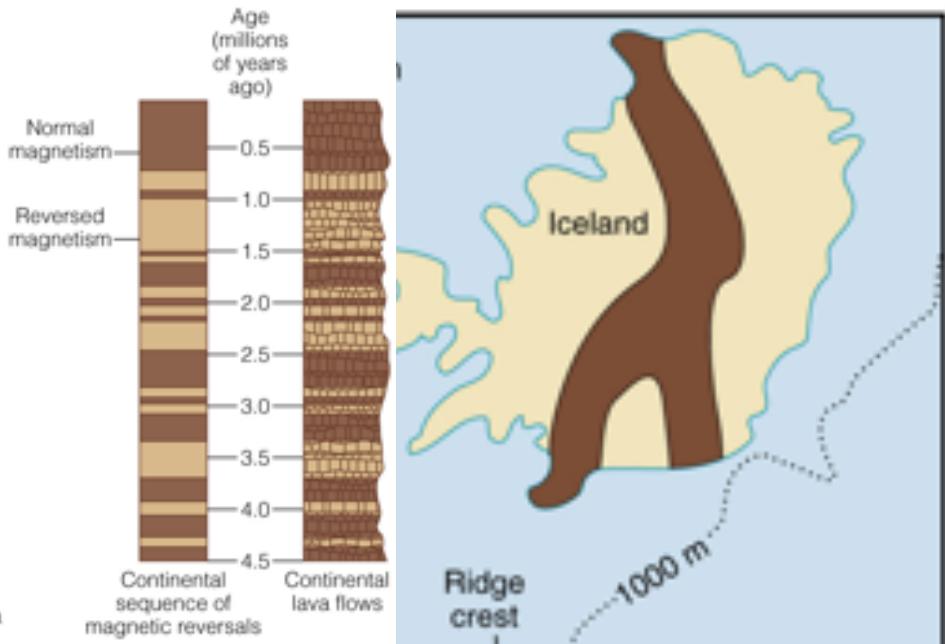
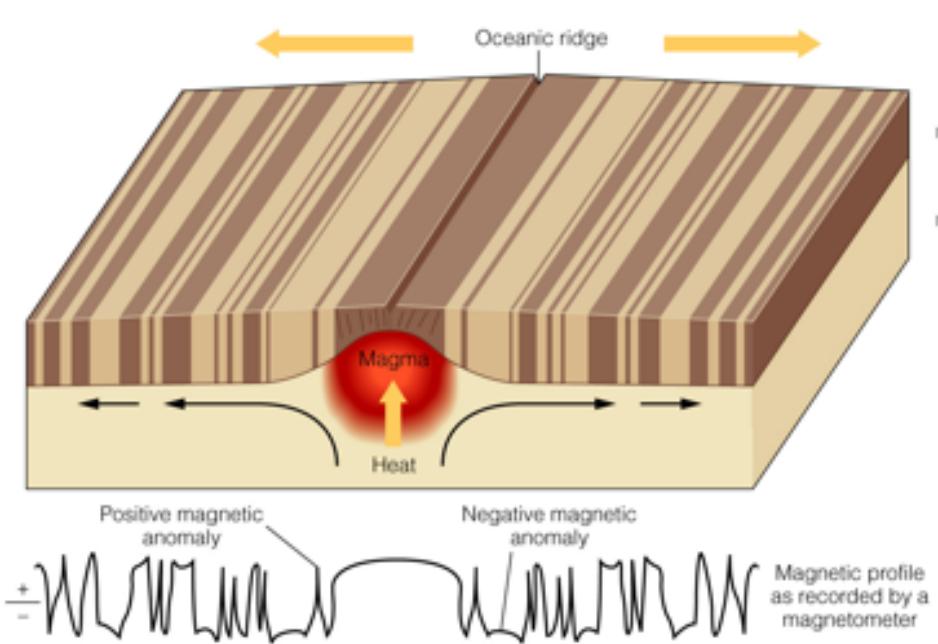


Mid-Atlantic Ridge



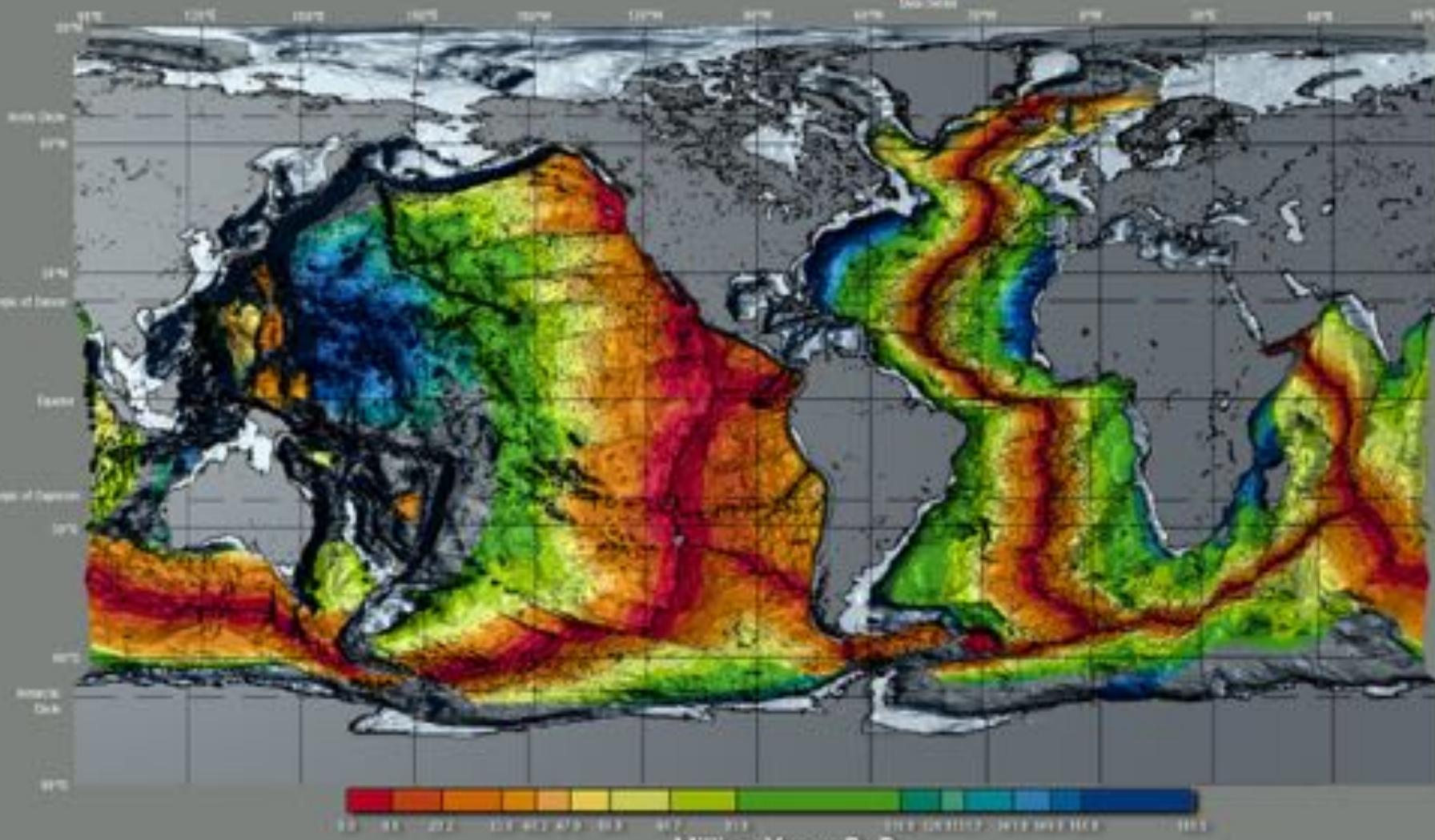


Magnetite Rob Lavinsky, iRocks.com



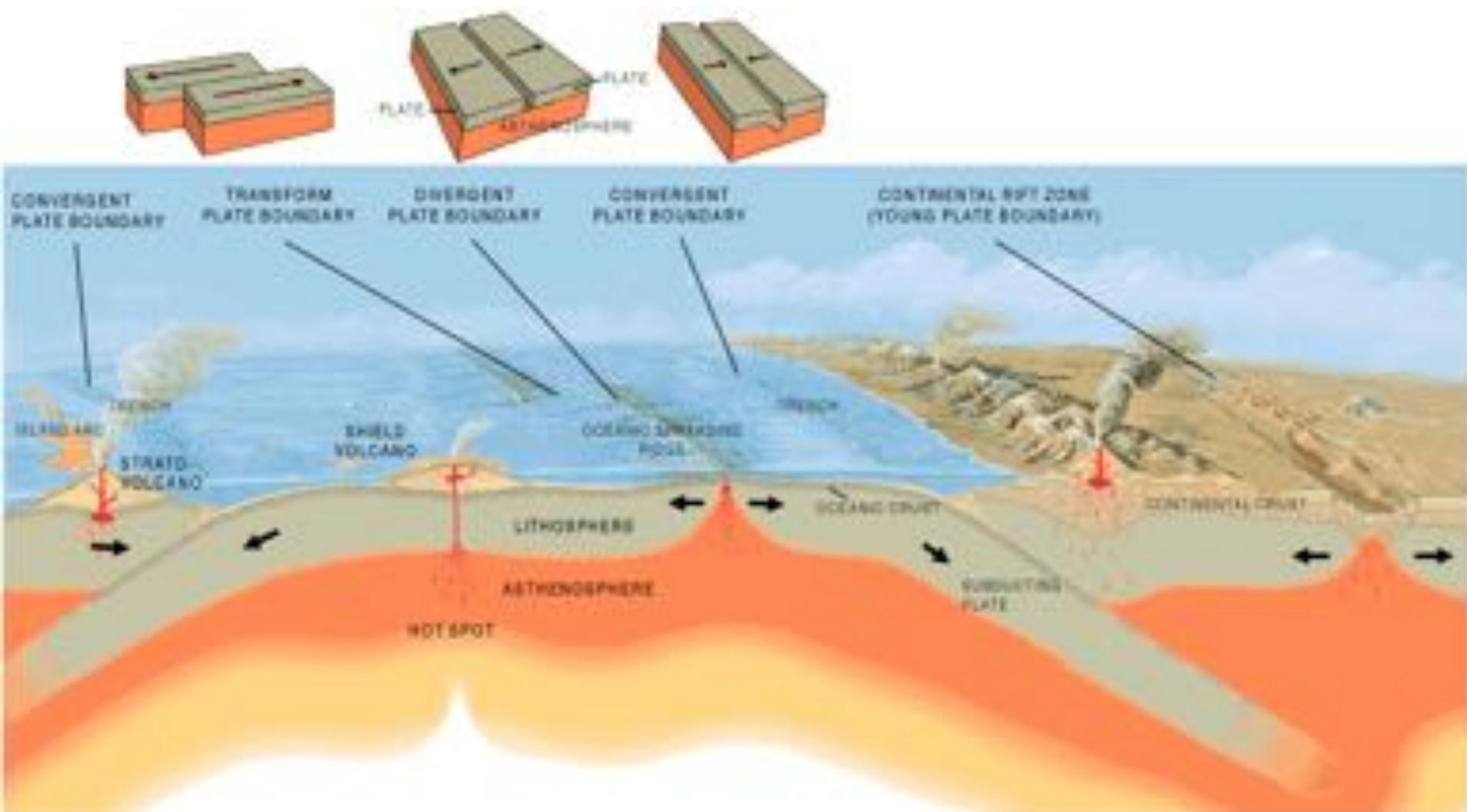
Magnetite Rob Lavinsky, iRocks.com

Crustal Age

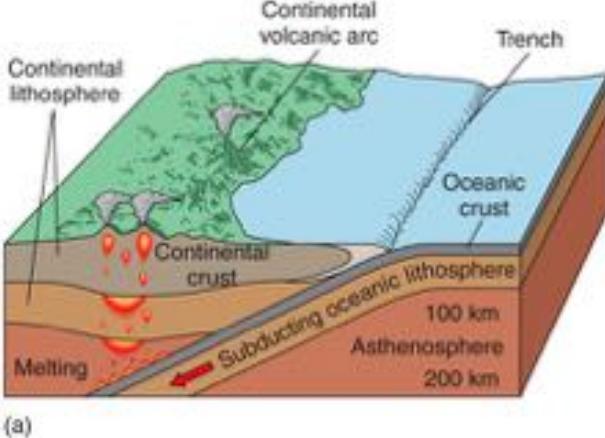


Source for the map from "Digital Age Map of the Ocean Floor" by Heezen, Kastner, Ruppel, Carlson, and Schreier, Digital Institute of Oceanography, Bull. Amer. Geophys. Union No. 62-30.

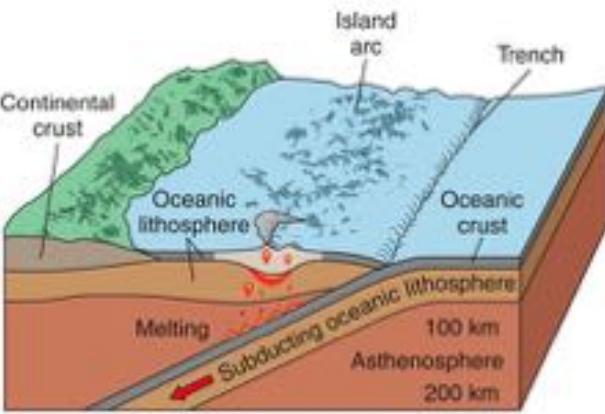
Three types of boundaries



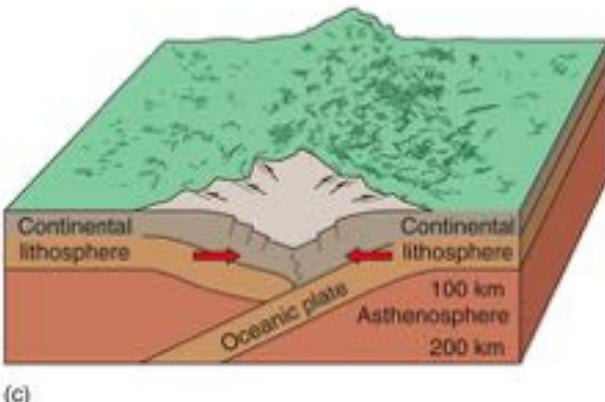
CONVERGENT



(a)



(b)



(c)

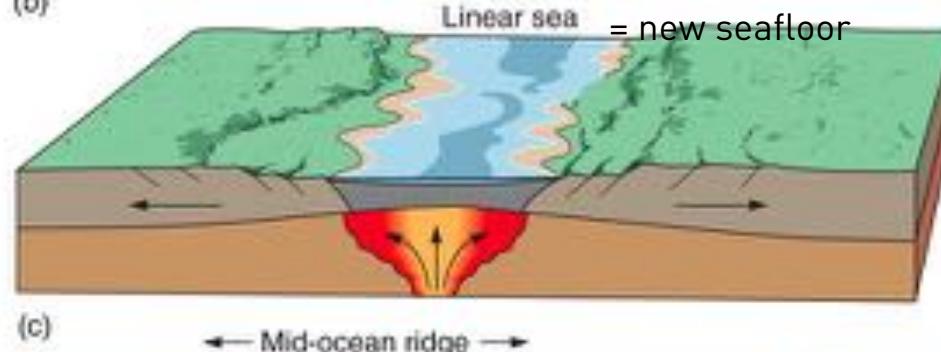
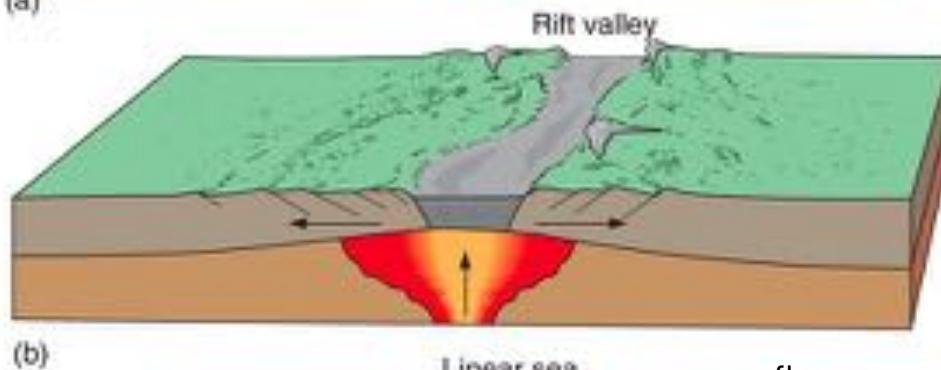
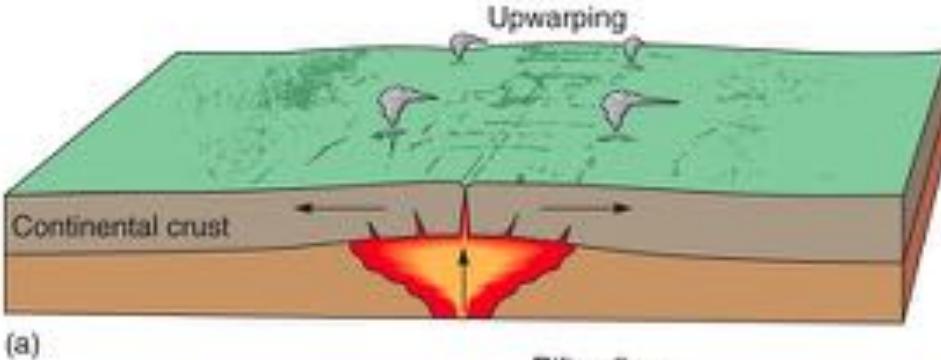


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Continental rifting

today:

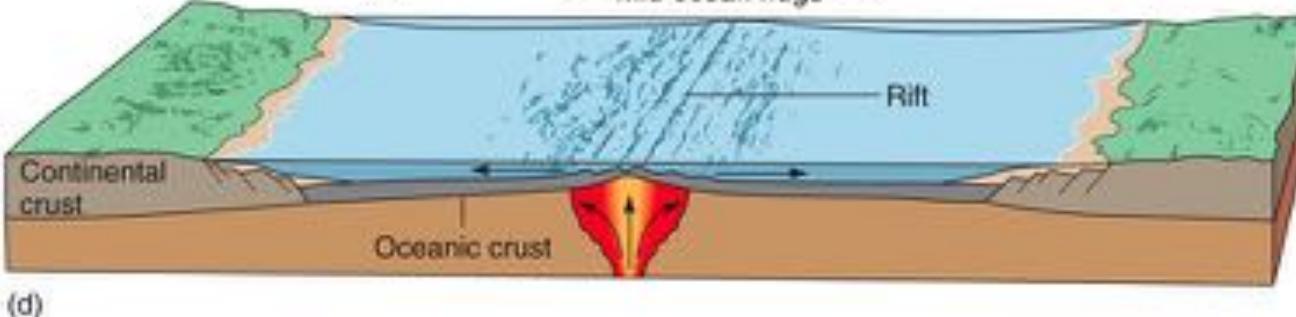
East African
Rift Valley



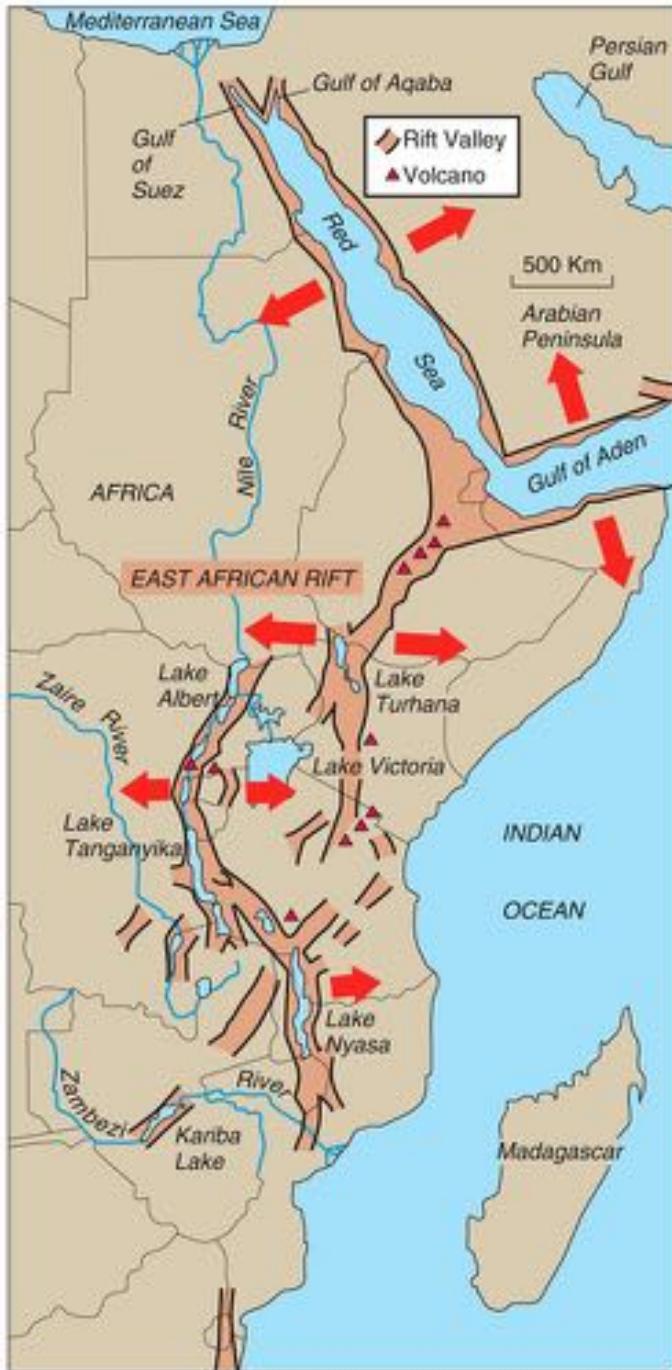
Red Sea

Atlantic
Ocean

Bigelow

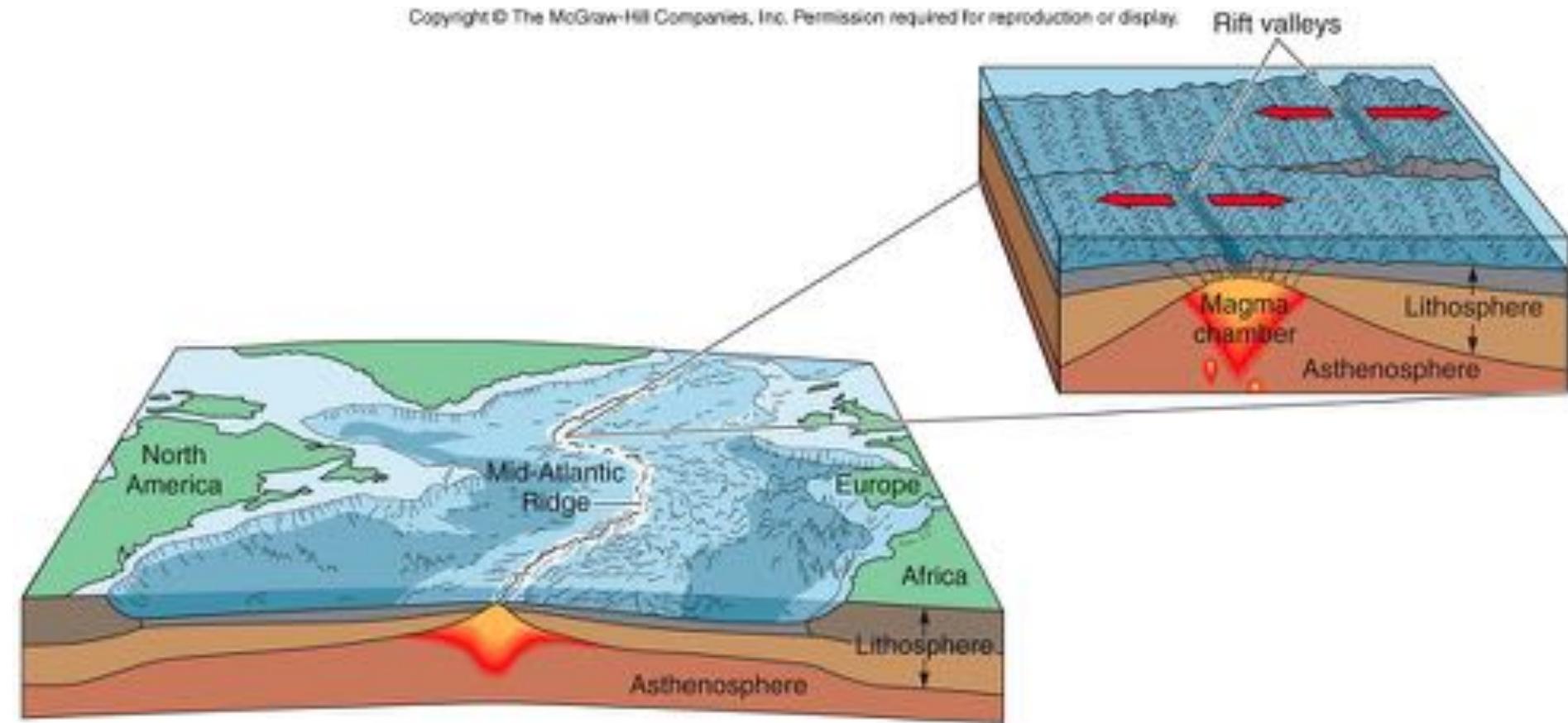


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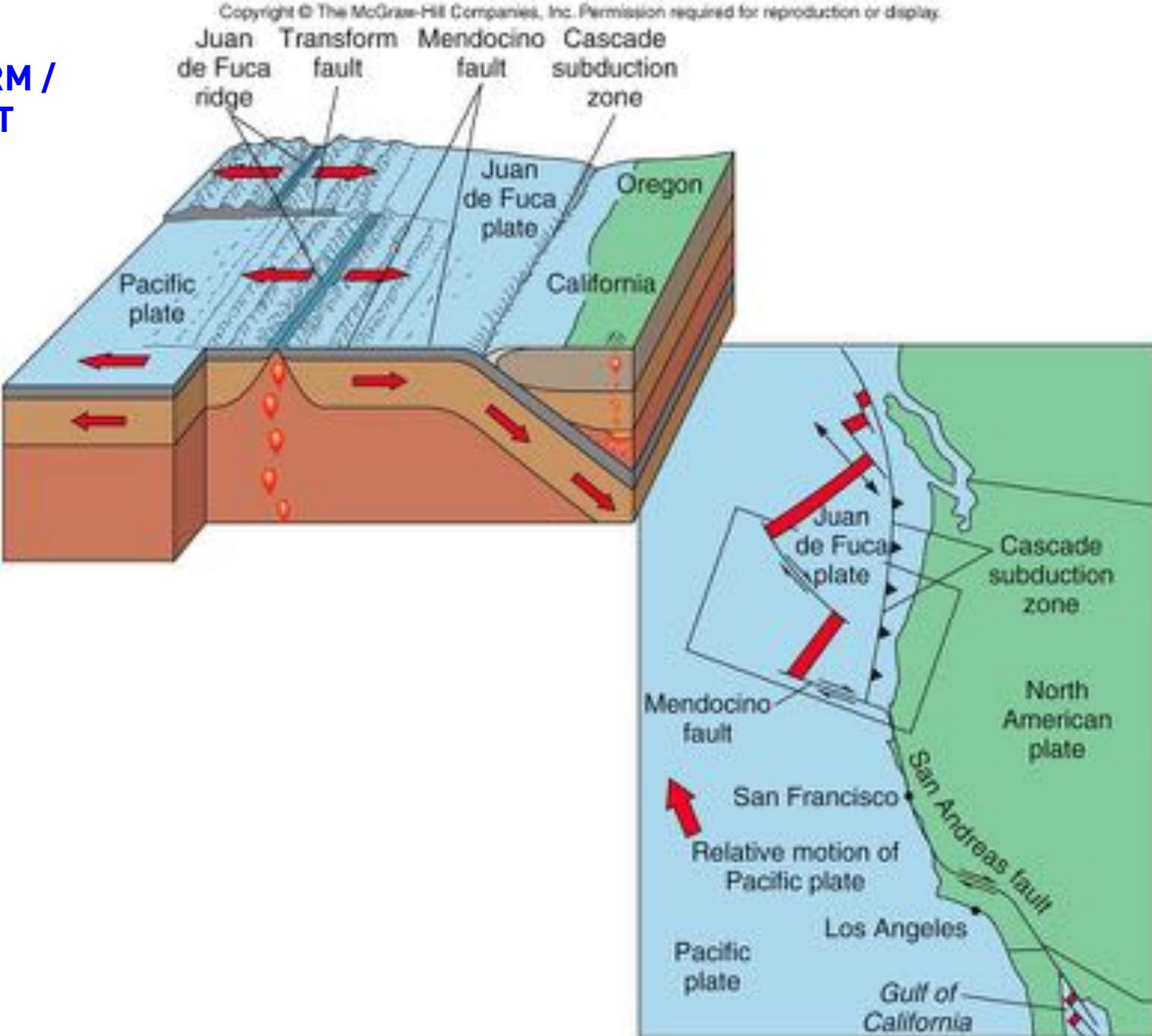


DIVERGENT

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TRANSFORM / DIVERGENT



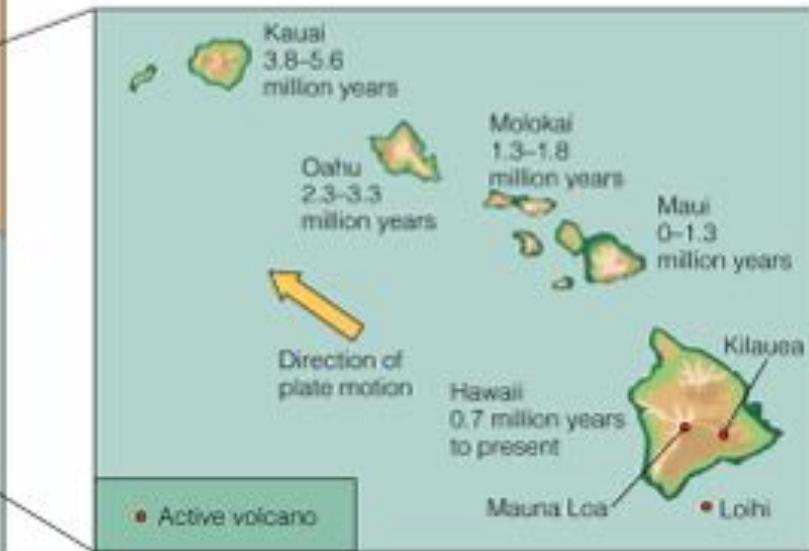
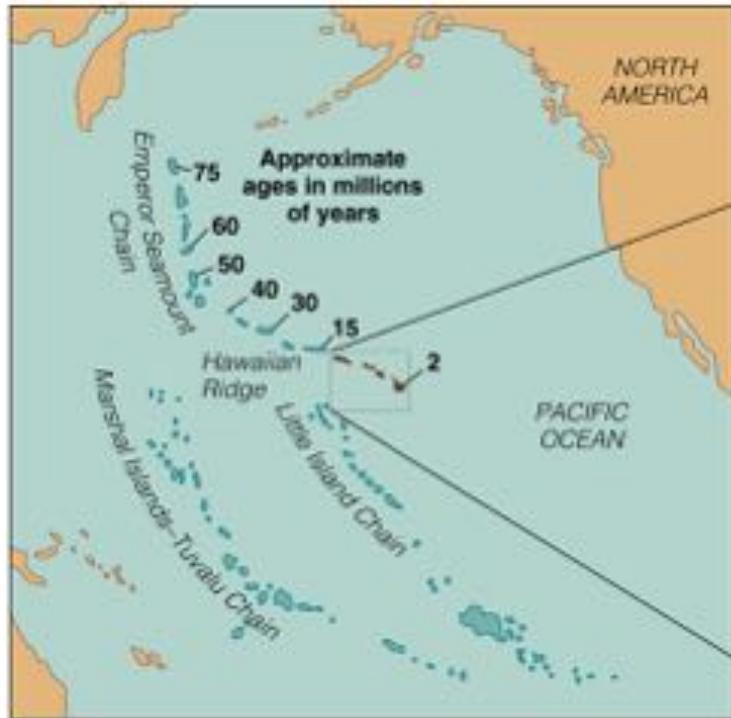
Bigelow

Table 3.4 Types and Characteristics of Plate Boundaries

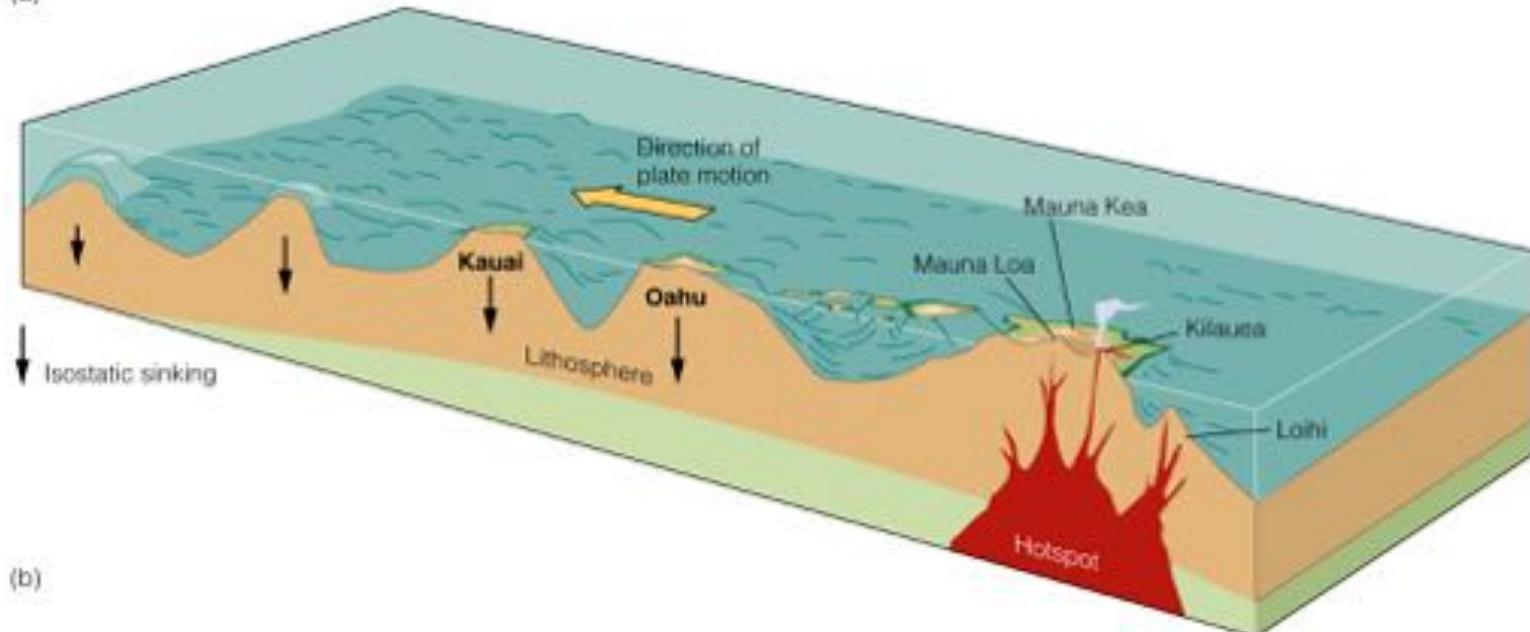
Plate Boundary	Types of Lithosphere	Geologic Process	Geologic Feature	Earthquakes	Volcanism	Examples
Divergent (move apart)	Ocean-Ocean	New sea floor created, ocean basin opens	Mid-ocean ridge	Yes, shallow	Yes	Mid-Atlantic Ridge, East Pacific Rise
	Continent-Continent	Continent breaks apart, new ocean basin forms	Continental rift, shallow sea	Yes, shallow	Yes	East African Rift, Red Sea, Gulf of Aden, Gulf of California
Convergent (move together)	Ocean-Ocean	Old sea floor destroyed by subduction	Ocean trench	Yes, shallow to deep	Yes	Aleutian, Mariana, and Tonga Trenches (Pacific Ocean)
	Ocean-Continent	Old sea floor destroyed by subduction	Ocean trench	Yes, shallow to deep	Yes	Peru-Chile and Middle-America Trenches (Eastern Pacific Ocean)
	Continent-Continent	Mountain building	Mountain range	Yes, shallow to intermediate	No	Himalaya Mountains, Alps
Transform (slide past each other)	Ocean	Sea floor conserved (neither created nor destroyed)	Transform fault (offsets segments of ridge crest)	Yes, shallow	No	Mendocino and Clipperton (Eastern Pacific Ocean)
	Continent	Sea floor conserved (neither created nor destroyed)	Transform fault (offsets segments of ridge crest)	Yes, shallow	No	San Andreas Fault, Alpine Fault (New Zealand), North and East Anatolian Faults (Turkey)



Hotspots



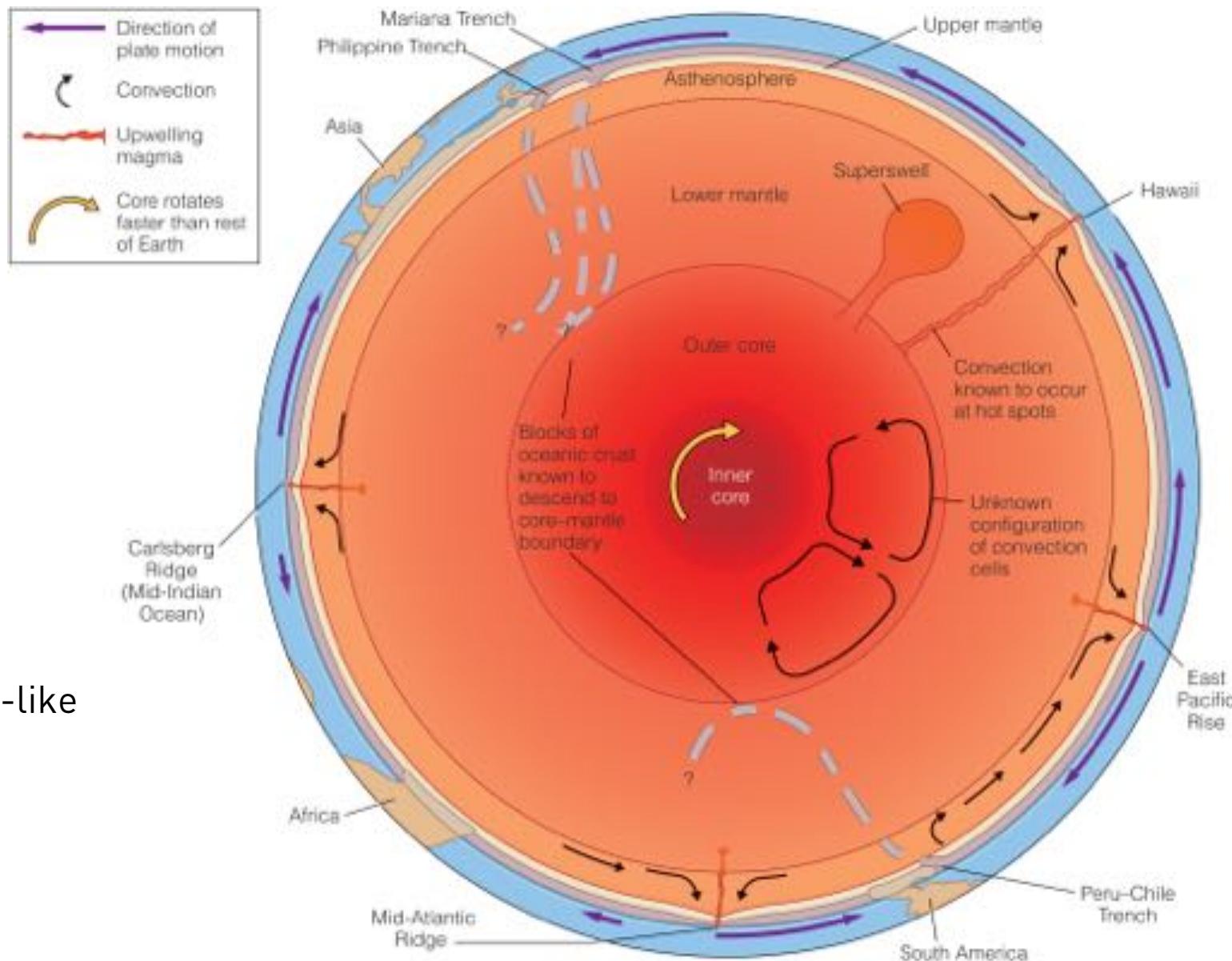
(a)



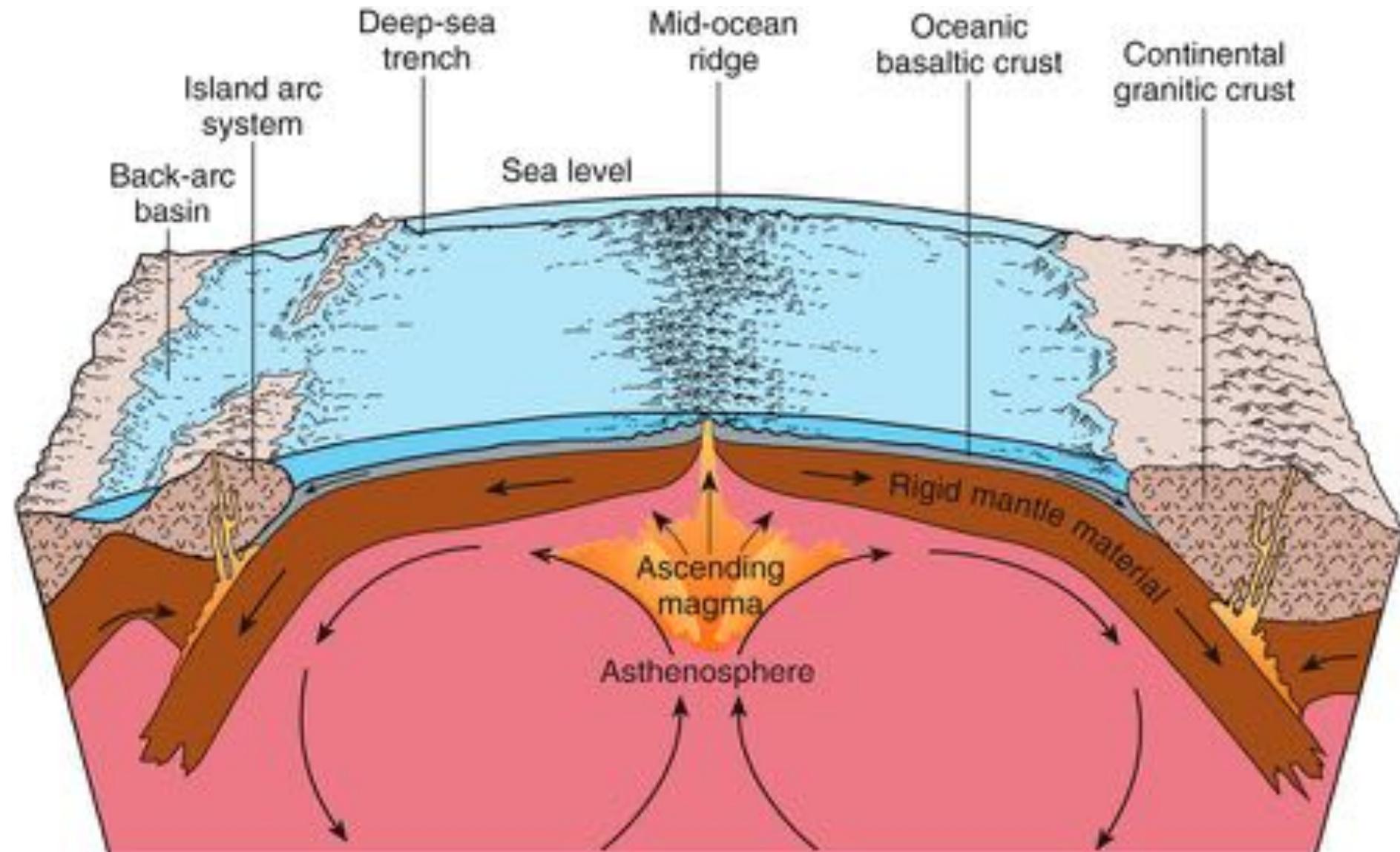
(b)

