Ocean Formation & Sea Floor

ES 383

Colby at Bigelow, September 2018

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Why do we have oceans?

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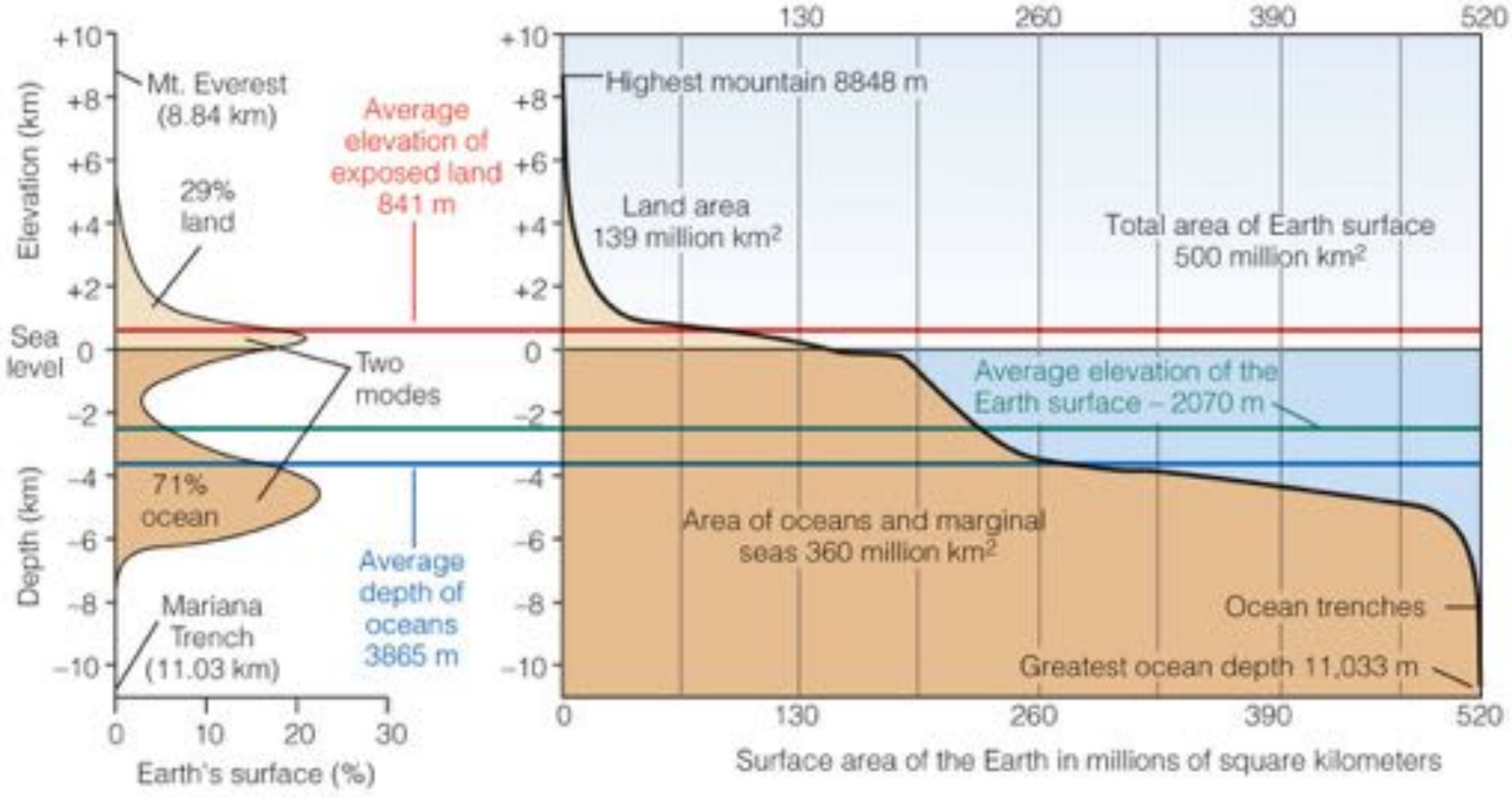
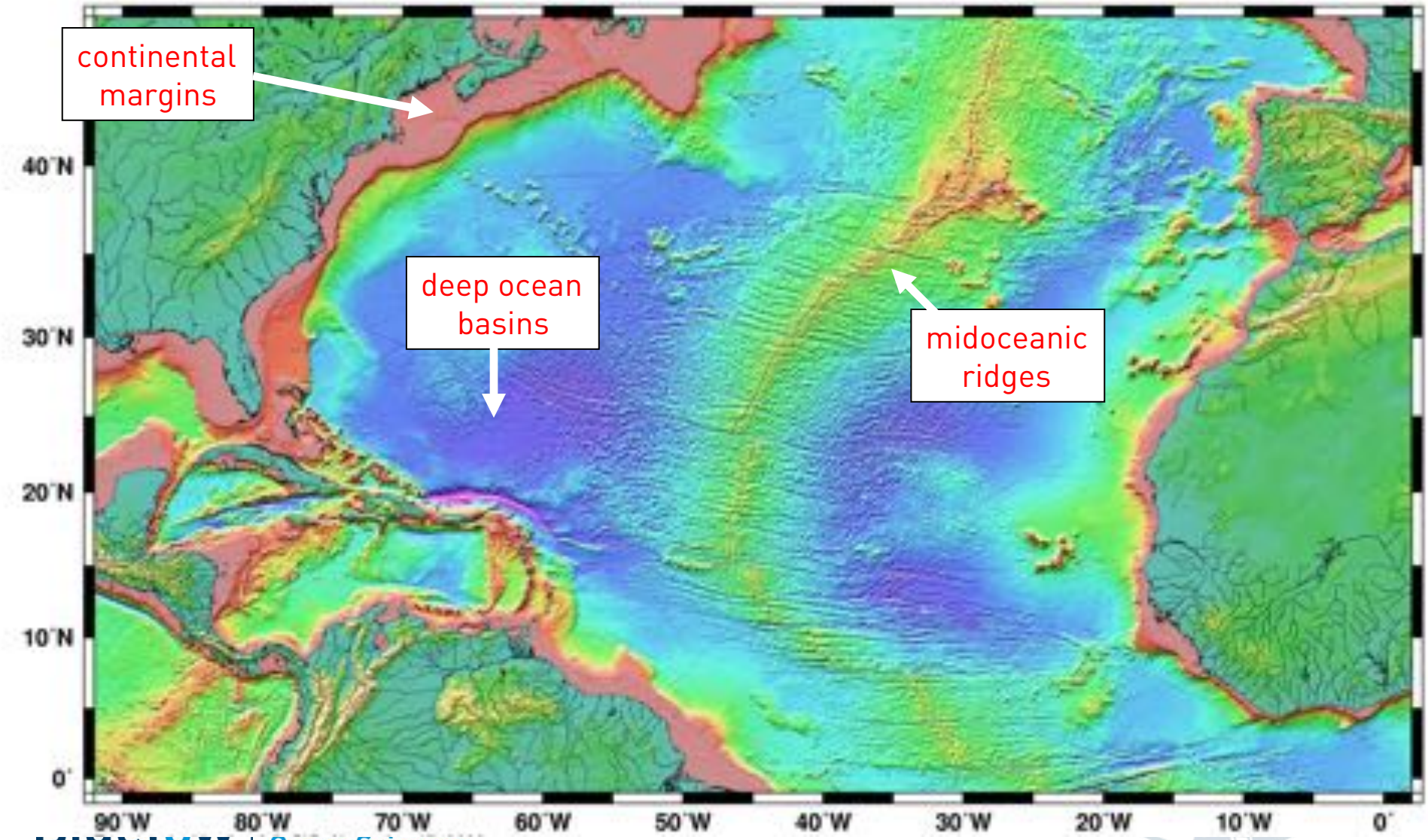
Why are there oceans and continents, and nothing in between?