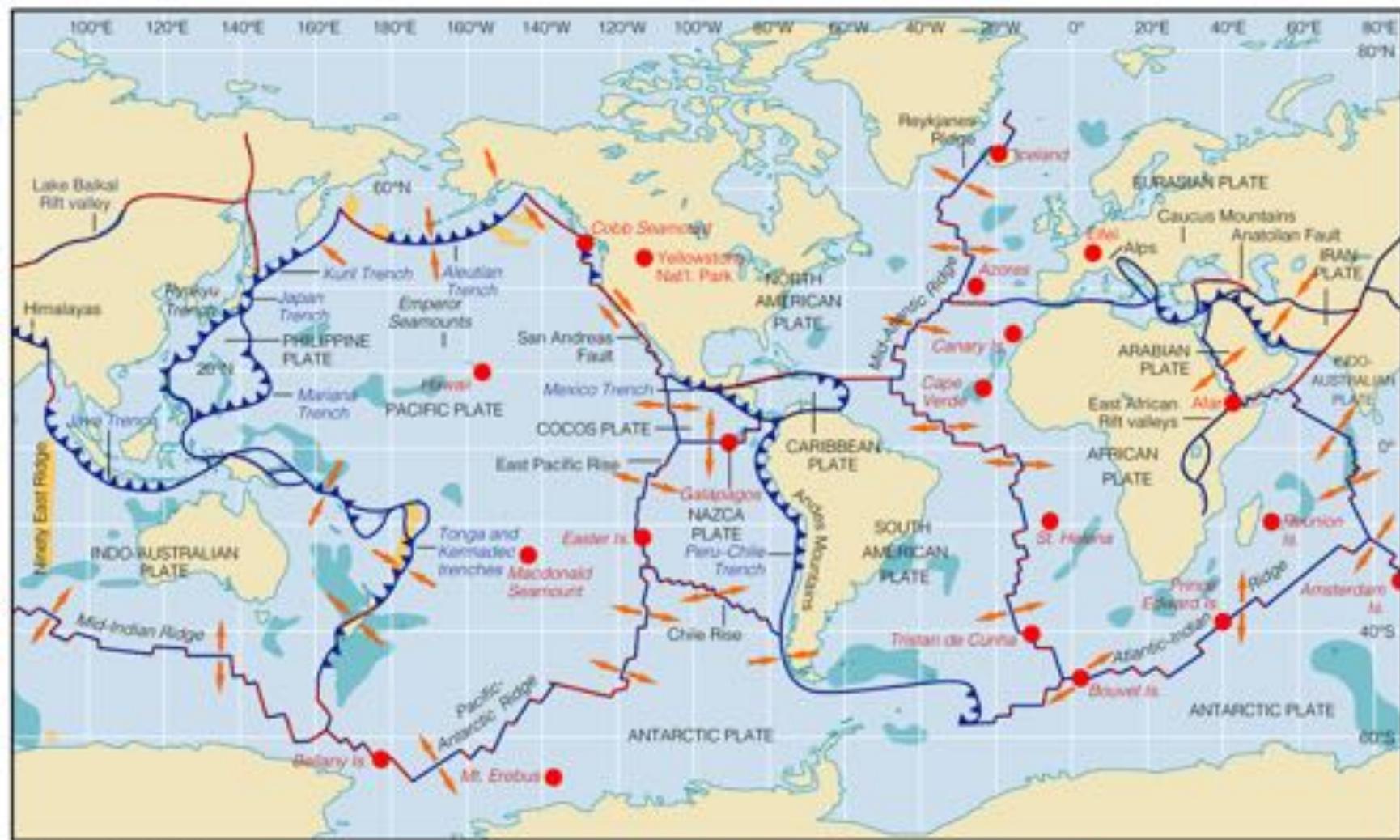


Putting the picture together



Continental Drift Theory





Miller's cylindrical projection



Oceanic plateau



Volcanic ridge

Volcanic center (hot spot)

Plate boundary
(transform fault)

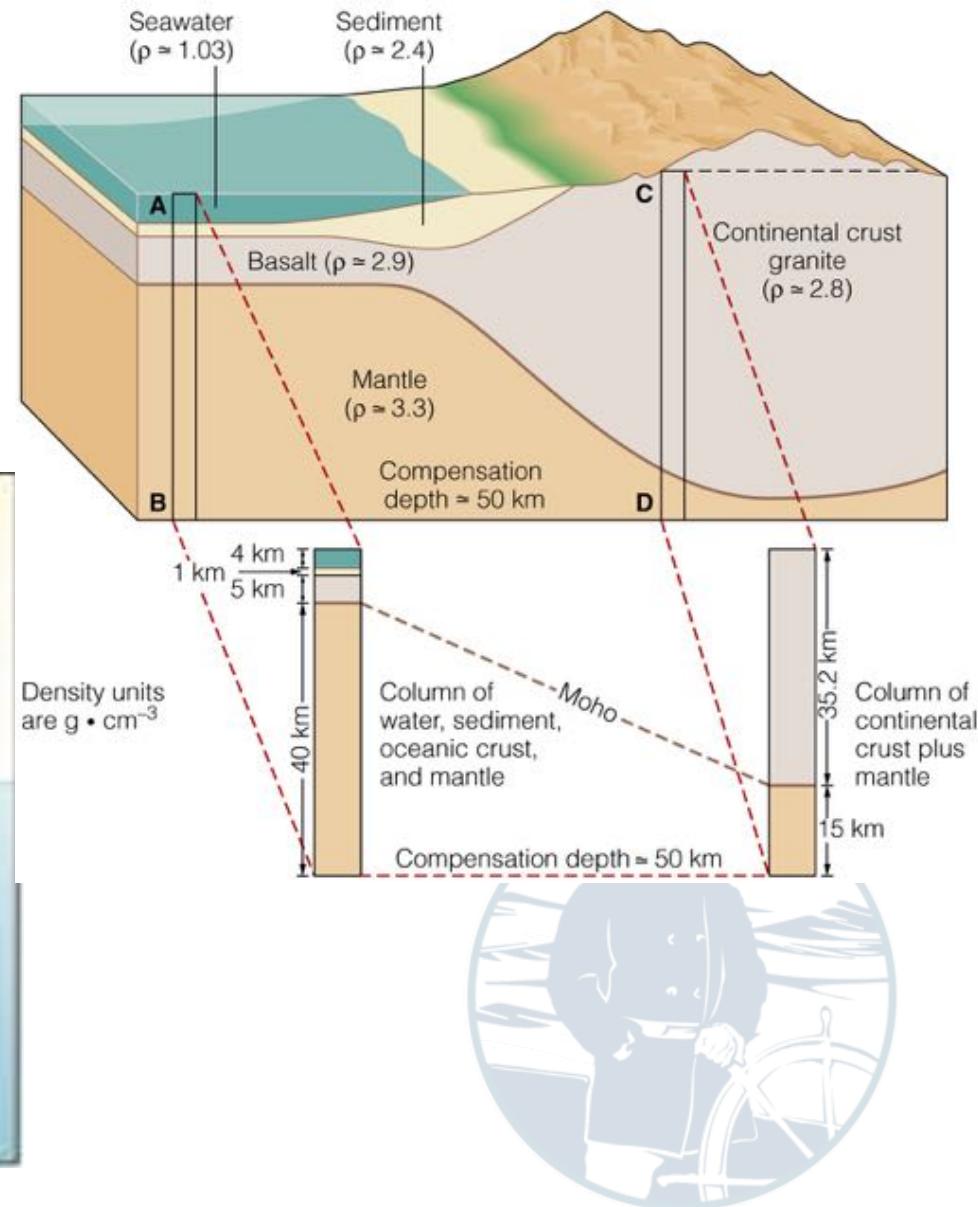
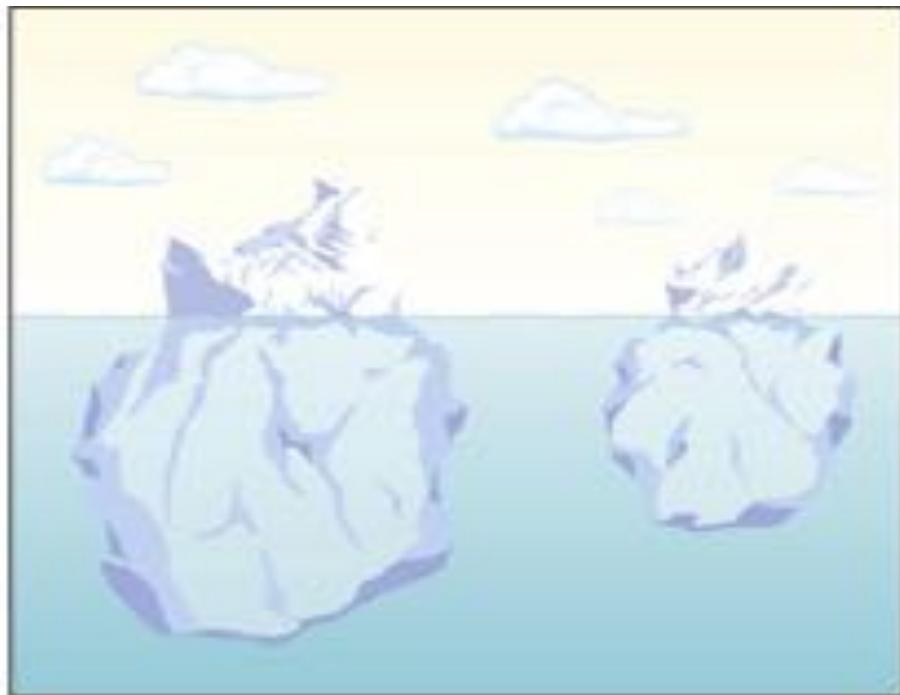
Subduction zone

Oceanic ridge
(spreading center)

Direction of movement
of plates relative to
each other

Why are there oceans and continents, and nothing in between?

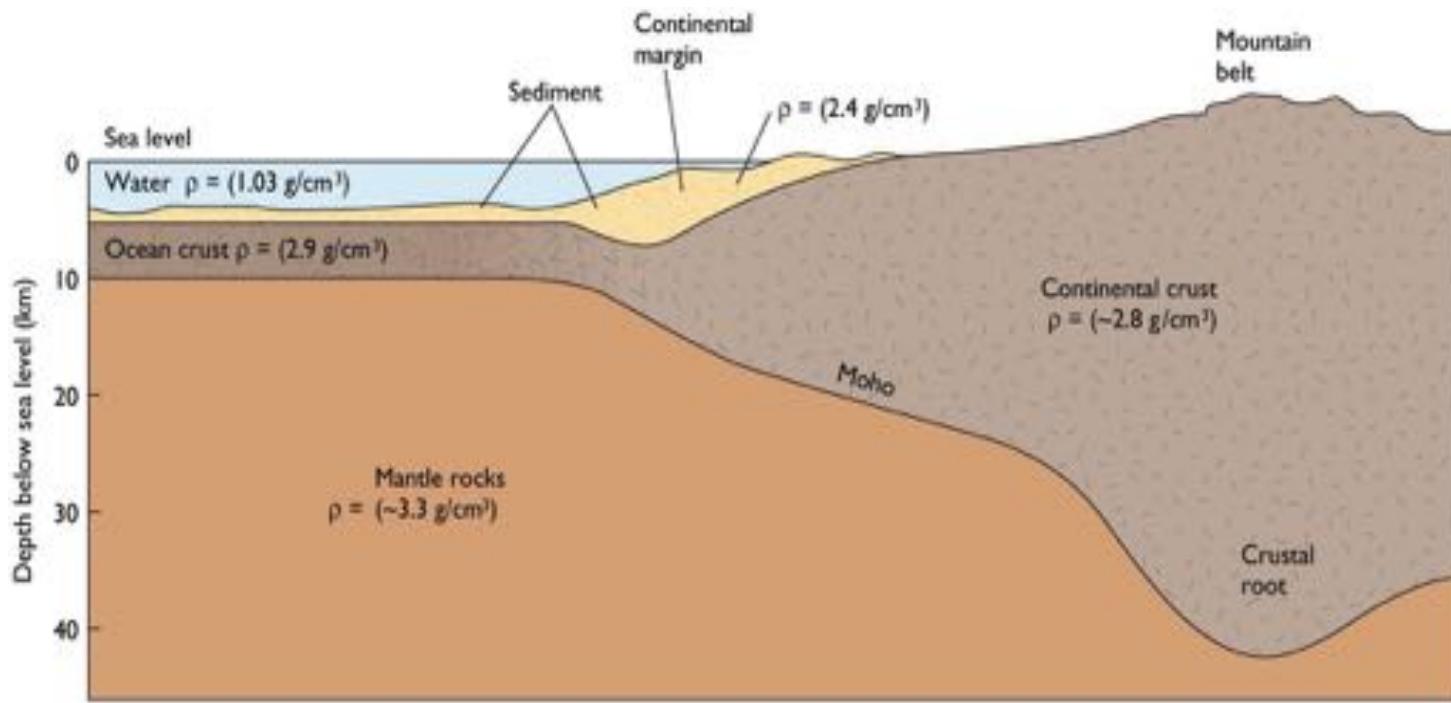
Isostasy: The balance of an object “floating” upon a fluid medium. Height of the mass above and below the surface of the medium is controlled by the thickness of the mass and its density (similar to ice floating in water).



Why are there oceans and continents, and nothing in between?

Continents are thick (30 to 40 km), have low density and rise high above the supporting mantle rocks.

Sea floor is thin (4 to 10 km), has greater density and does not rise as high above the mantle.



Oceanic Crust Versus Continental Crust

Oceanic crust

- Thin, more dense
 - Mostly basalt
 - mean density $\sim 3.0 \text{ g cm}^{-3}$
 - Thickness 4-10 km
- Ocean basins
- Subducted during plate convergence
- Young <200M yrs

Continental crust

- Thick, less dense
 - Mostly granite
 - av. density $2.7\text{-}2.8 \text{ g cm}^{-3}$
 - Thickness 25-40 km
- Buoyant continents
- Preferentially preserved during plate convergence
- Old >3500M yrs

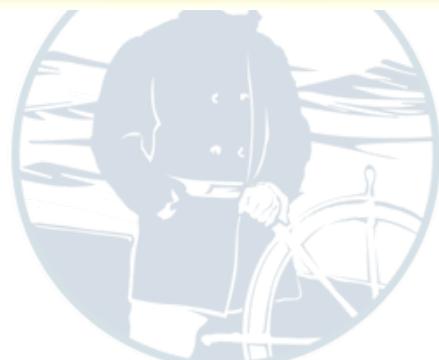


Physical layers of the earth

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Table 2.1 Layers of the Earth

Layer	Depth (km)	Thickness (km)	State	Composition	Density (g/cm ³)	Temperature (°C)
Crust						
Continental	0–65	40 (average)	Solid	Silicates rich in sodium, potassium, and aluminum	2.67	-89–1000
Oceanic	0–10	7 (average)	Solid	Silicates rich in calcium, magnesium, and iron	3.0	0–1100
Mantle	Base of crust–2891	2866	Solid and mobile	Magnesium-iron silicates	3.4–5.6	1100–3200
Outer core	2891–5149	2258	Liquid	Iron, nickel	9.9–12.2	3200
Inner core	5149–6371	1222	Solid	Iron, nickel	12.8–13.1	4000–5500

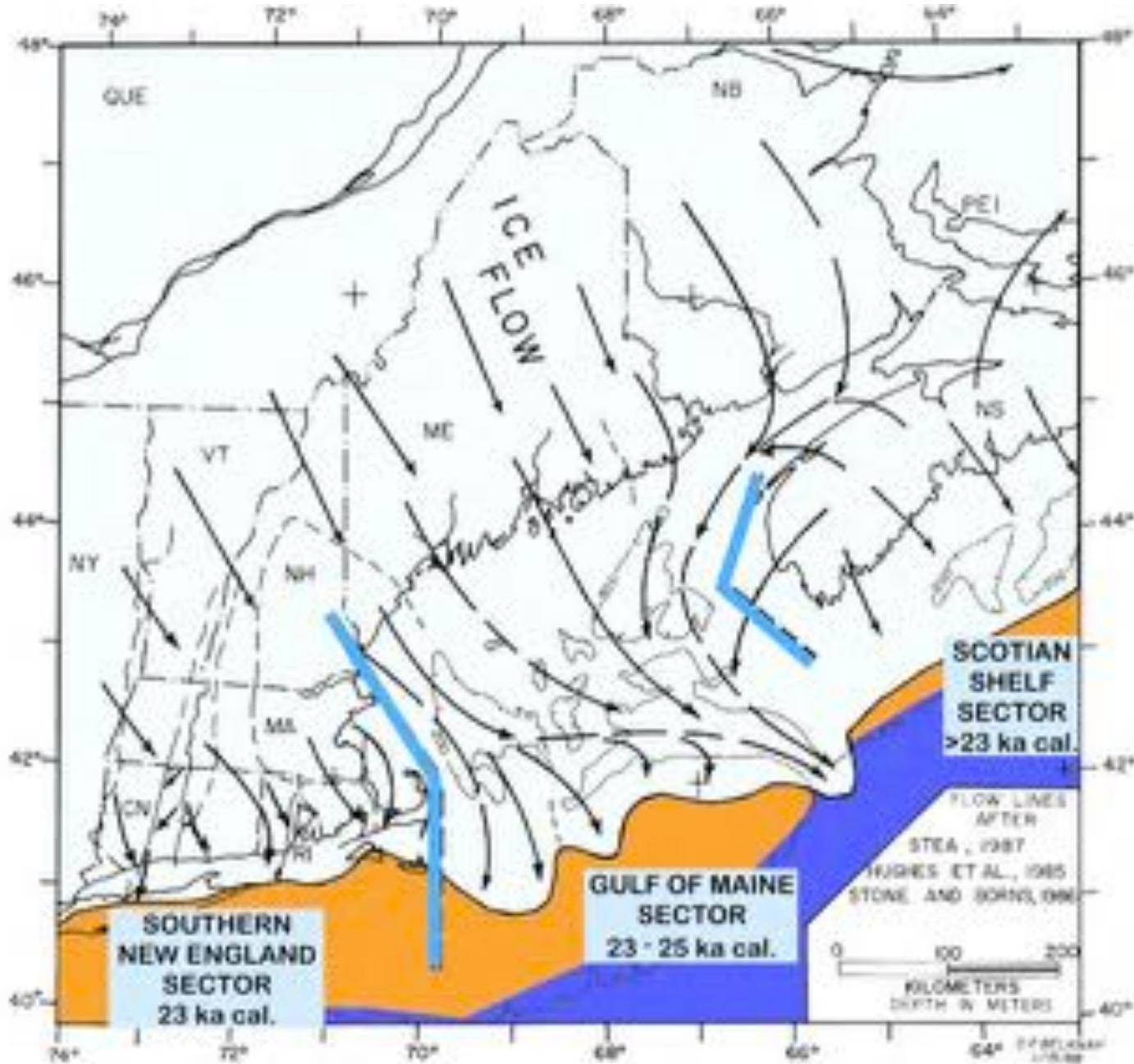


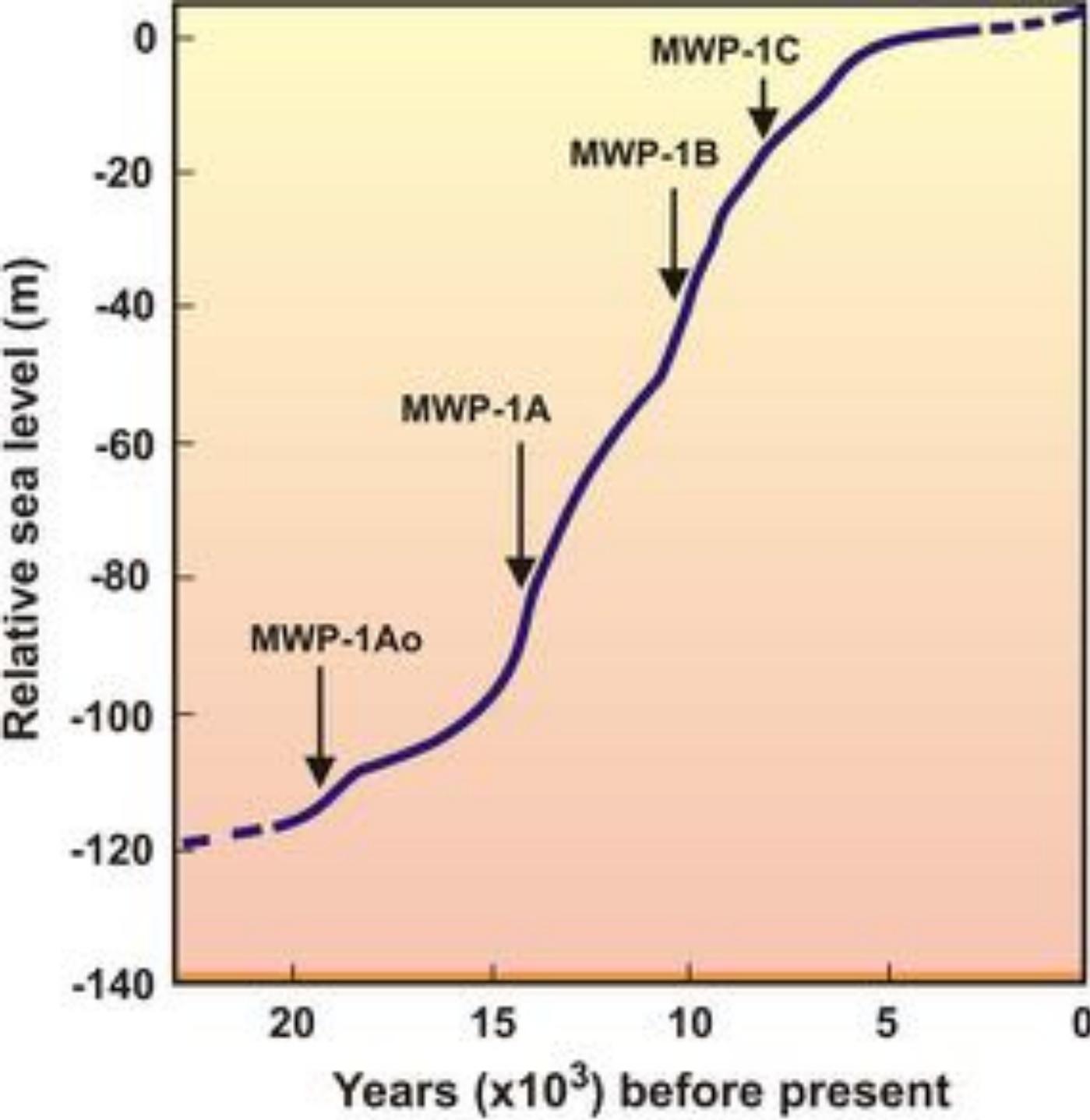
Key Properties and processes

- Density
 - Layering of earth
 - Isostasy of continents
- Convection
 - Overturning within layers
 - Convection-like process moves plates