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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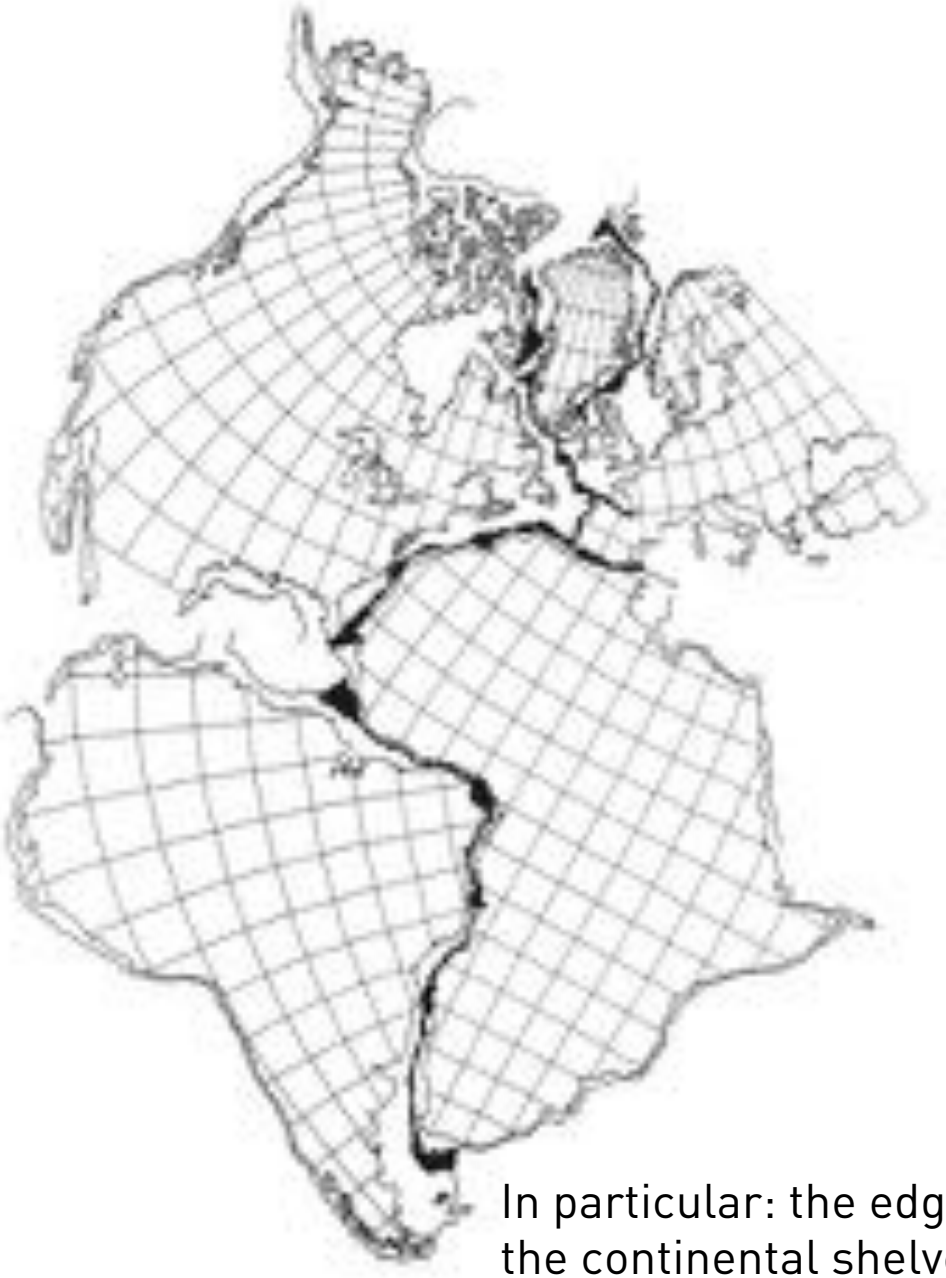
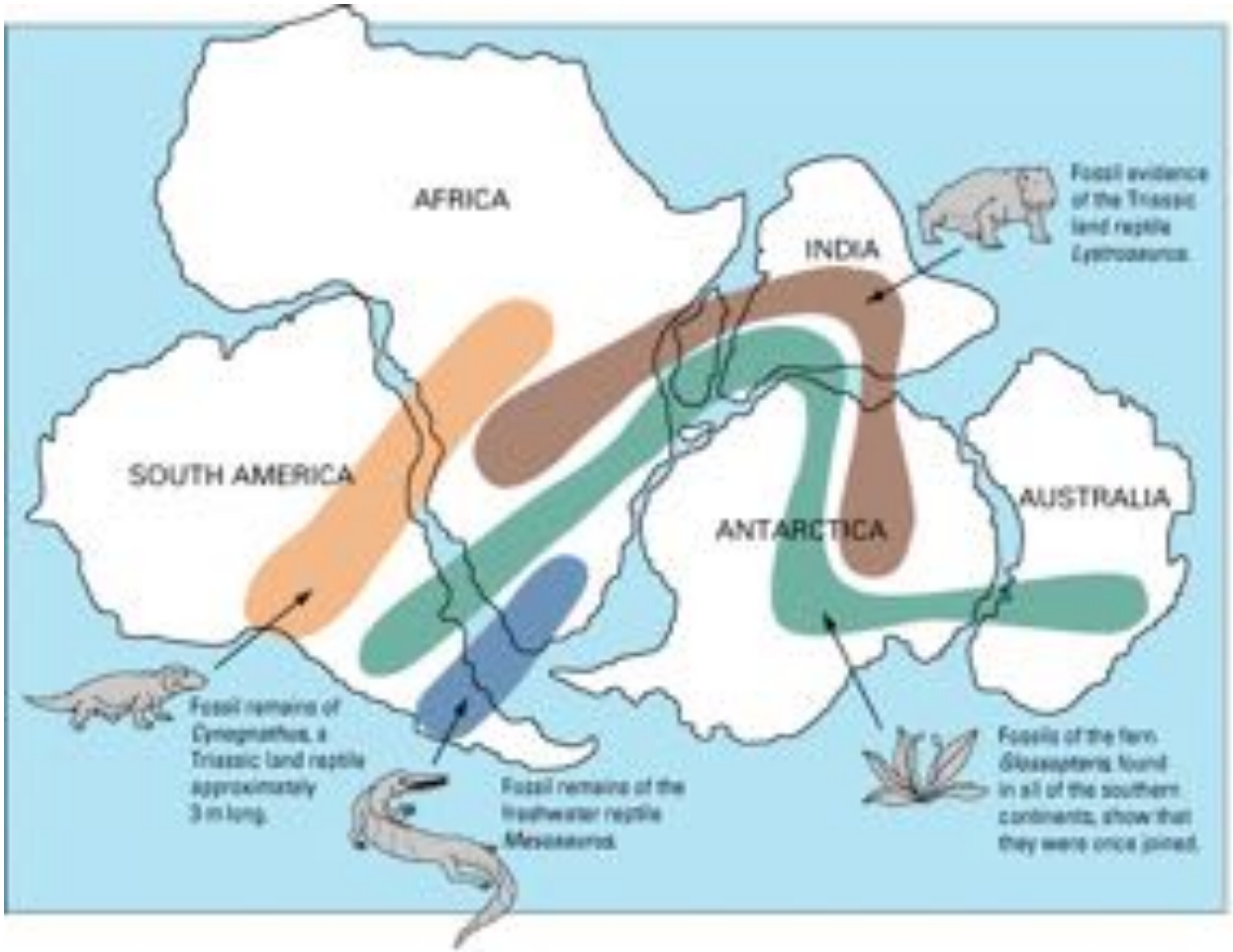