A local note on isostacy

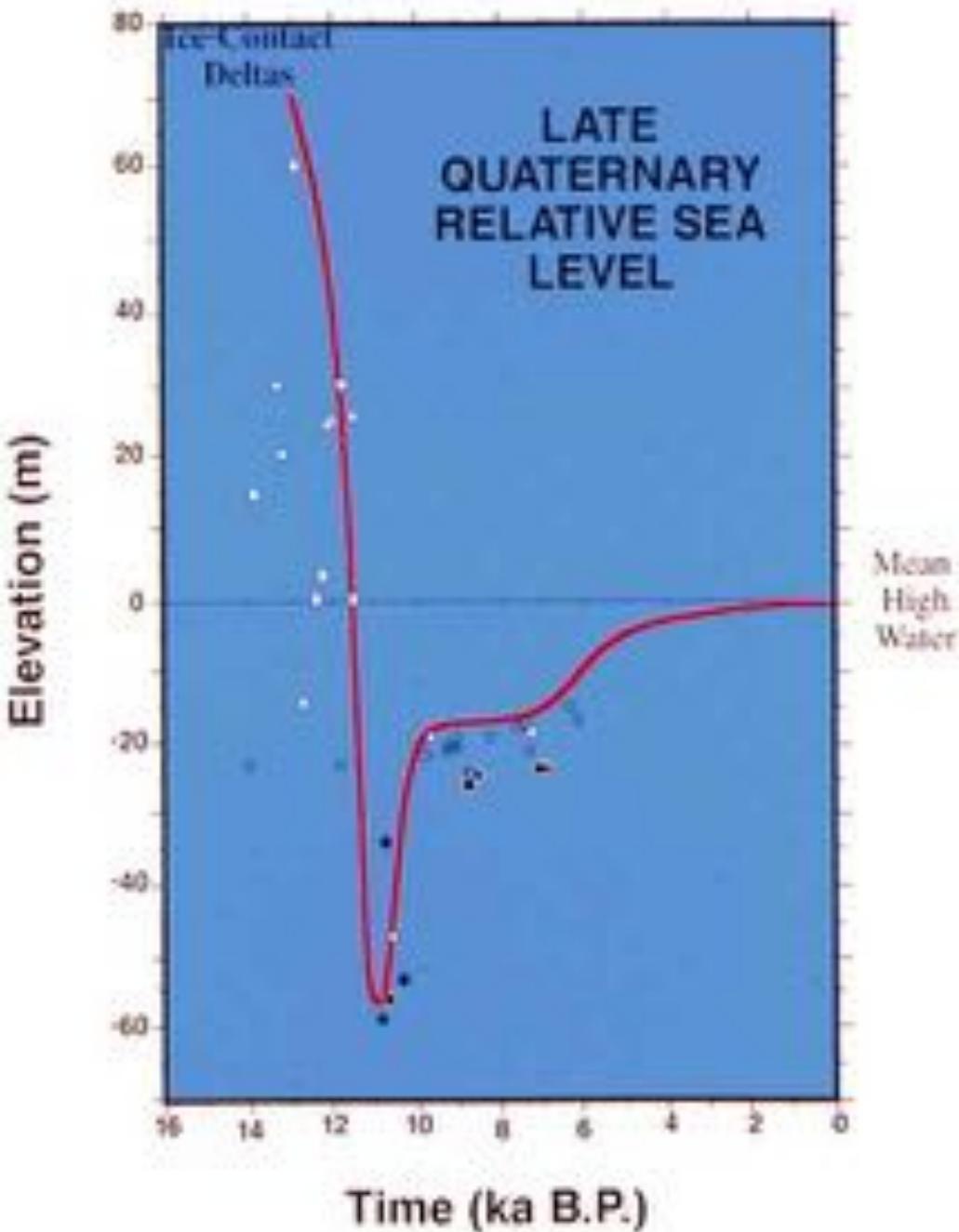




Global sea level
rise since last
ice age

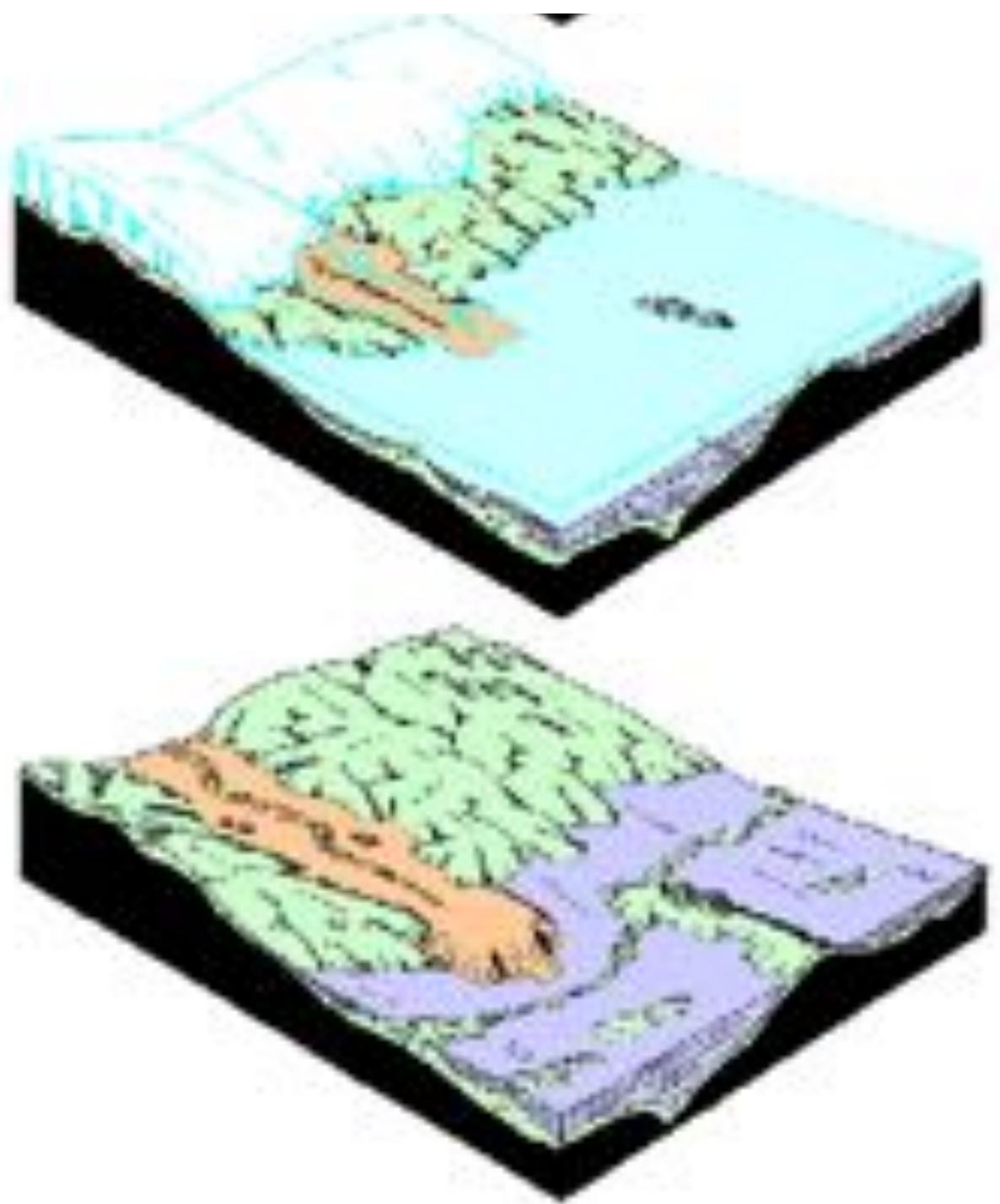


Image credit: NASA



Maine sea level
rise since last
ice age







<https://www.youtube.com/watch?v=uGcDed4xVD4>



The Sea Floor



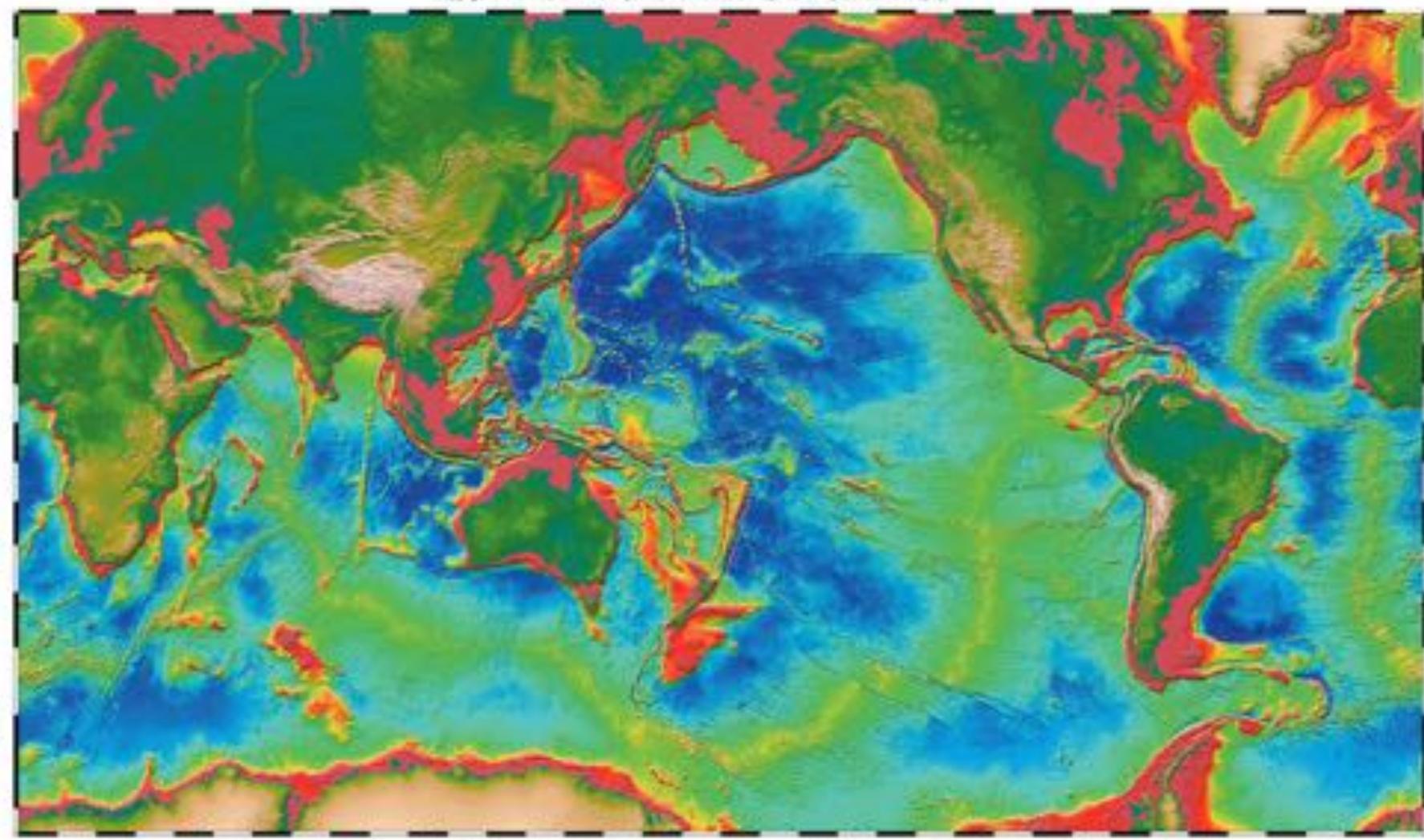
Topography of the sea floor

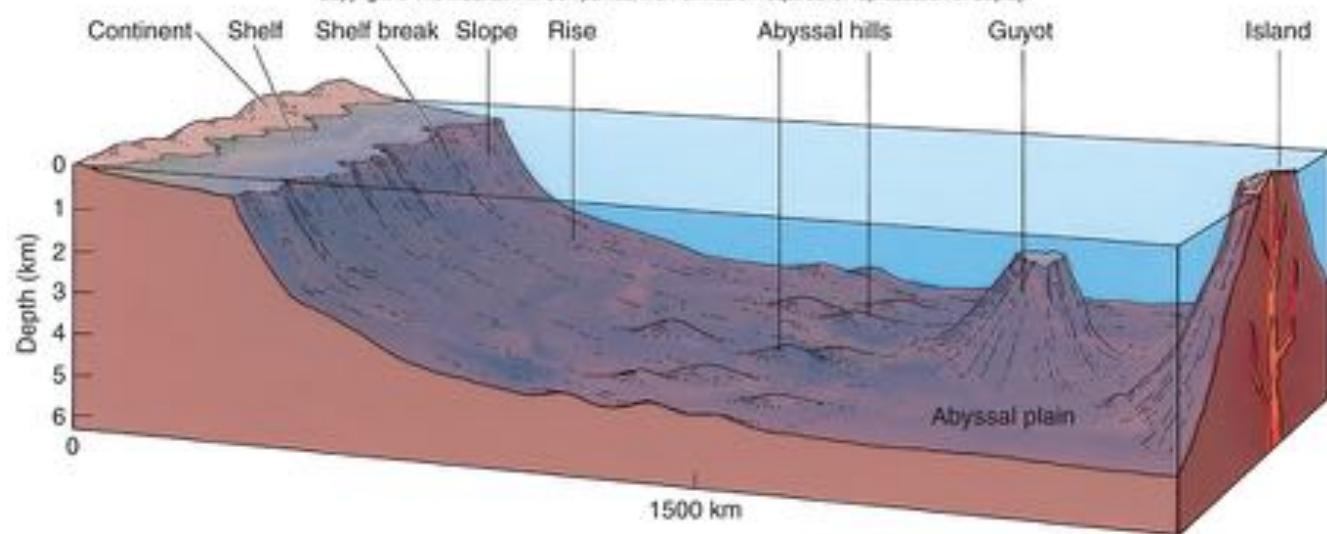
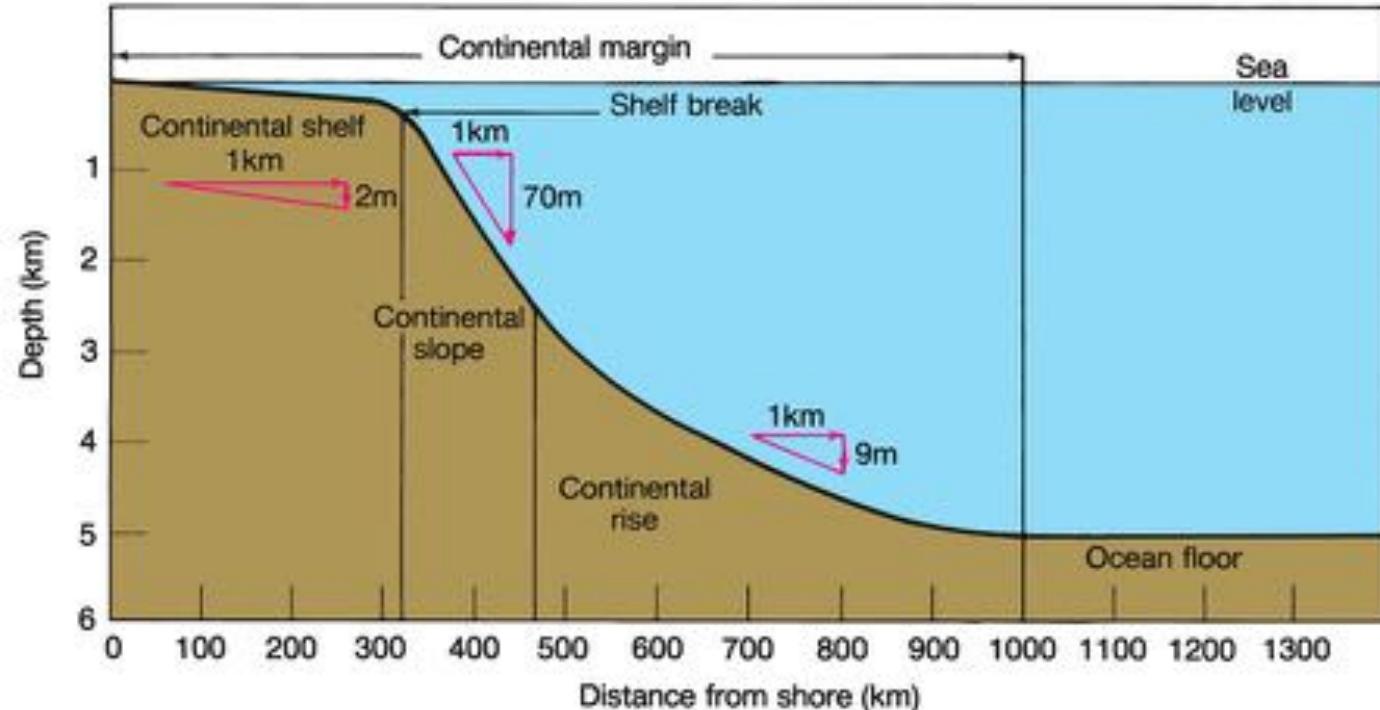
- Longer mountains than on land
- Wider and flatter valleys
- Deeper and steeper canyons
- Mapping: echo-sounders, side-beam sonars; multi-beam sonars, satellite altimetry, combined with GPS



Bottom topography of the world's oceans

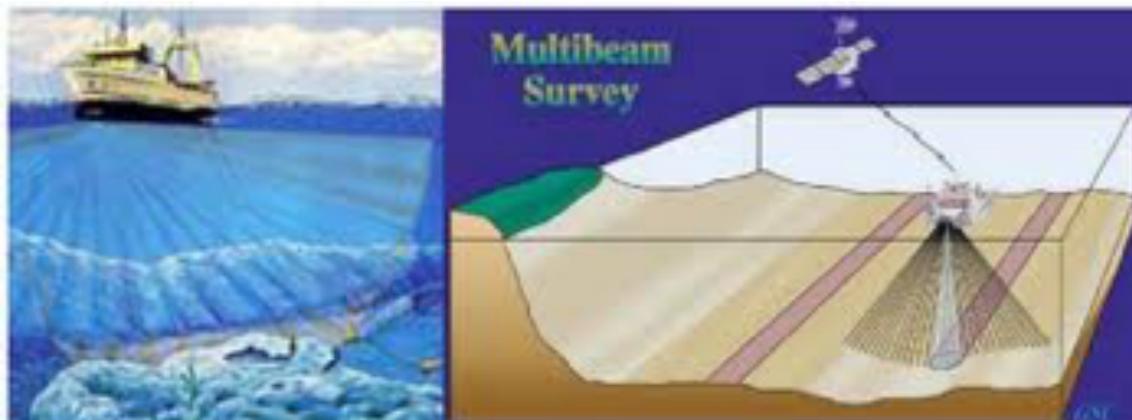
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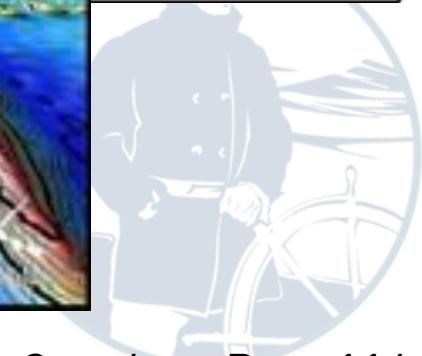
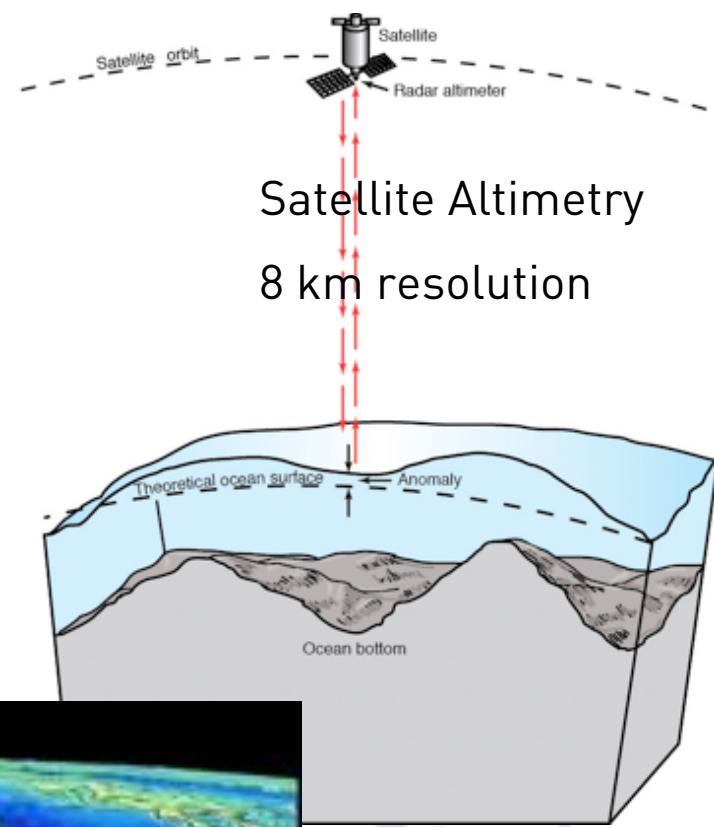
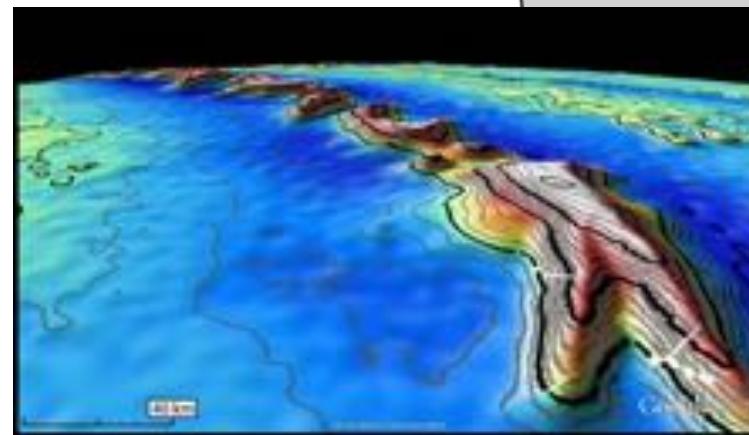
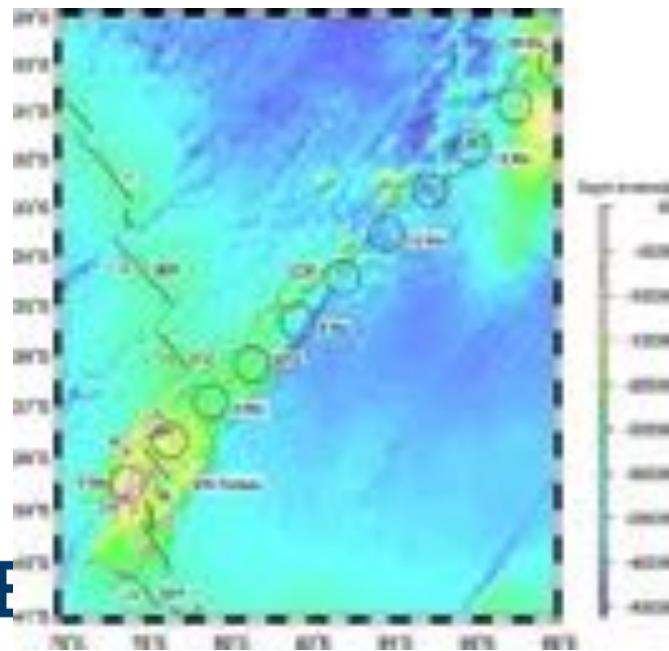