In particular: the edges of the continental shelves (not the coastlines)

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



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

Alfred Wegener → **Proposed continental drift (1912)**

-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

ory for
iences

How can continents "drift"?

Plate Tectonics

Unifying theory in geology

Explains:

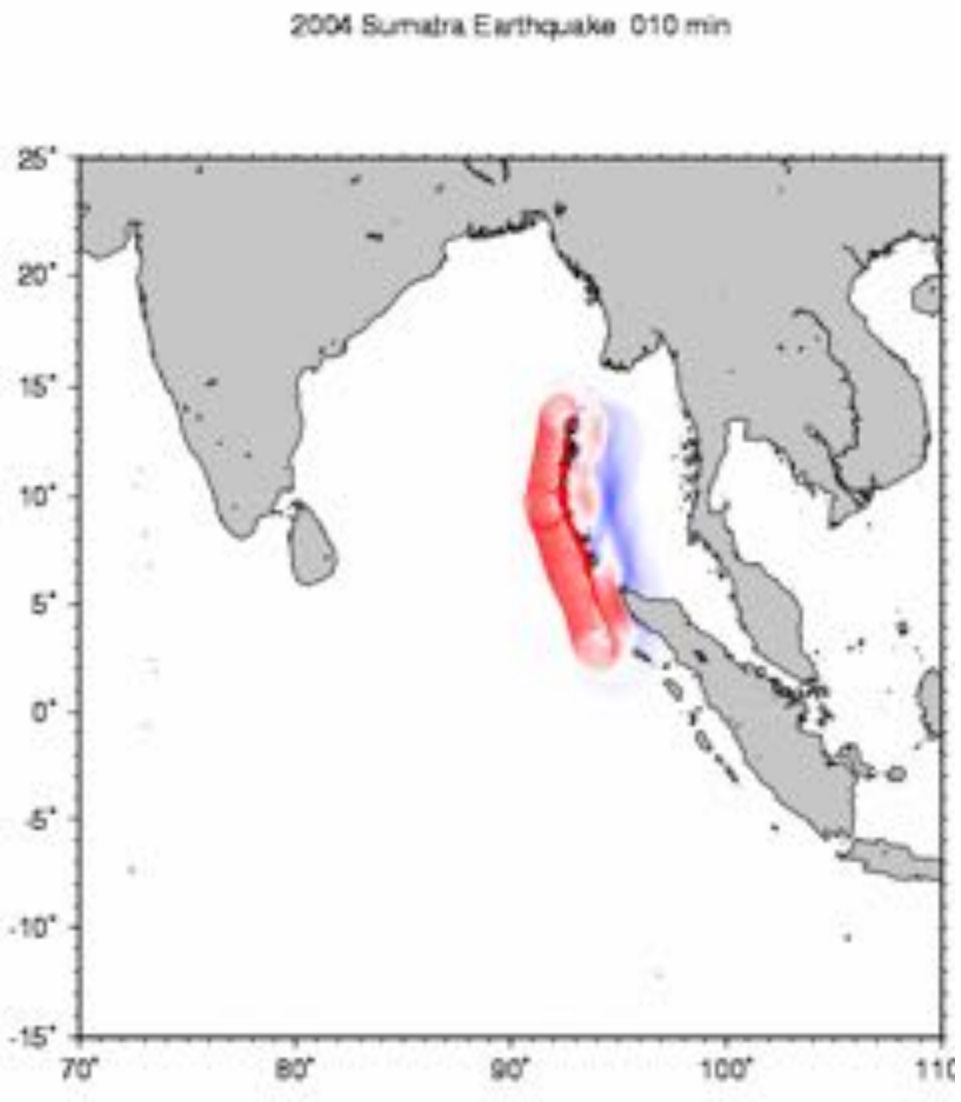
- Locations and shapes of the oceans
- Locations and characteristics of earthquakes and volcanoes
- The age and composition of the sea floor
- The shape of the earth's surface