Determining bottom topography

Shipboard multibeam echosounding: 10-20 km swaths at 200 m resolution



NOAA/NGDC



Sediments

Solid materials produced, transported or deposited by water or air to form layers

Particles that physically sediment or settle to the bottom (from Latin: sedere, to settle)

Sedimentation rate ≠ Accumulation rate

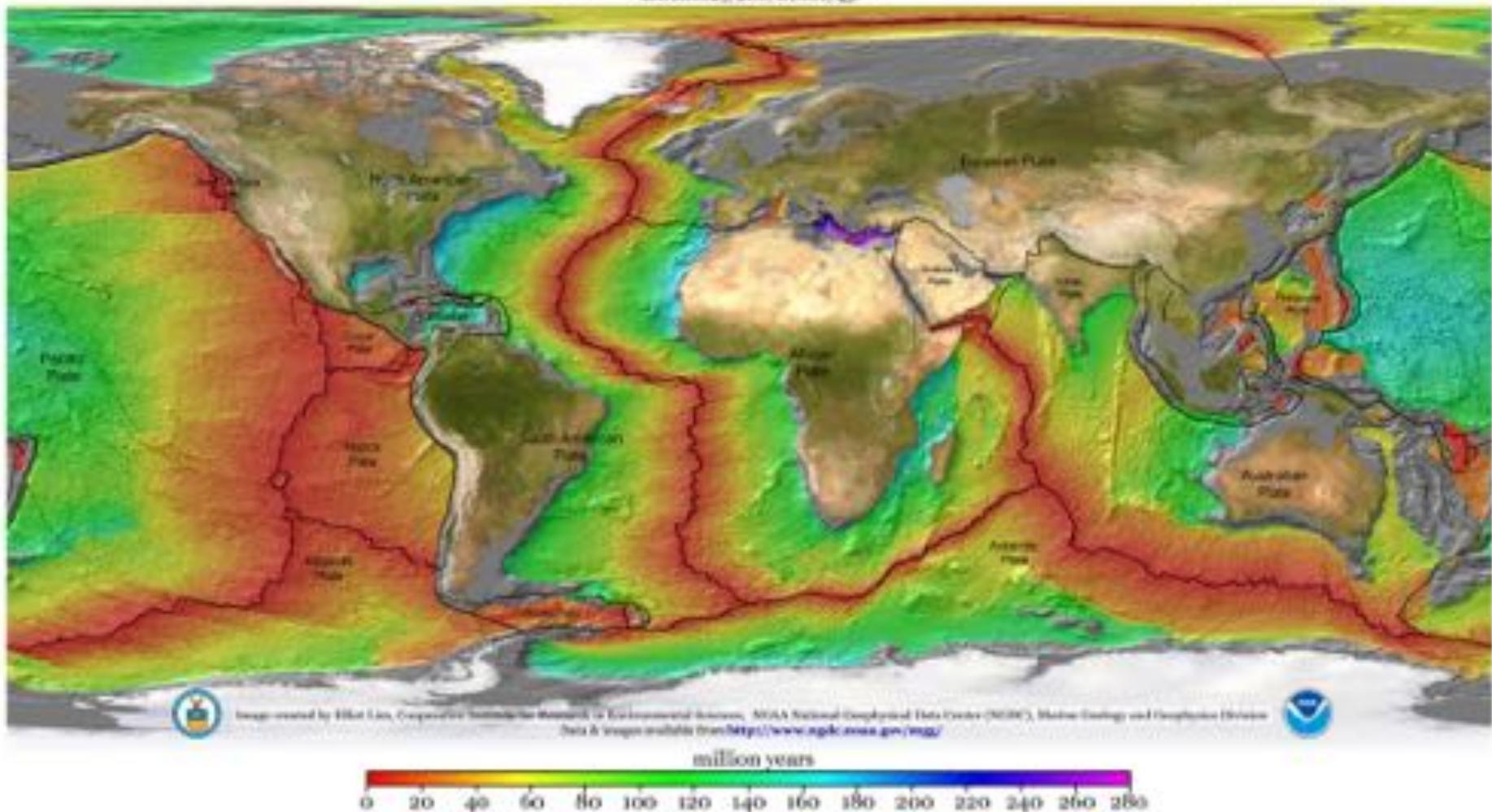
Note: marine sedimentation is the major way carbon is buried



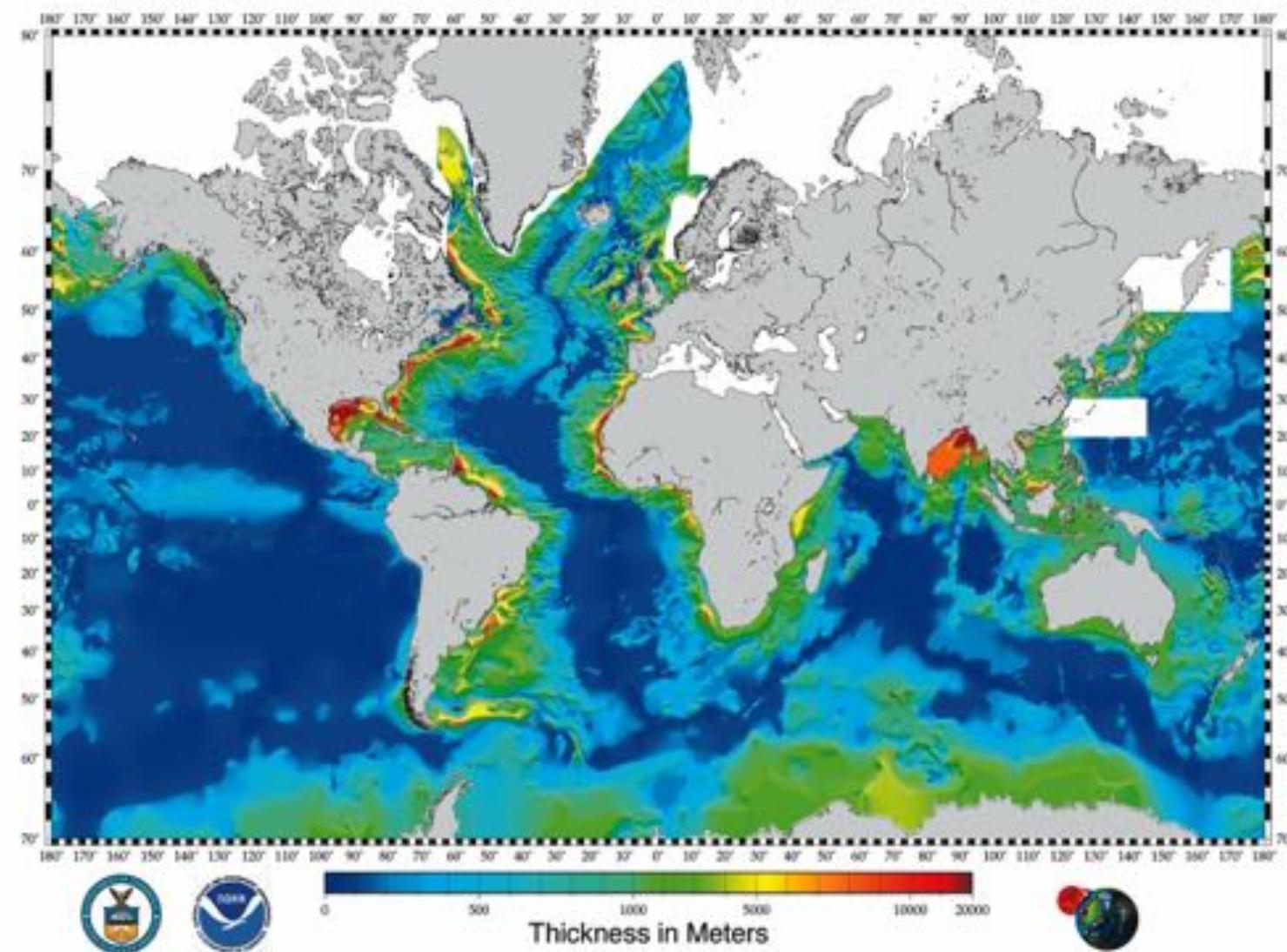
Age of Oceanic Lithosphere (m.y.)

Data source:

Mulder, R.D., M. Schrijvers, C. Gaina, and W.R. Roest 2008. Age, spreading rates and spreading symmetry of the world's ocean crust, *Geochem. Geophys. Geosyst.*, 9, Q04006, doi:10.1029/2007GC001743.



Total Sediment Thickness of the World's Oceans & Marginal Seas



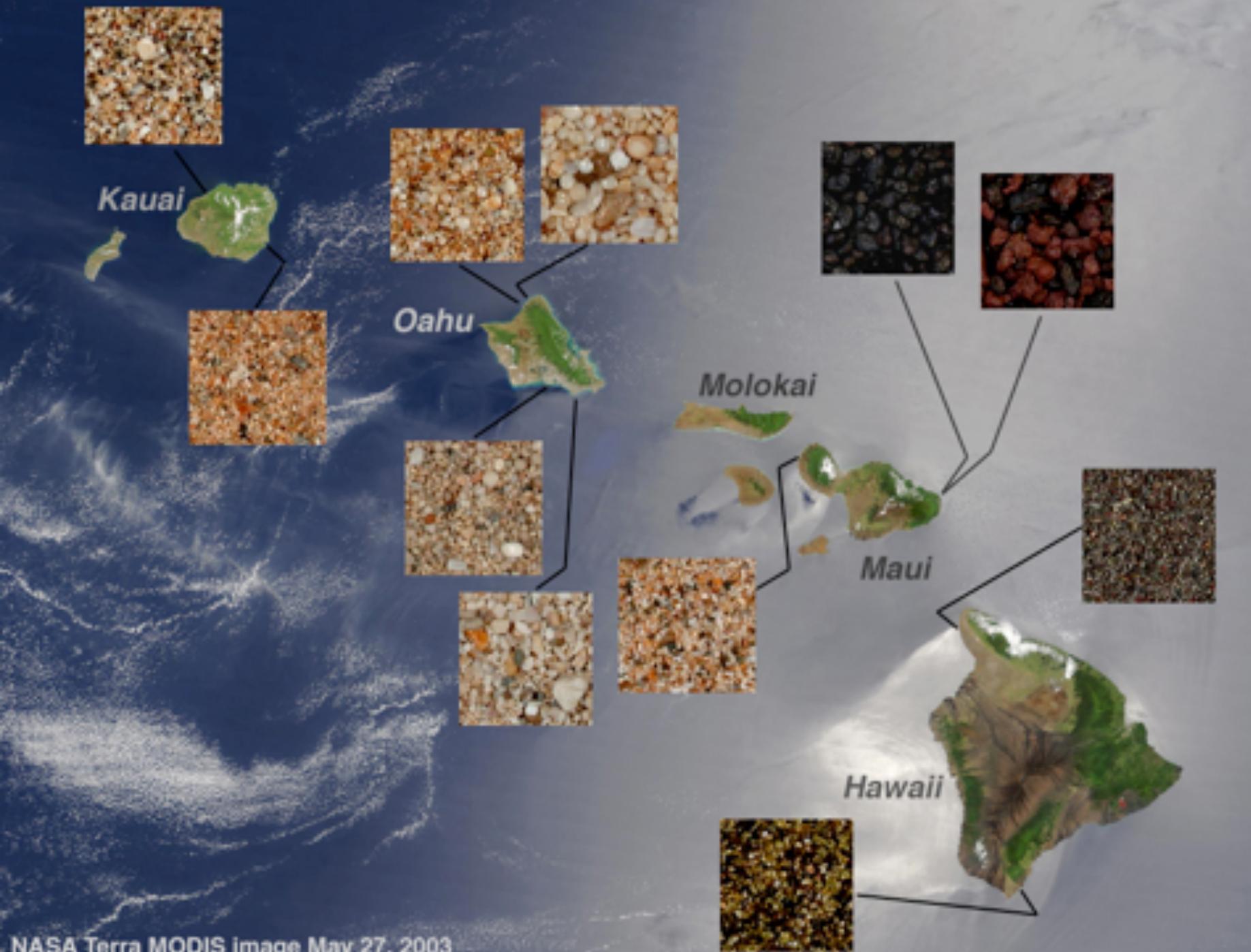


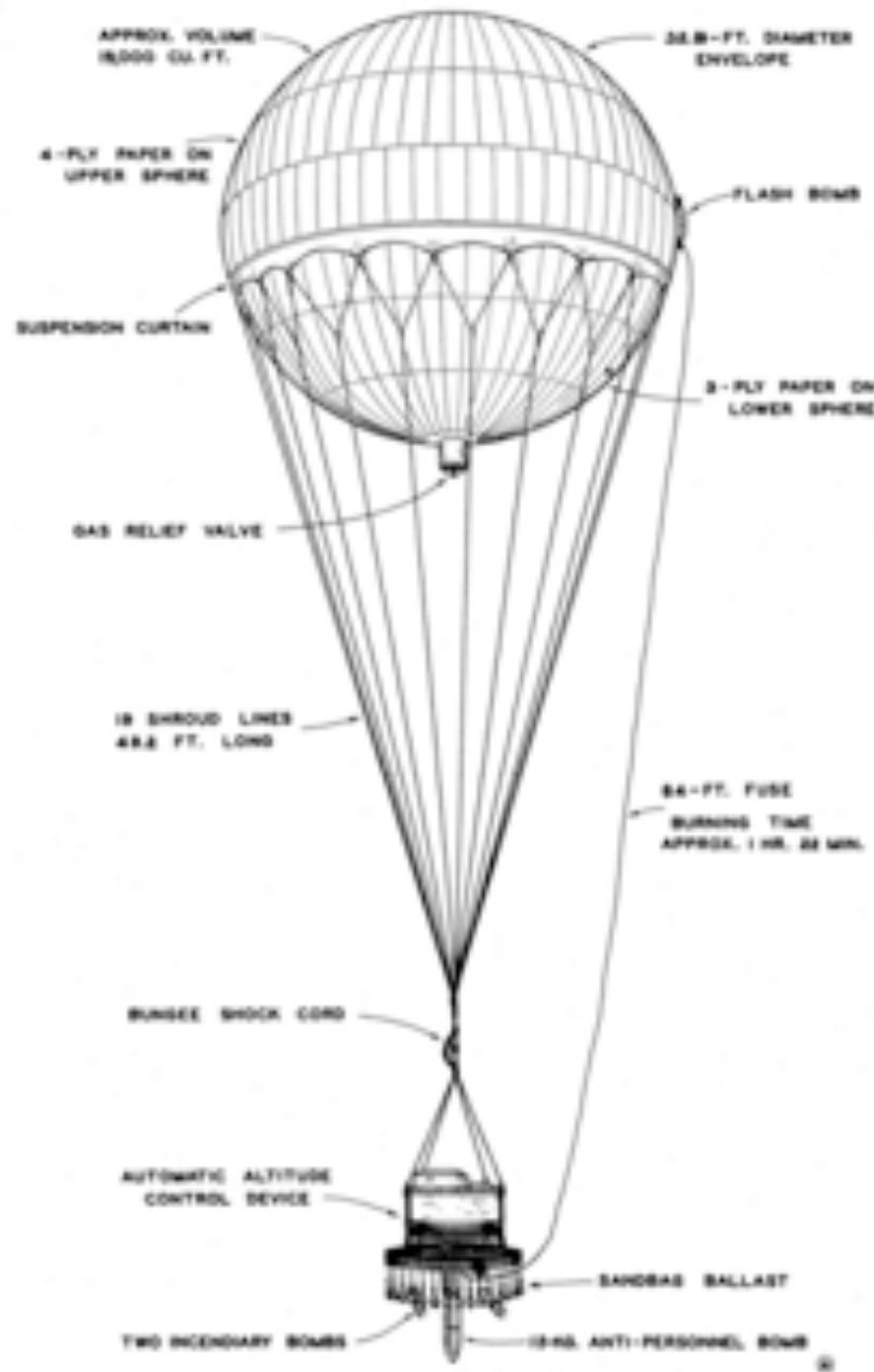
Classification Exercise

Which one is a Florida beach?









How Geologists Unraveled the Mystery of Japanese Vengeance Balloon Bombs in World War II

“...Some of the foram species identified had only been previously described in Japanese geologic papers dealing with beaches north of Tokyo on the eastern shore of Honshu...”

http://web.mst.edu/~rogersda/forensic_geology/Japenese%20vengeance%20bombs%20new.htm



Two classifications: (1) Classification by grain size



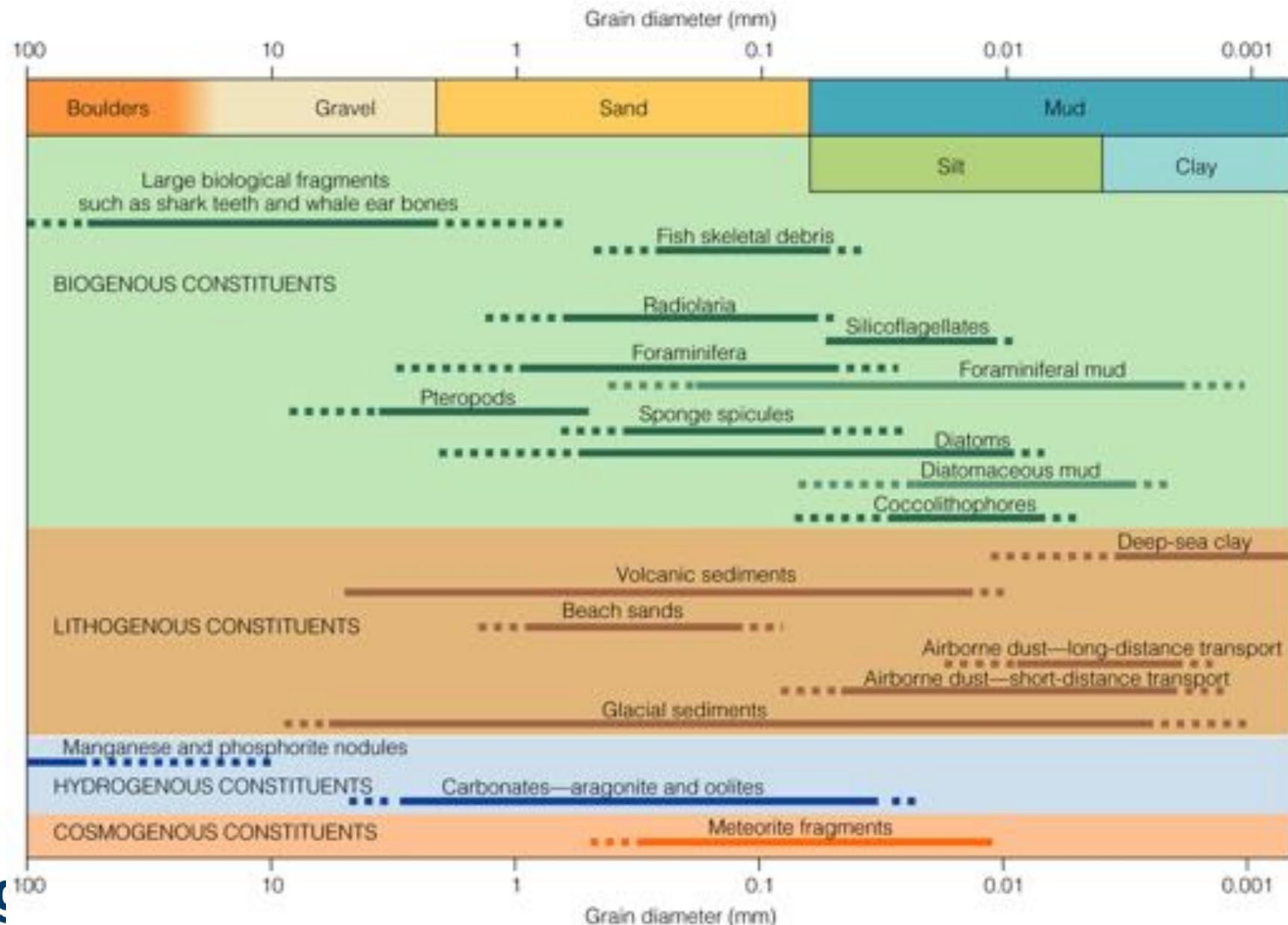
Images: D. Belknap



Stokes Law

$$v_s = \frac{2}{9} \frac{(\rho_p - \rho_f)}{\mu} g R^2$$

Two classifications: (1) Classification by grain size



Two classifications: (1) Classification by grain size
(2) Classification by origin

Lithogenous—fragments of rock from terrestrial sources

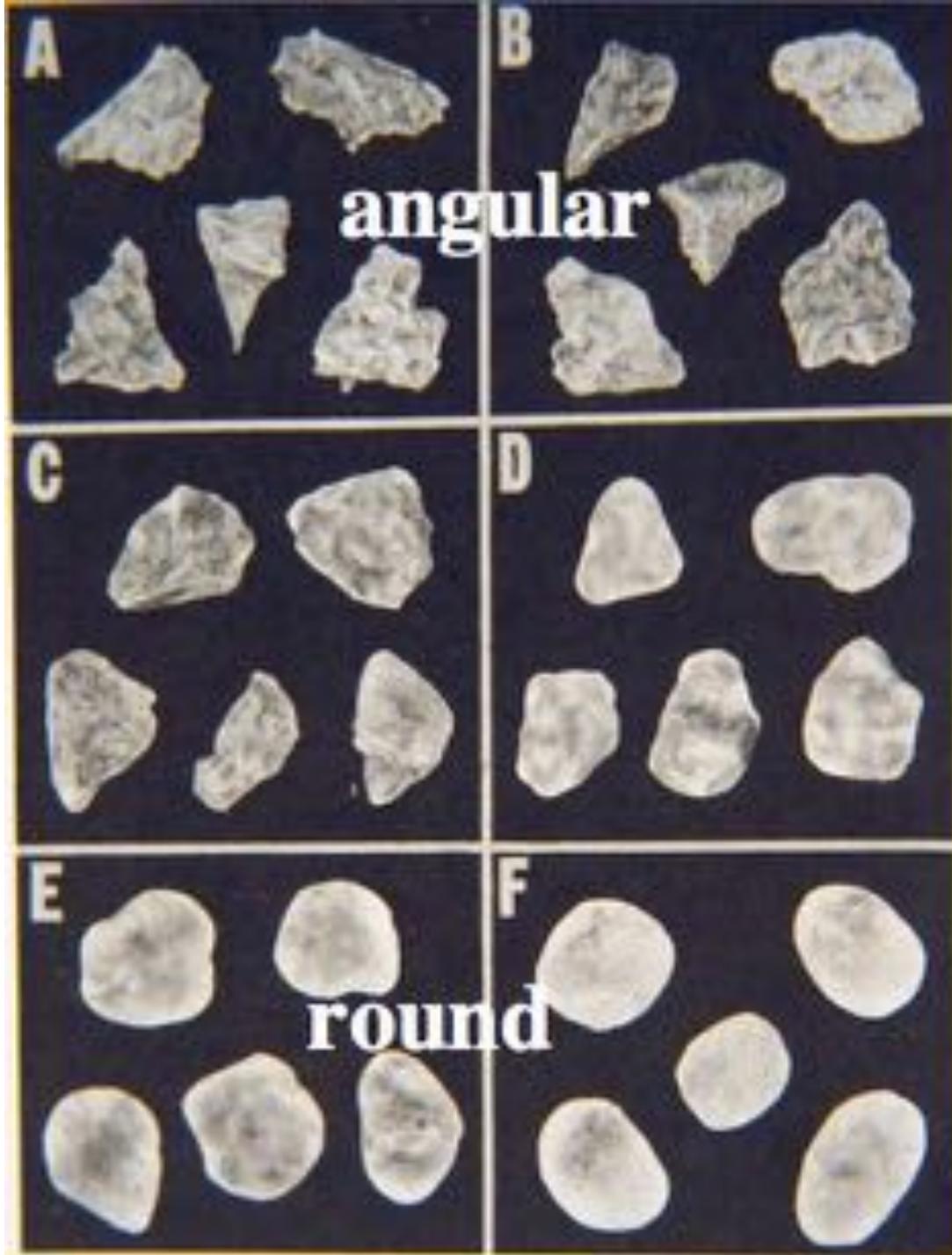
Biogenous—remains of marine organisms, mostly hard parts

Hydrogenous—formed by precipitation of dissolved substances

Cosmogenous—fragments of meteorites



Comment: Classification by size and by origin doesn't tell the whole story



Comment: Classification by size and by origin doesn't tell the whole story



Shingles, disc shaped

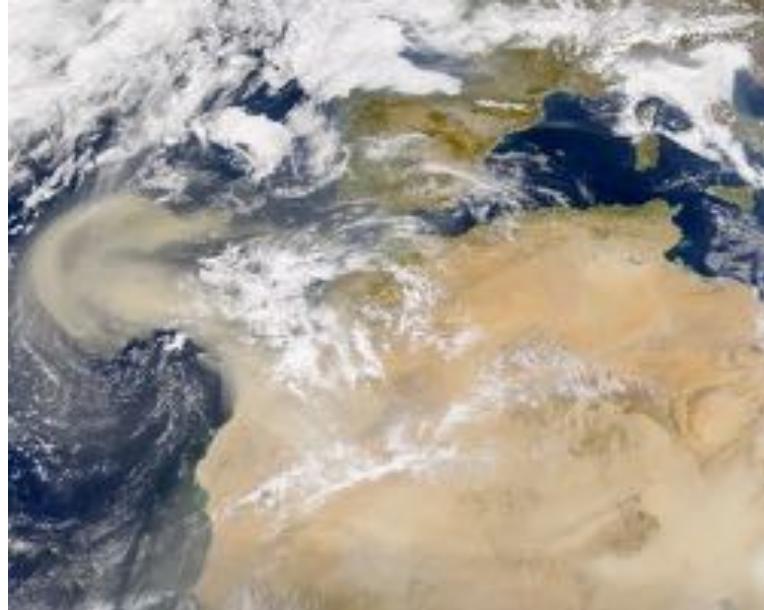
round, “rollers”

Lithogenous

Rock particles eroded or weathered

- freshwater runoff
- glaciers
- waves
- winds
- landslides
- ships

~ 1 mm – 10 cm per 1000 year



Biogenous

~ 1 cm per 1000 yr

Calcareous oozes



shallow, warm



Ucl.ac.uk



wikipedia.com

Siliceous oozes



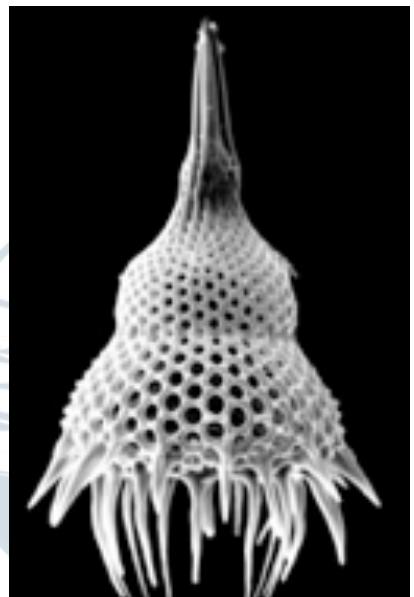
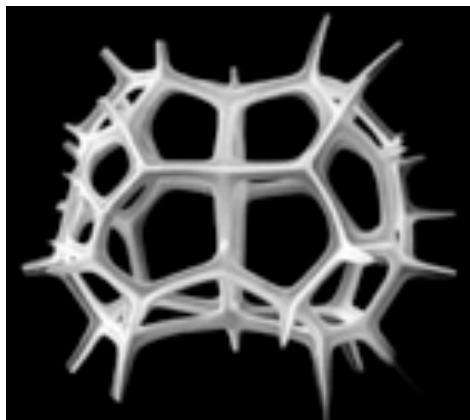
colder, deeper water



Bige

ocean sciences

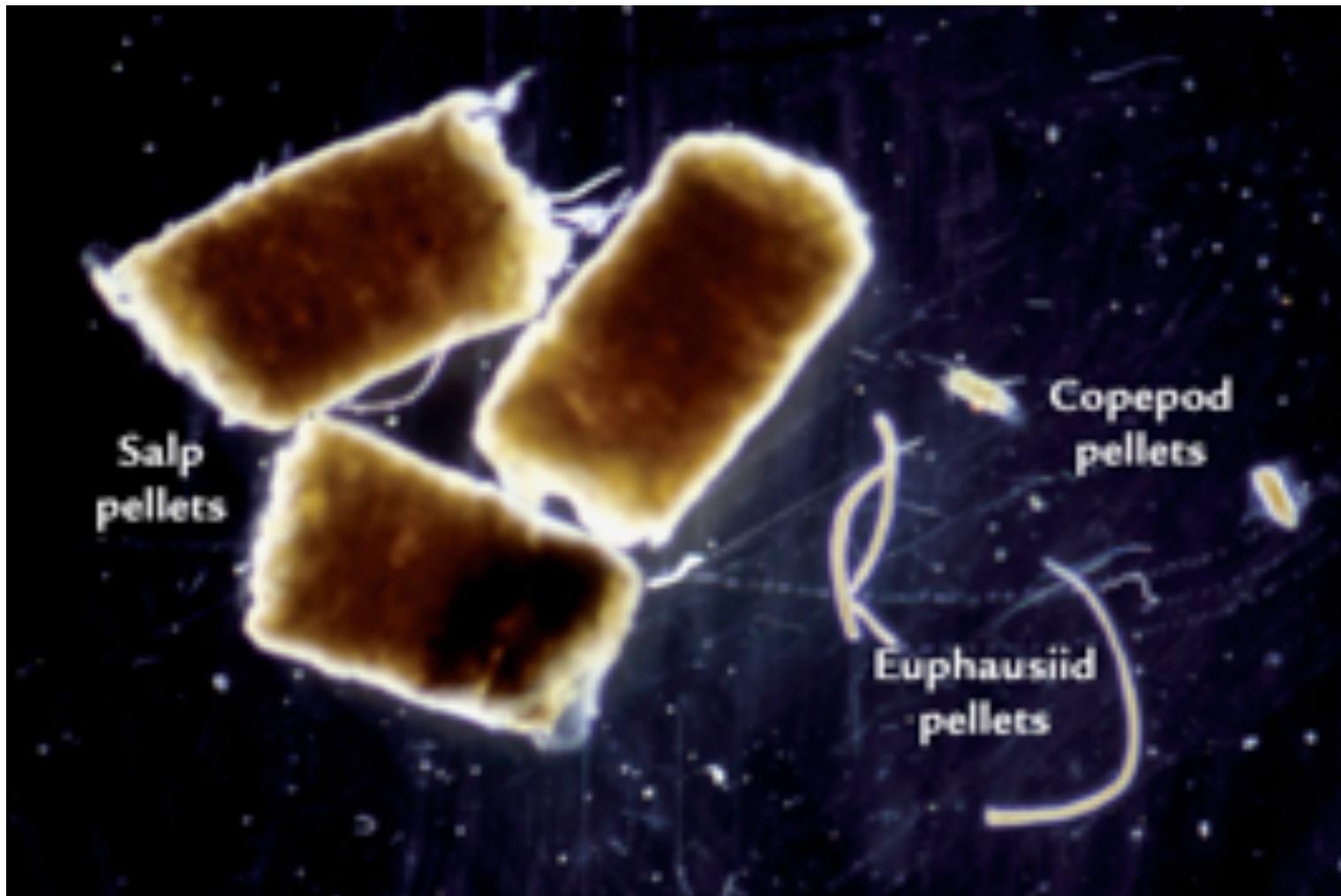
micrographia.com



radiolarians.org

Biogenous

Soft deposits: *Plankton poop is a major area of research*



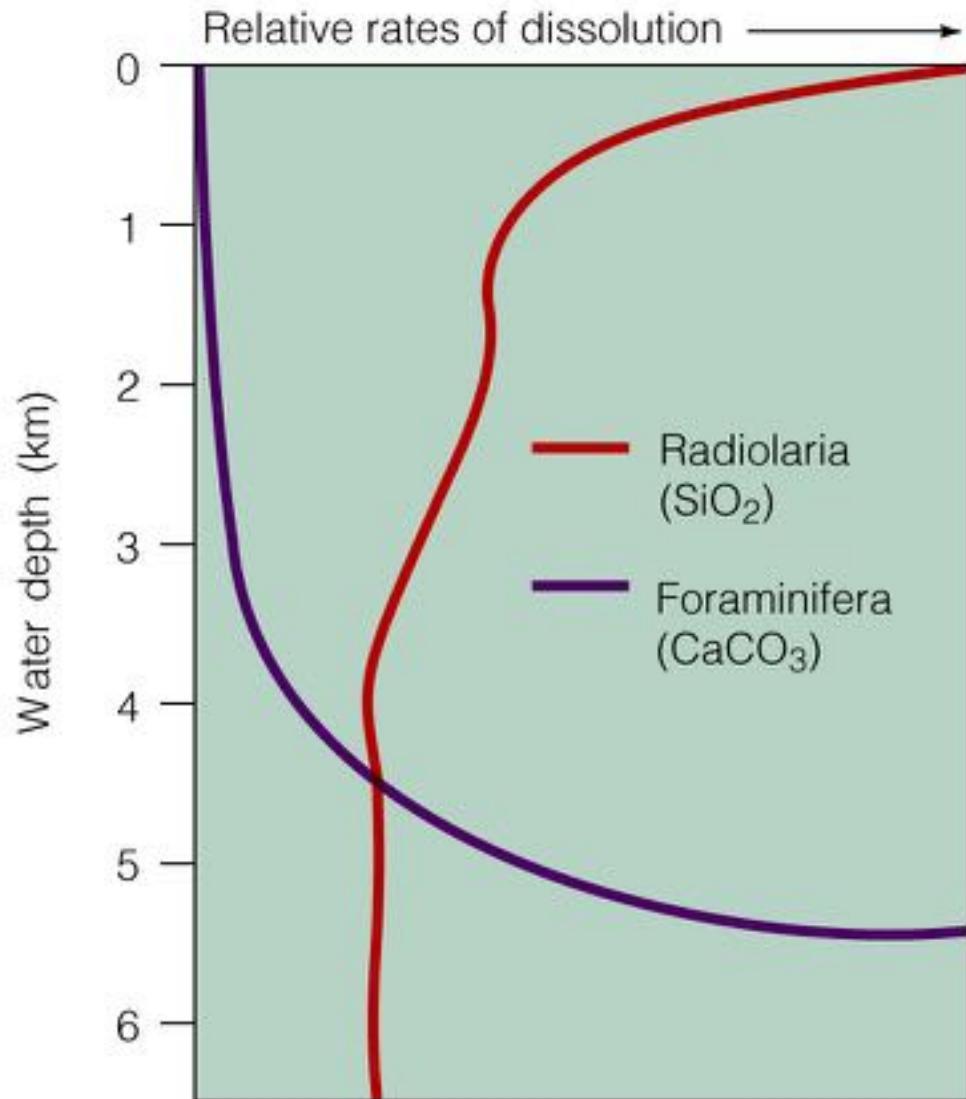
Carbonate Compensation Depth (CCD)

Below a certain depth, seawater is undersaturated with respect to calcium carbonate.

→ calcareous debris starts to dissolve

→ dissolution rate increases with depth

At the CCD, all calcium is dissolved

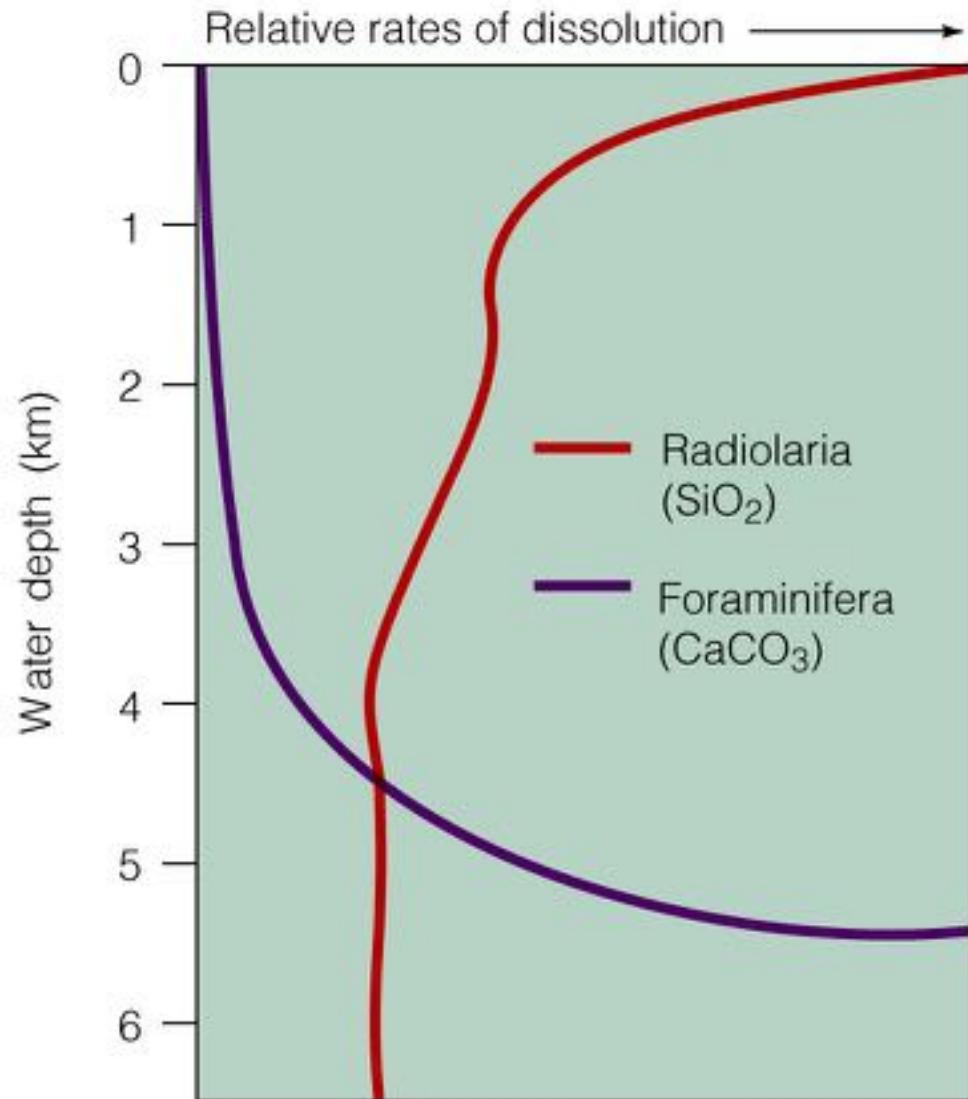


Carbonate Compensation Depth (CCD)

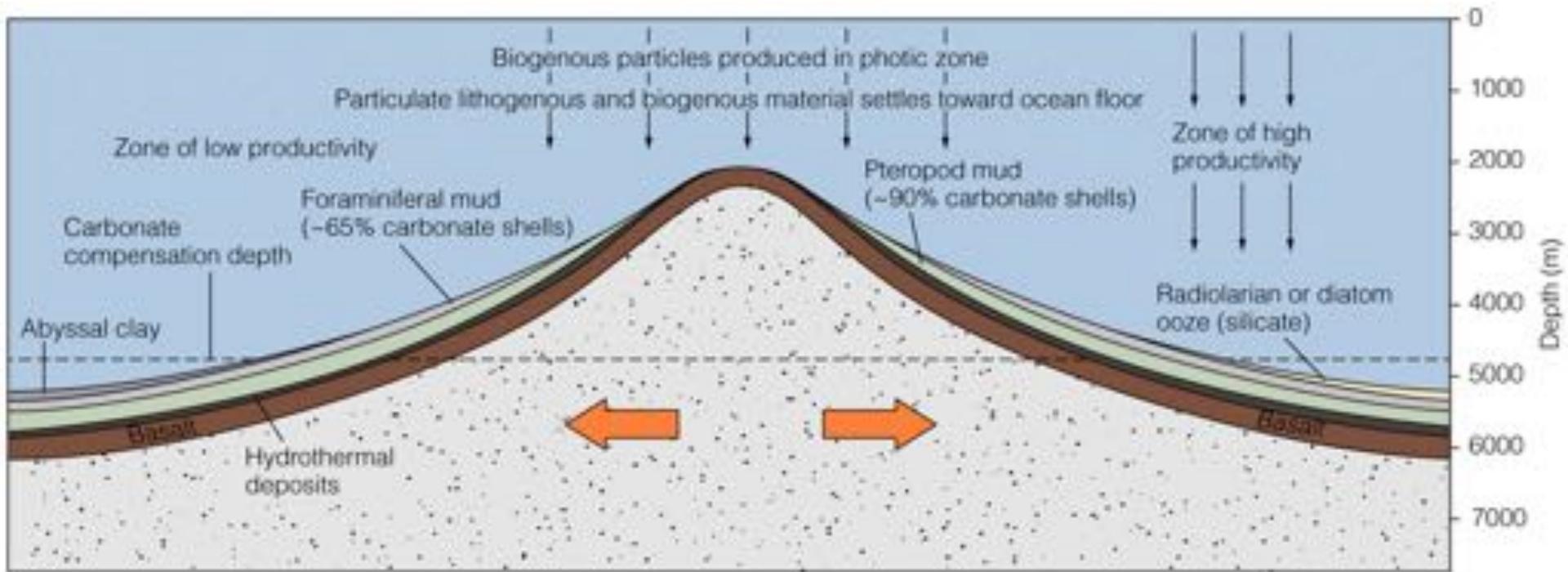
The CCD depends on pressure and temperature, the concentration of dissolved carbon dioxide, and the pH

The CCD is shallower where the deep water has spent longer away from the surface and so accumulated more carbon dioxide

CCD is deeper in the South Atlantic than the North Atlantic, and even deeper in the Pacific.