Theory has been accepted for ~ 70 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



Courtesy: K. Satake, unpublished

Sea level:

RISE

FALL

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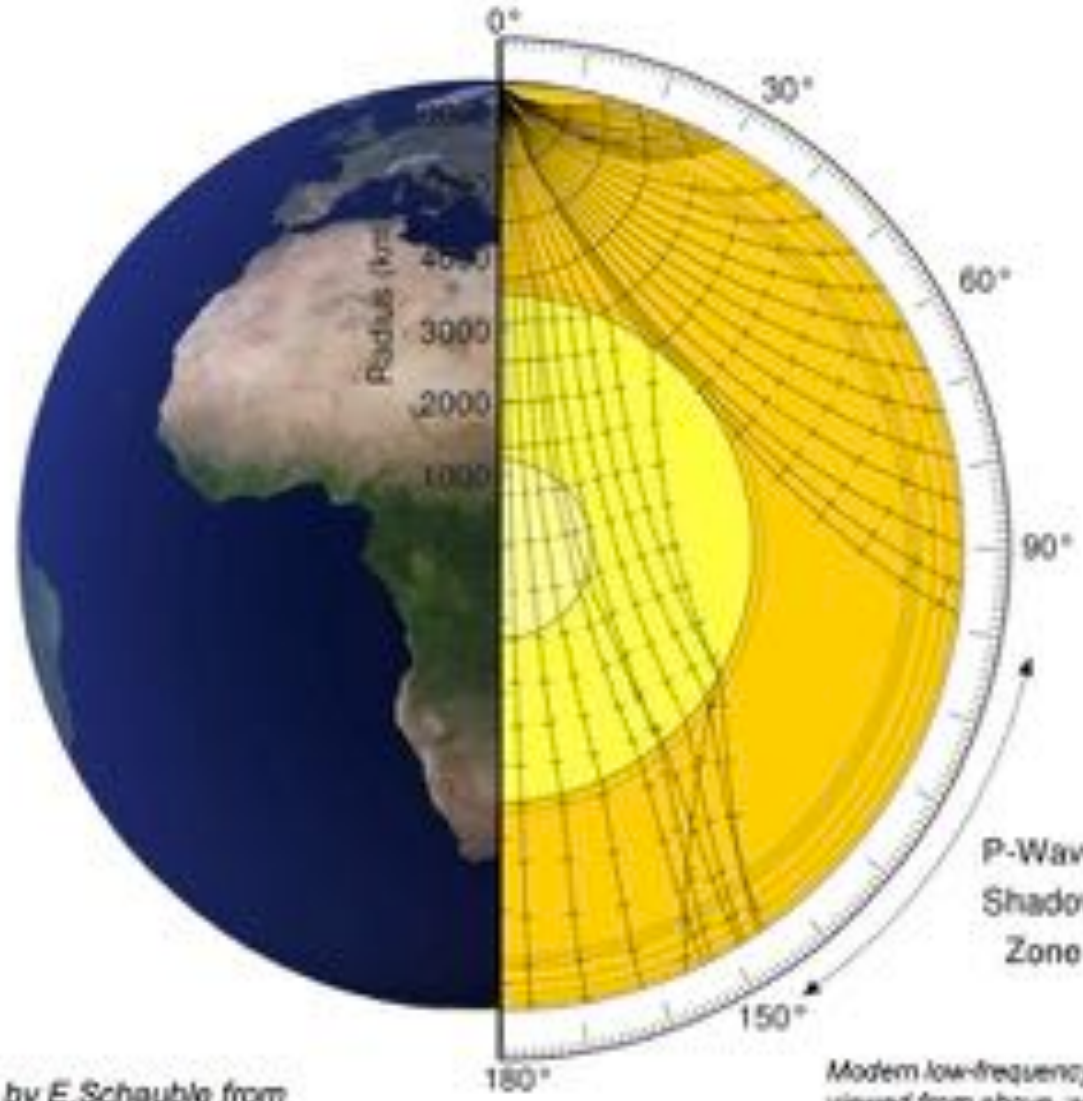
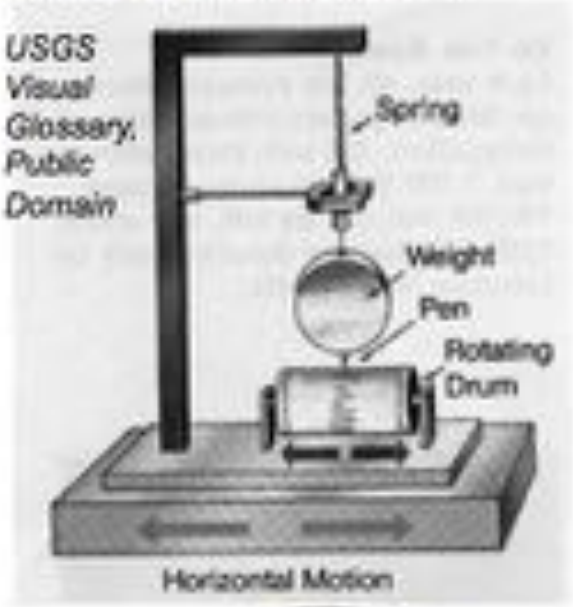
Earthquake waves are detected with a seismometer



Modified by E.Schauble from NASA, Wikimedia CC images



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

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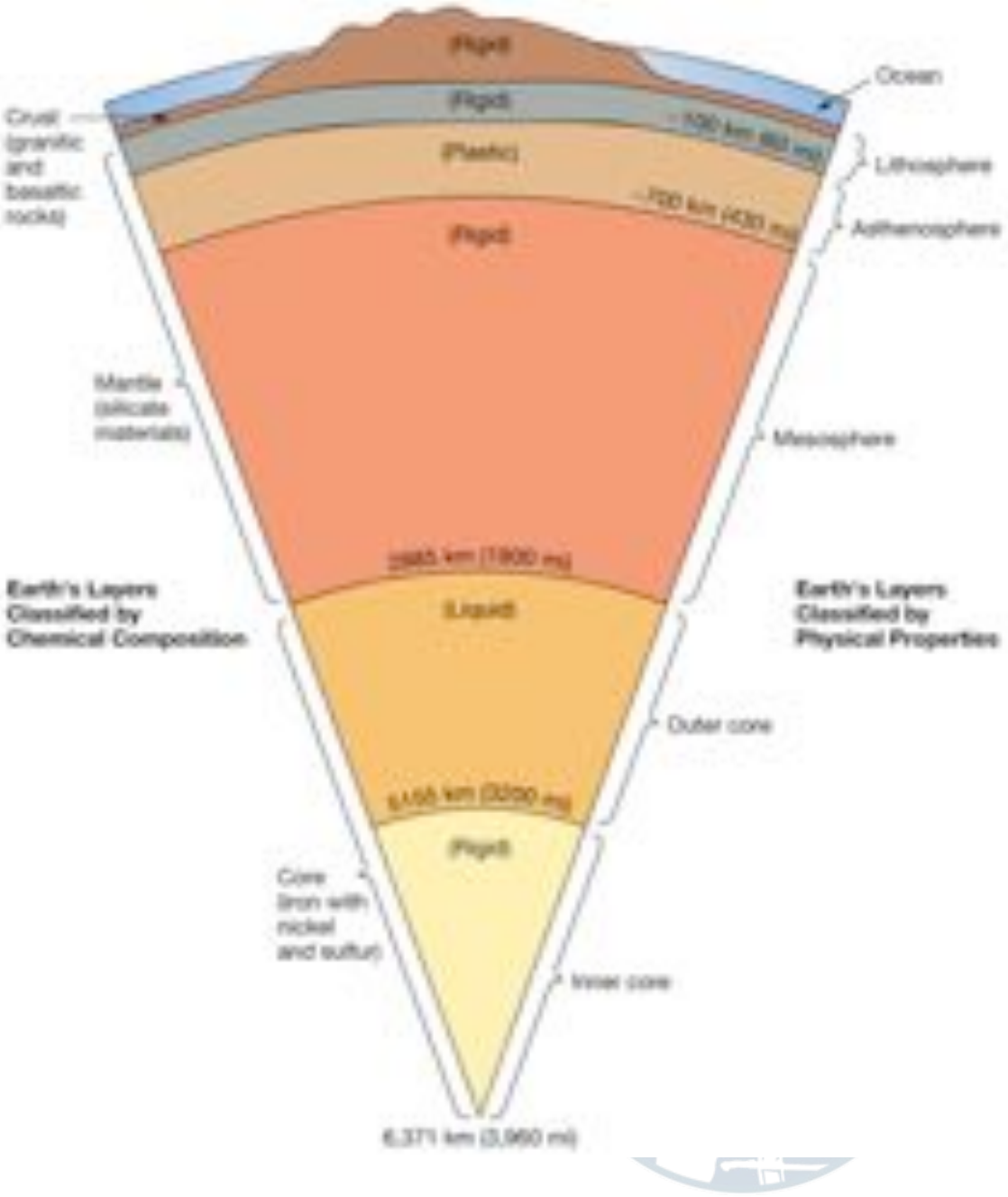
"SEISMAC"

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.