Carbonate Compensation Depth (CCD)



CCD not fixed

- moves with seafloor spreading
- can change with climate change



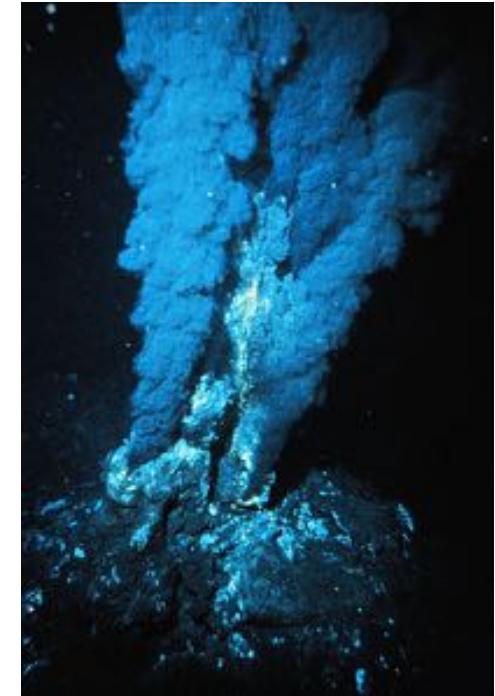
Hydrogenous

Metals from hydrothermal vents

Iron, manganese, copper, cobalt, lead, nickel silver, zinc

Discovered in 1970s

Probably abundant along spreading centers



Manganese nodules

Dissolved ions adsorbing onto particle
(e.g. shark tooth)

~1 – 10 mm per million years

Sedimentation rate slow
(e.g. Pacific)

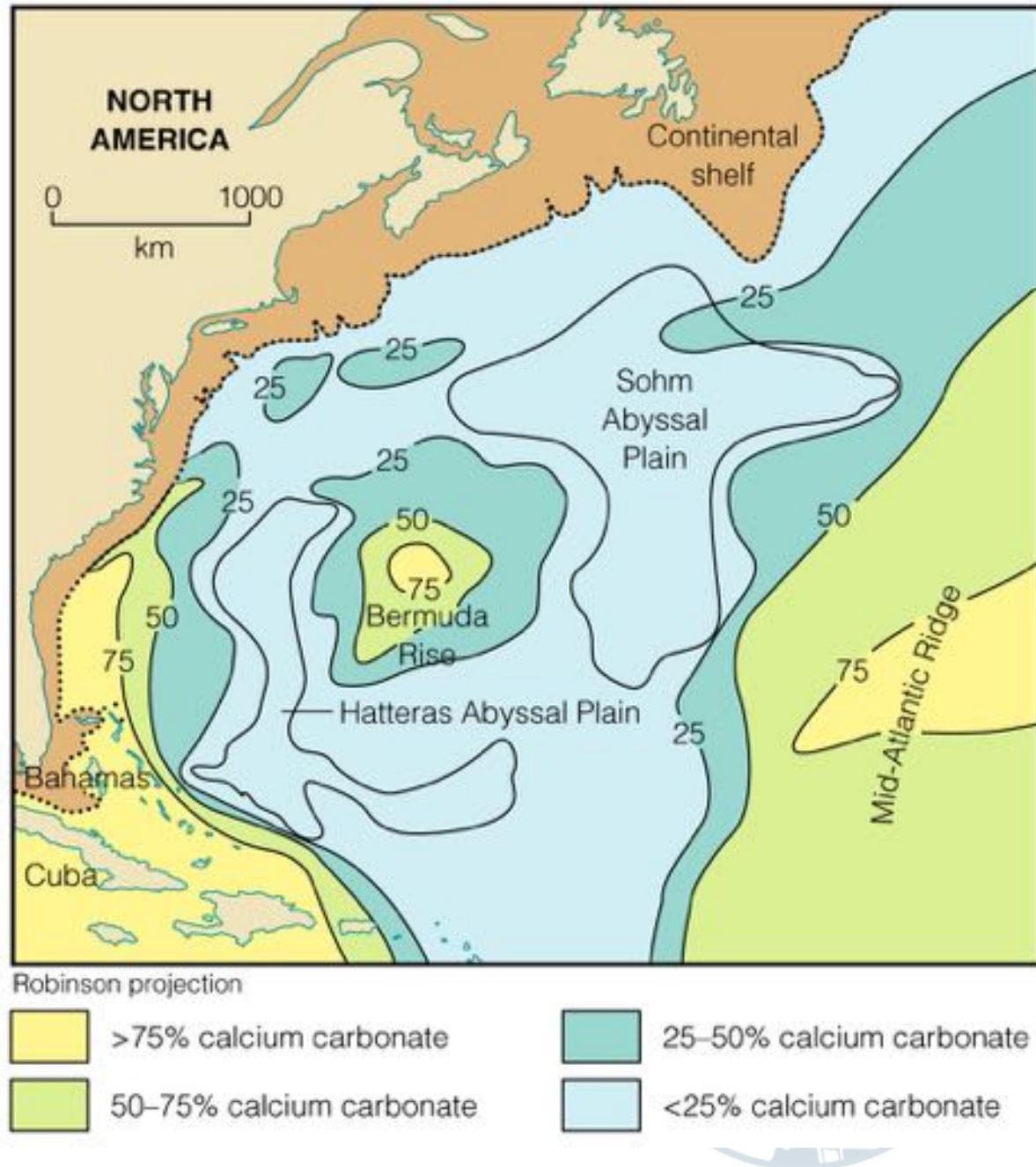


Hydrogenous

Carbonates

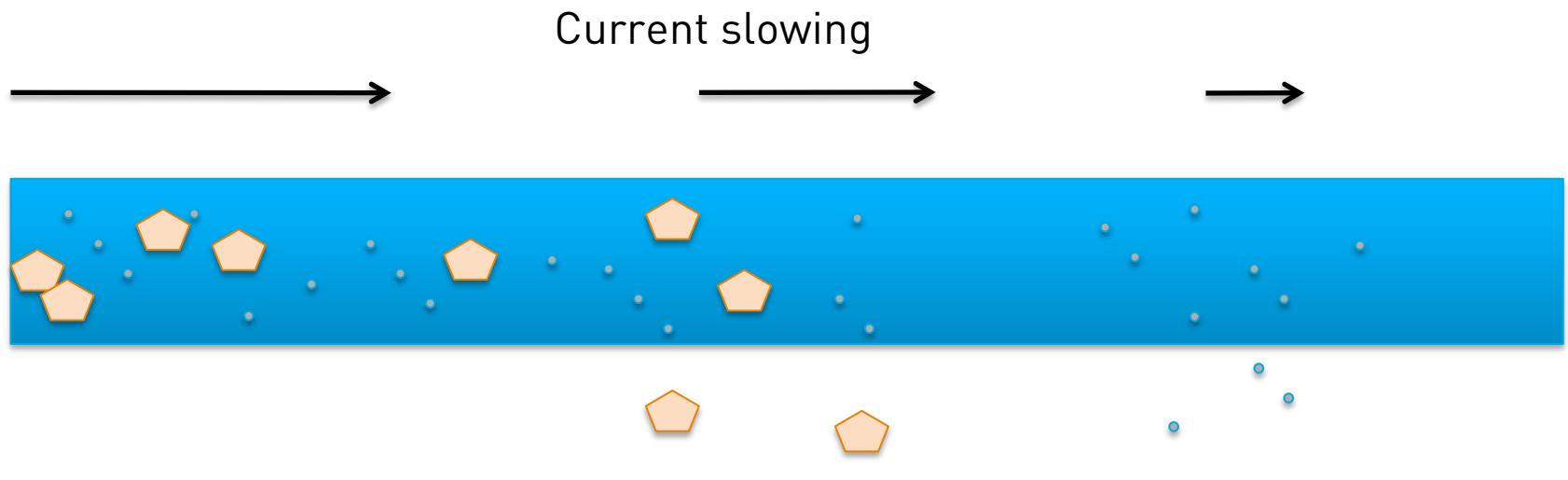
CaCO_3 precipitates from sea water

High temperature, low CO_2



How sediment is moved

Ocean Currents

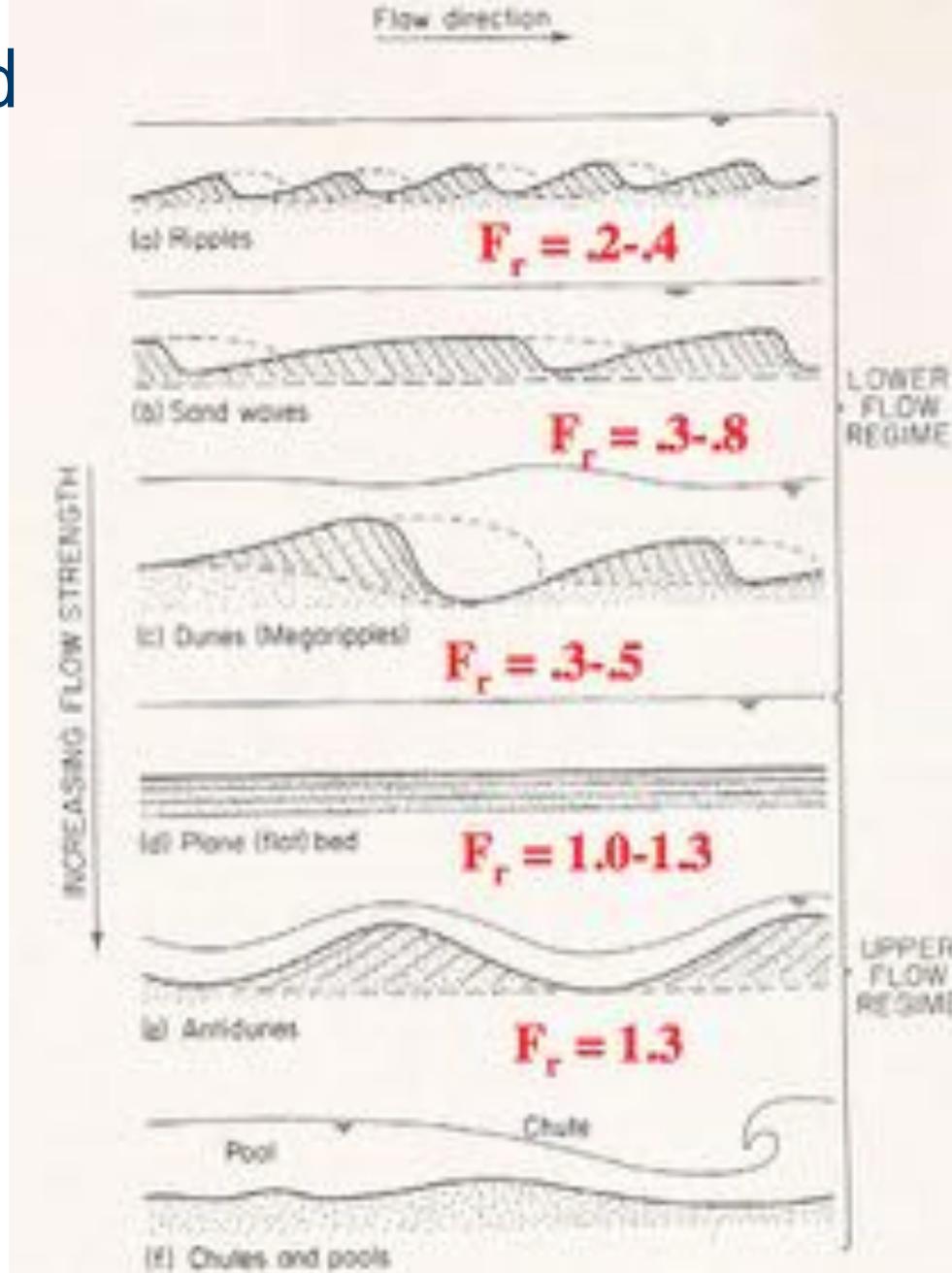


How sediment is moved

Waves

Froude number

$$Fr = \frac{V}{\sqrt{gd}}$$



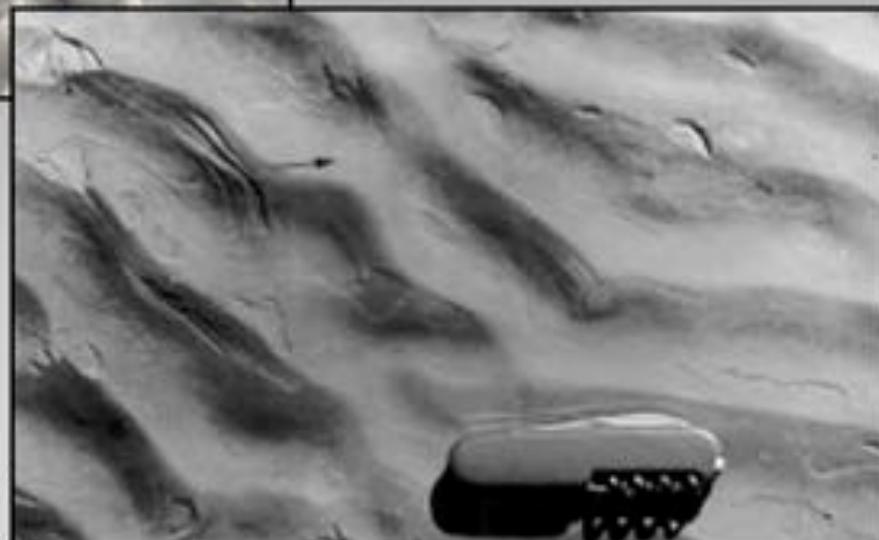
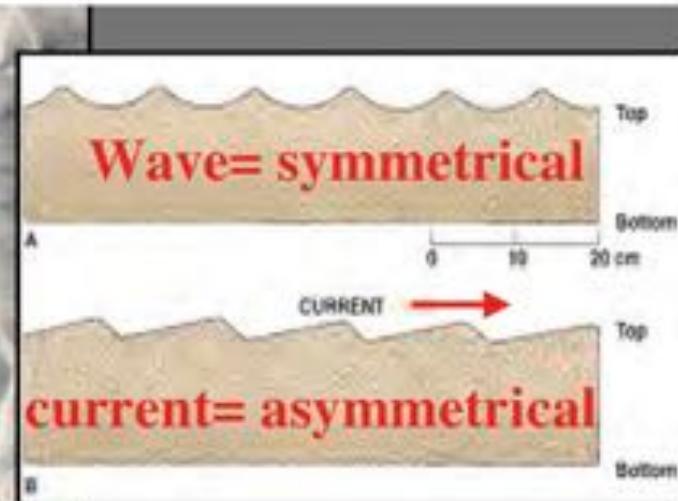
How sediment is moved



current ripples

$$F_r = v/(gd)^{0.5} = .2 - .4$$

Bigelo

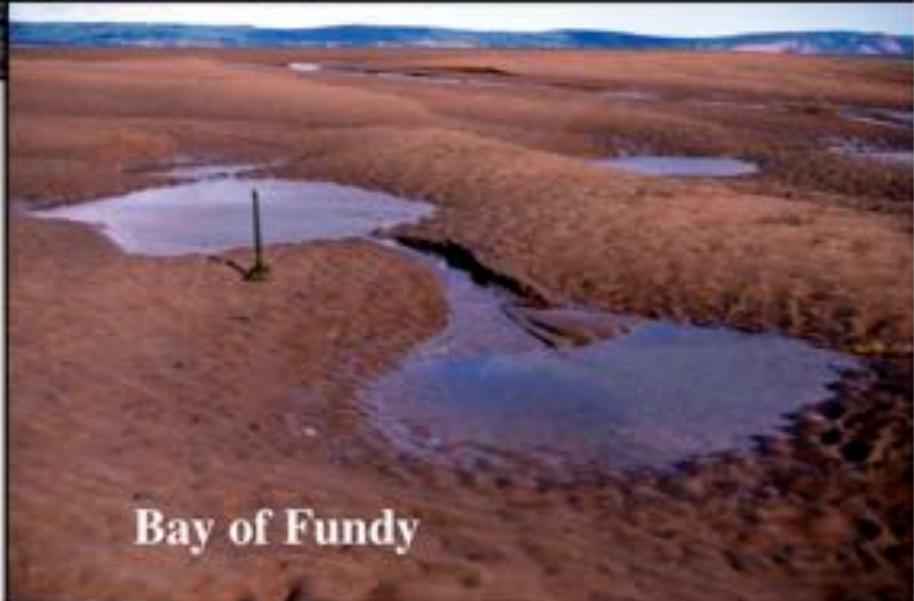


Wave ripples

How sediment is moved



Planed-off
Megaripples
and megaripples



Bigelo

Images: D. Belknap

How sediment is moved

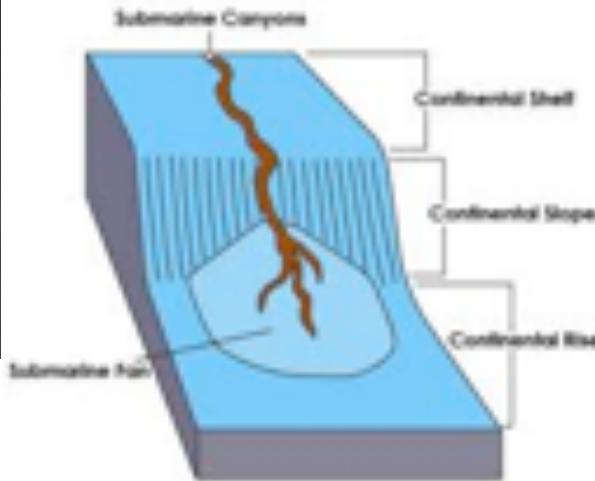
Turbidity currents



Turbulent downslope currents

Results from storms or earthquakes

Often near canyons, forming fans at bottom

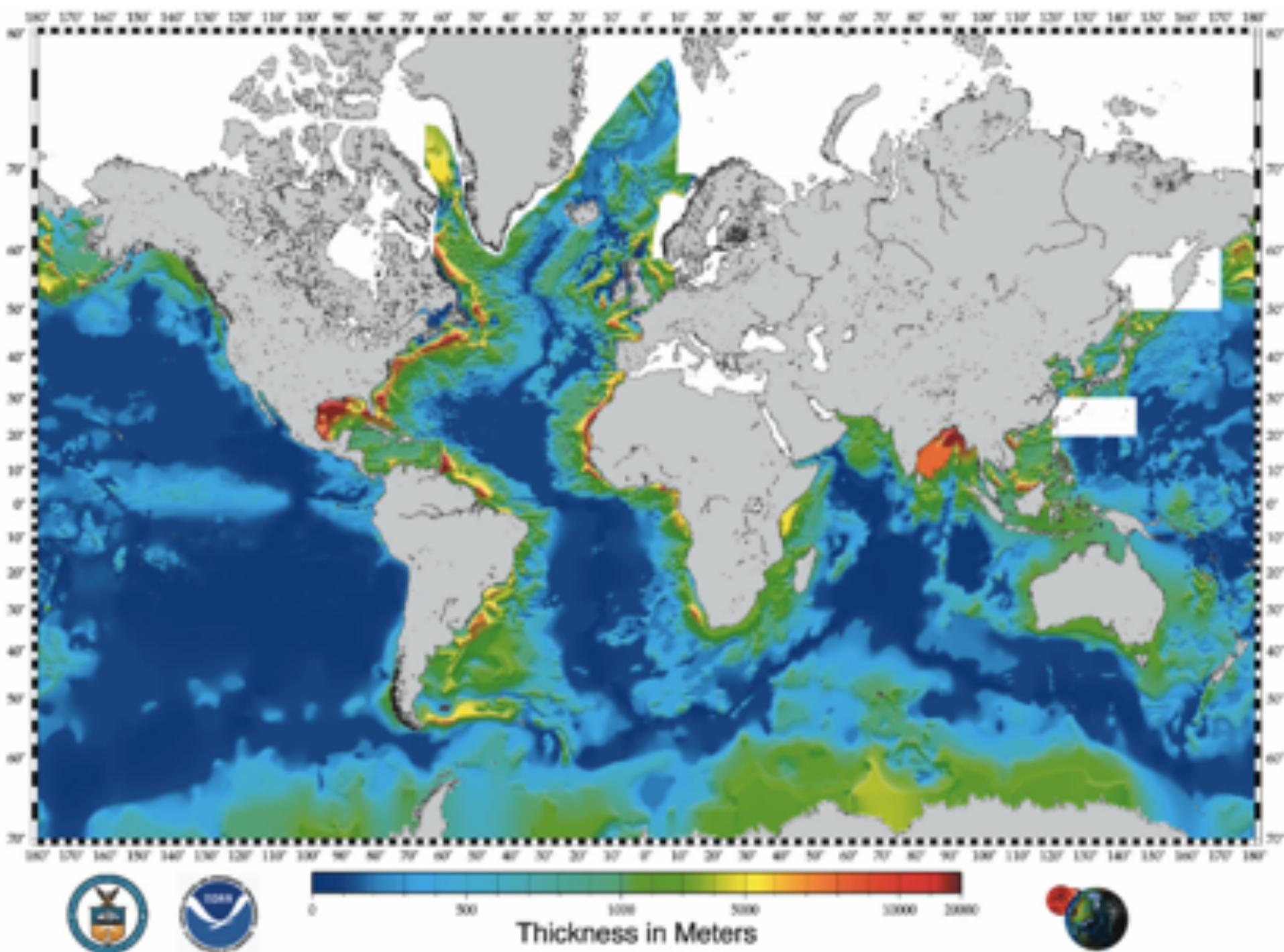


How sediment is moved

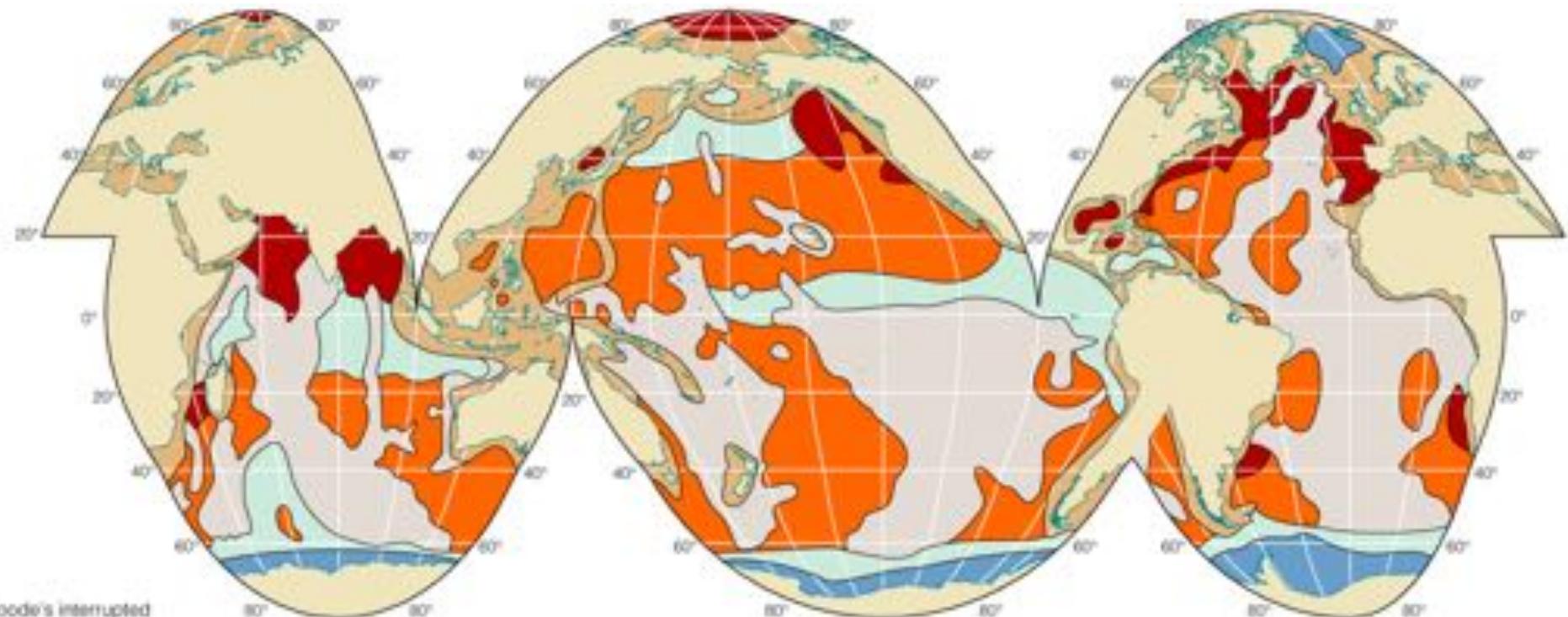


Newfoundland tsunami

7.2 magnitude



Surface Sediment Distribution



Goode's interrupted
projection

Calcareous
sediments

Siliceous
sediments

Deep-sea
clay

Terrigenous
sediments

Glacial
sediments

Continental shelf deposits
(variable composition)

(a)