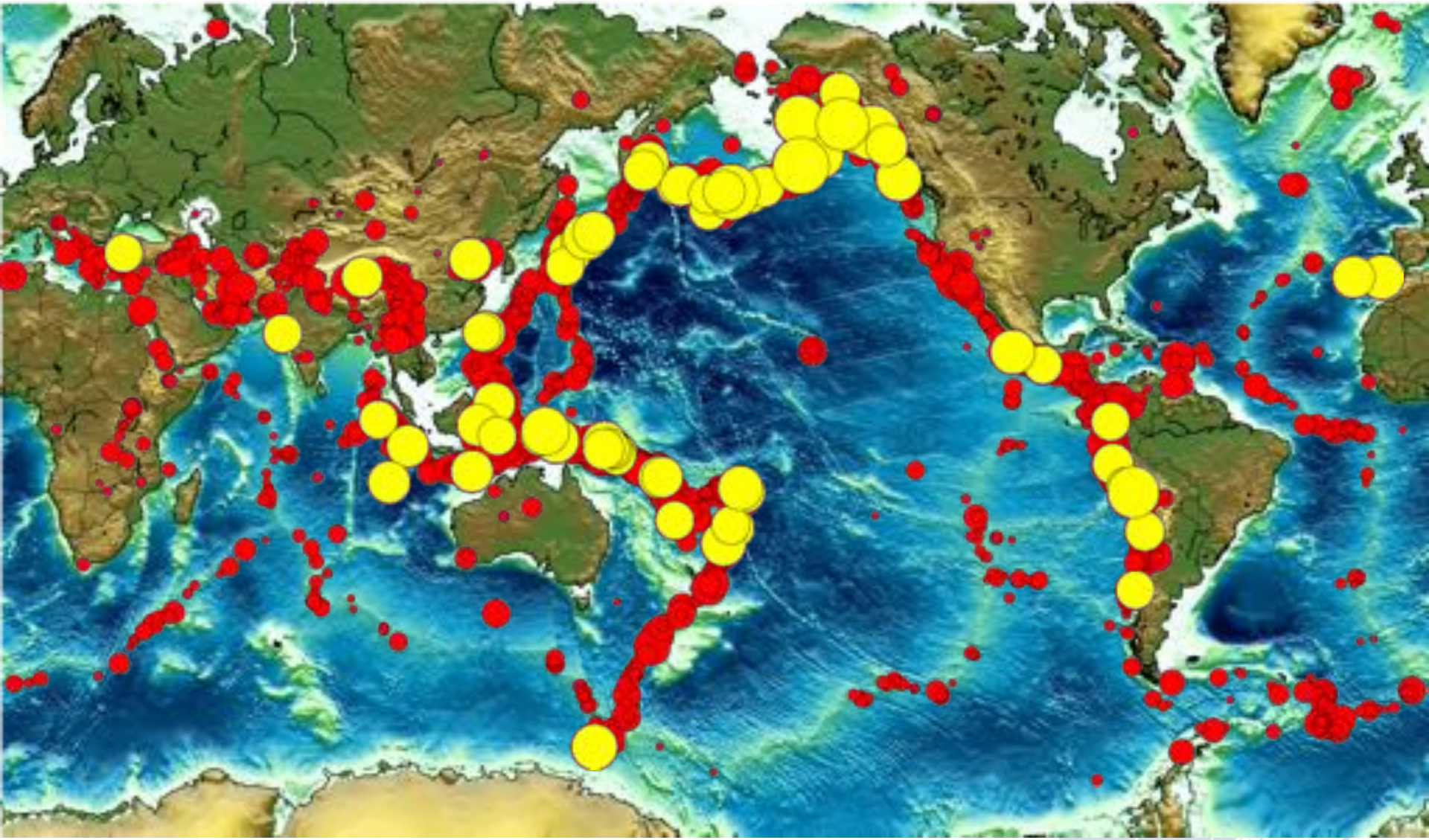
Note: rigid Lithosphere is only about 100 km thick (often much thinner)