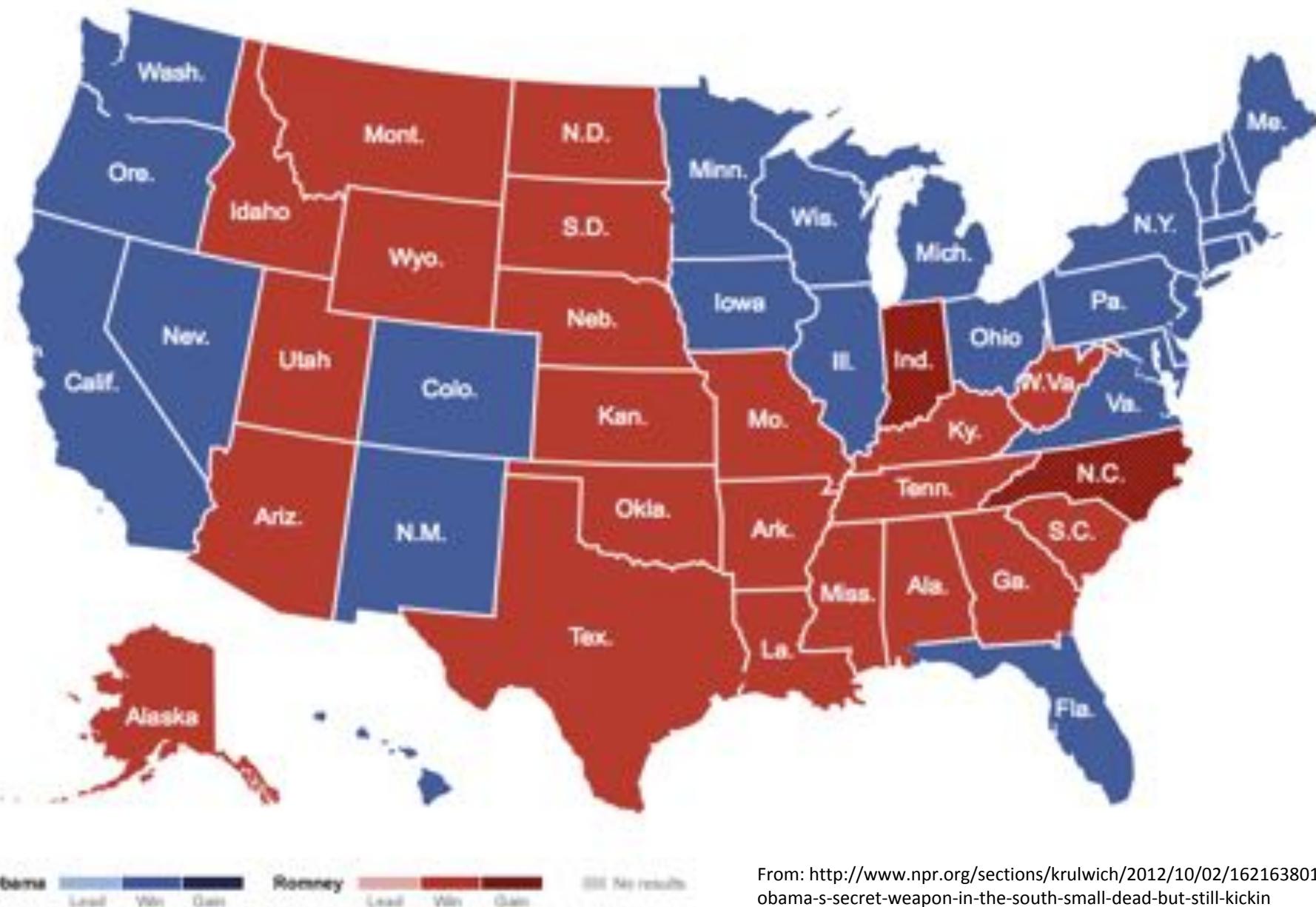


Crossing disciplines: Sedimentation and politics

From: <http://www.npr.org/sections/krulwich/2012/10/02/162163801/obama-s-secret-weapon-in-the-south-small-dead-but-still-kickin>

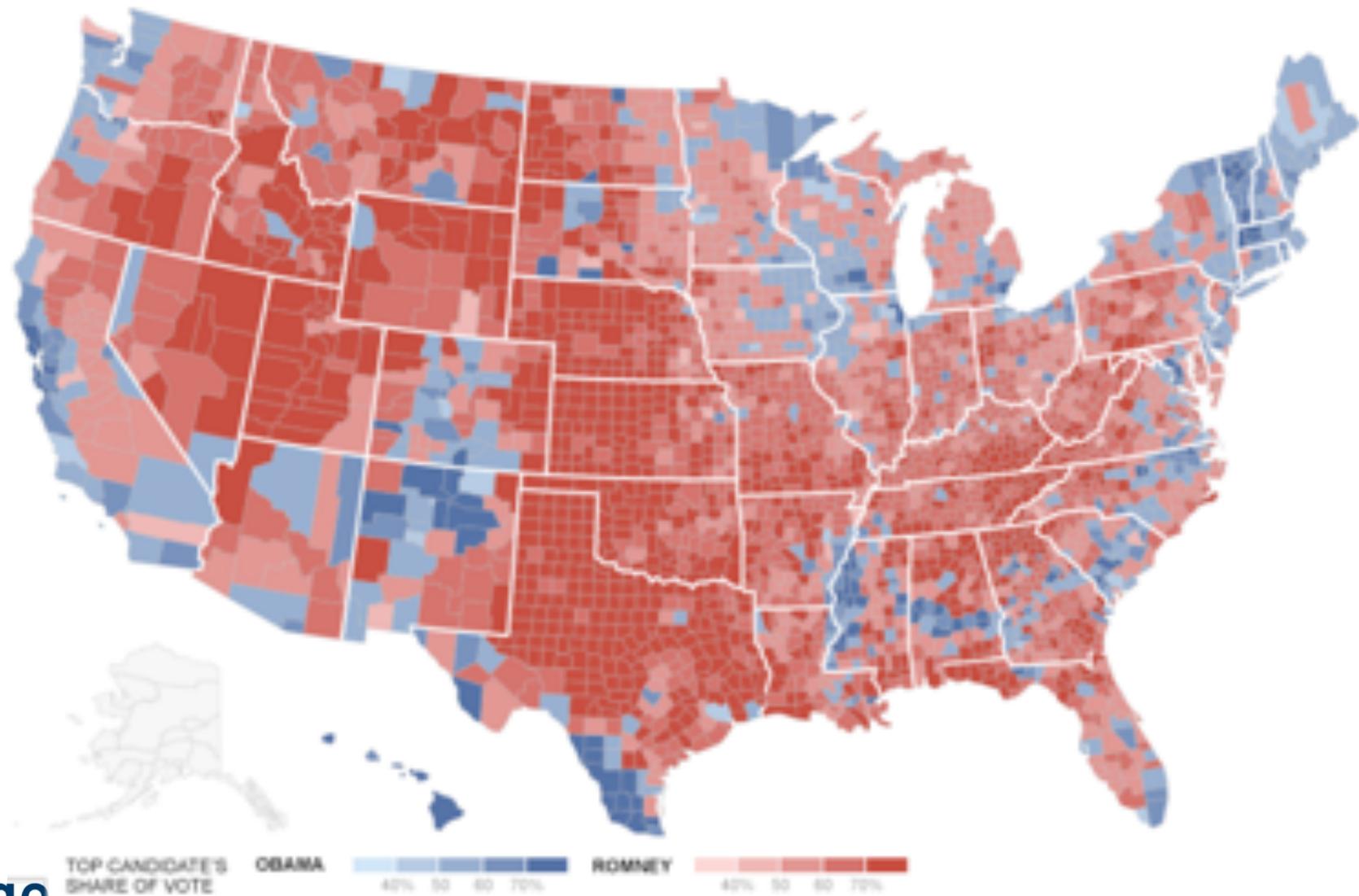


Crossing disciplines: Sedimentation and politics

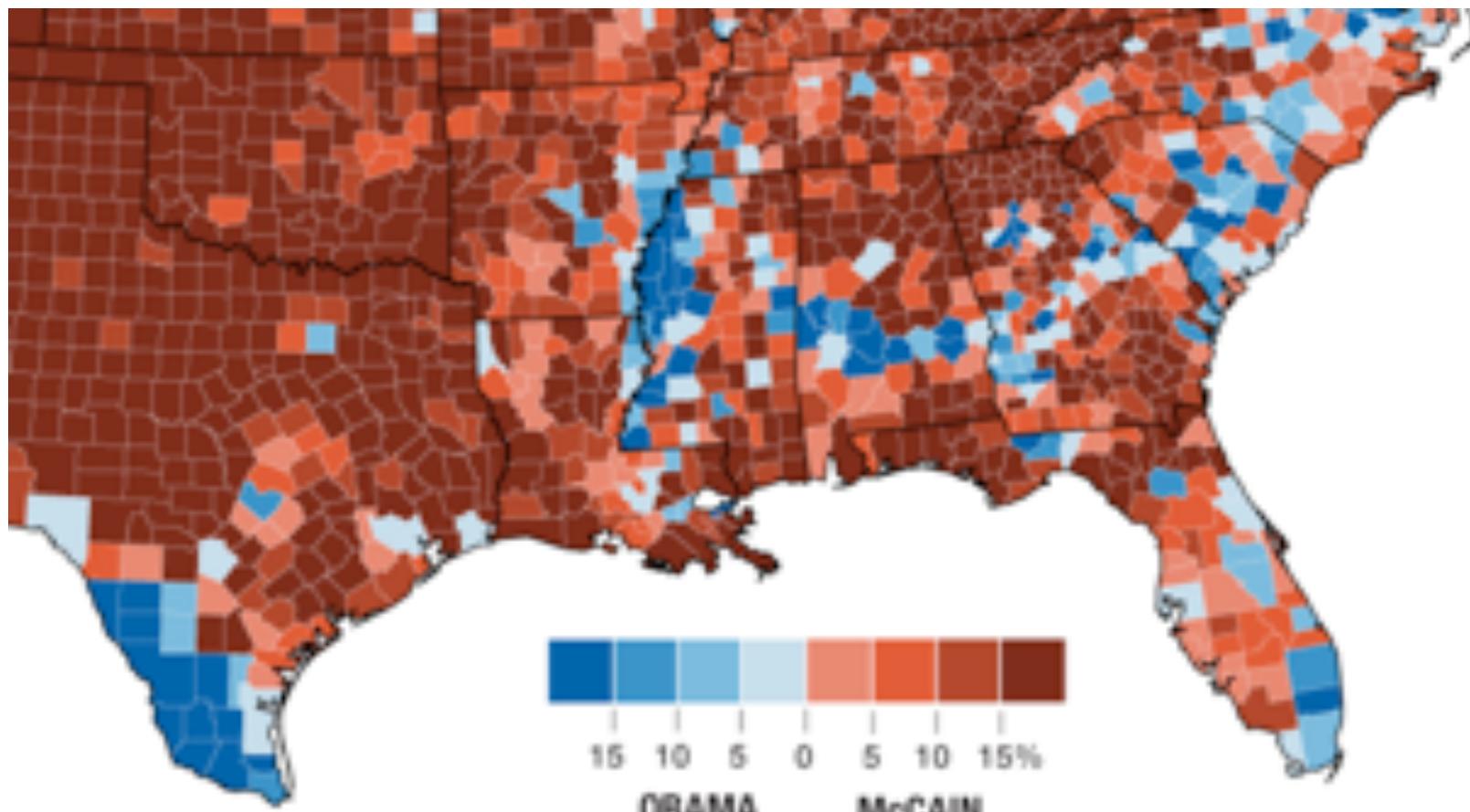


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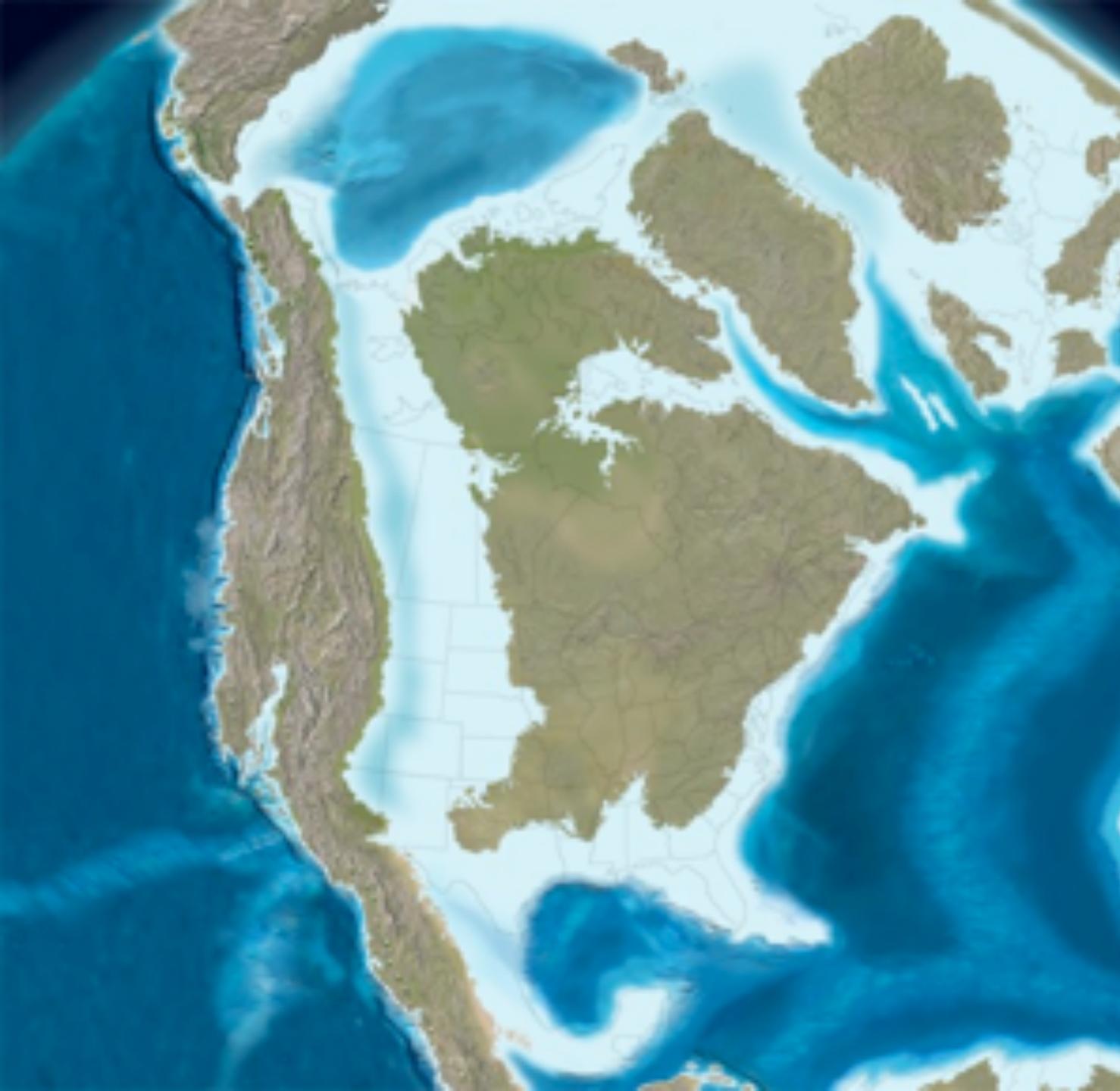
U.S. Election 2012



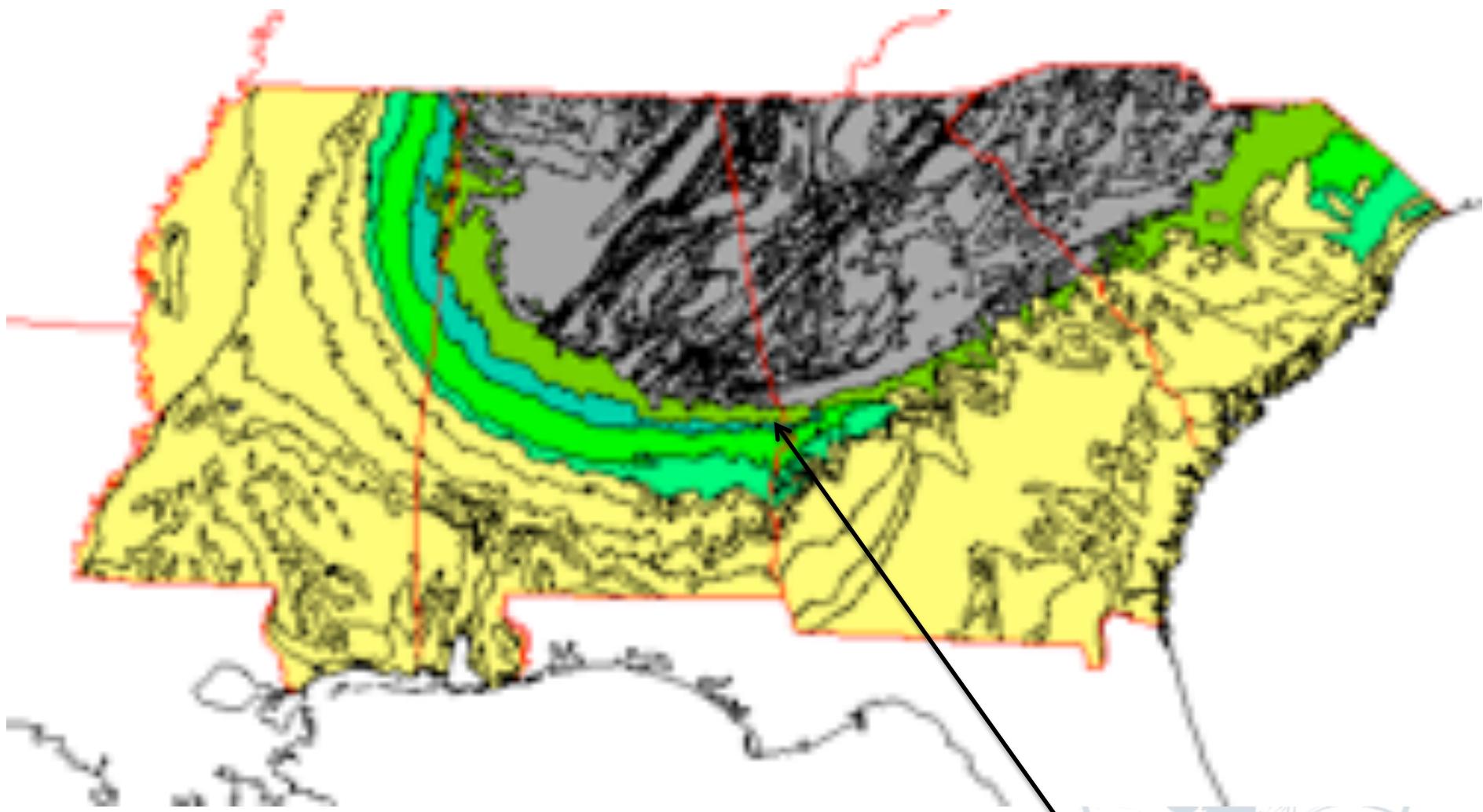
US Election 2008



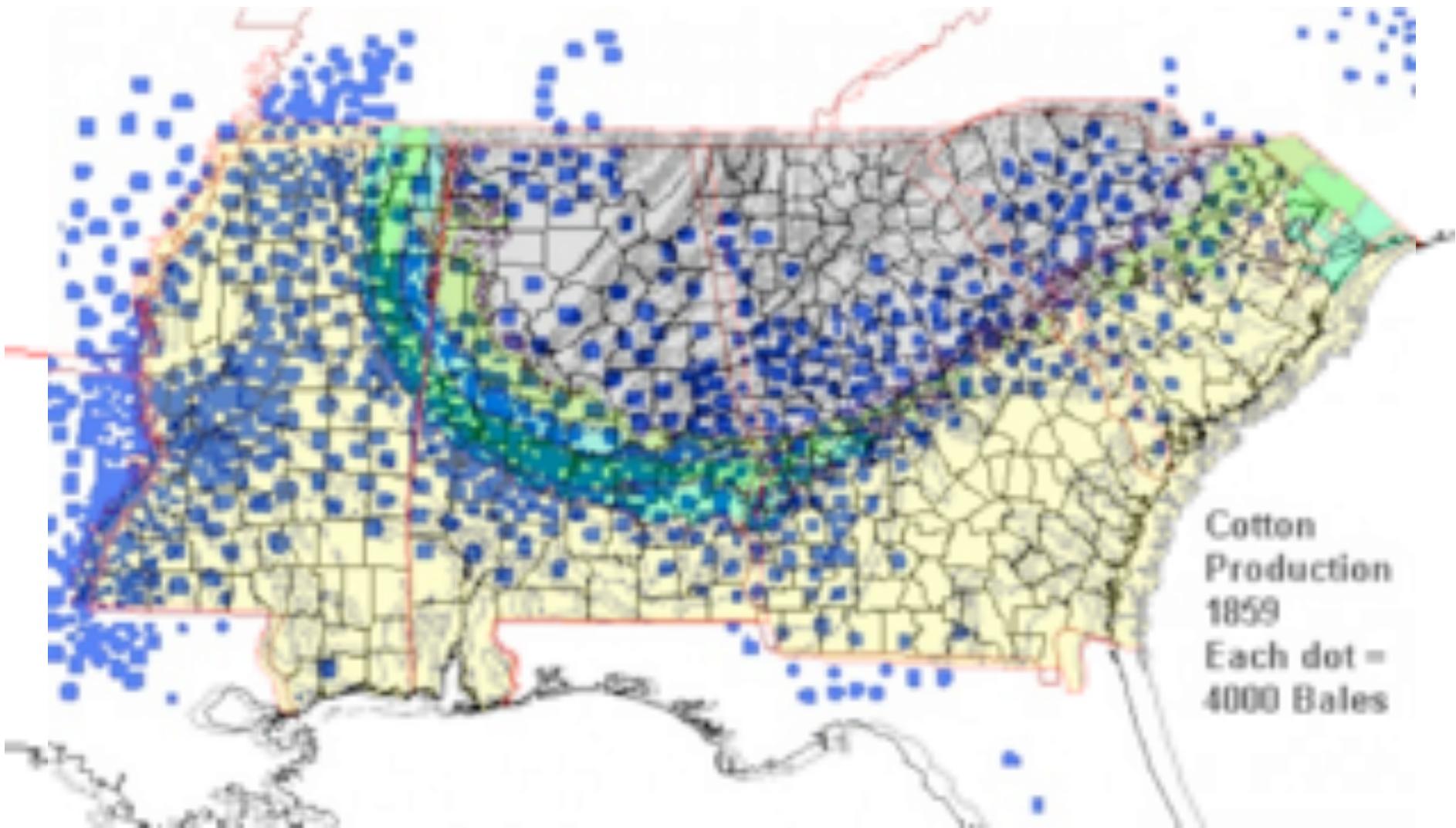
Late Cretaceous
85 mya



U.S. Election and ancient oceans



U.S. Election and ancient oceans



U.S. Election and ancient oceans