~ skin on an apple



Slide credit: Emanuele Di Lorenzo, Georgia Tech

World Seismicity



Most "Great" earthquakes are subduction mega-thrust events

Many large earthquakes occur along subduction zones

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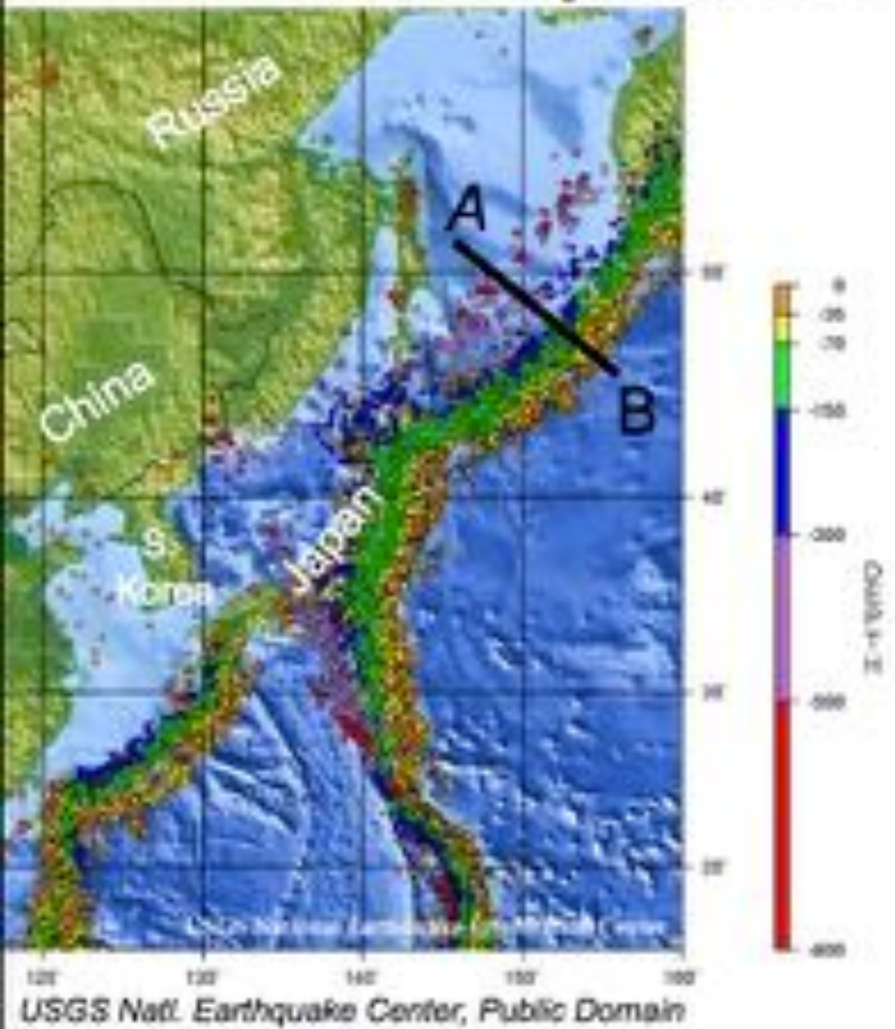
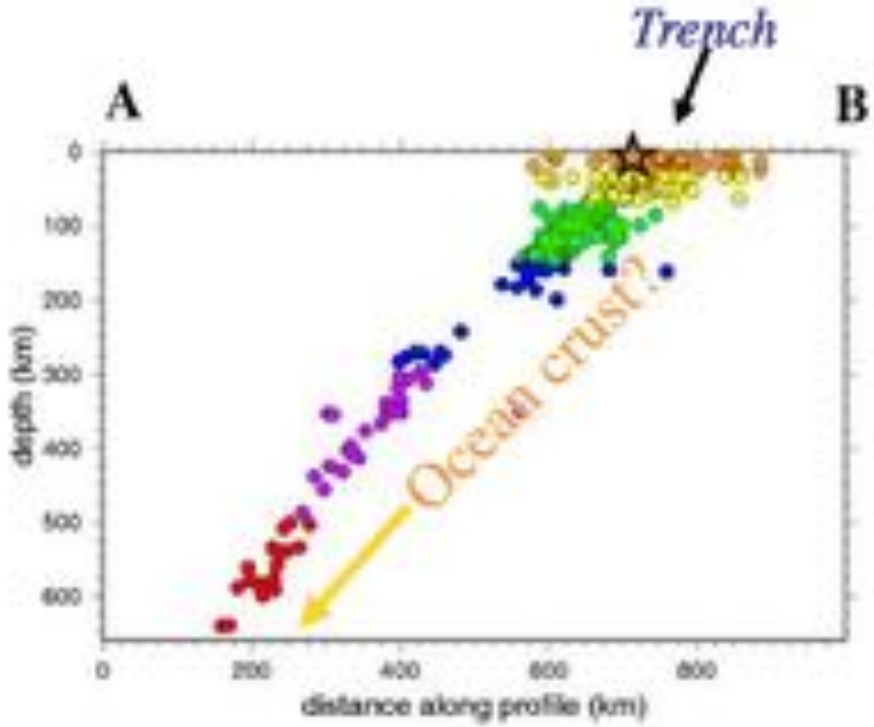
Slide credit: Emanuele Di Lorenzo, Georgia Tech

Earthquakes near Trenches



USGS Natl. Earthquake Center, Public Domain



USGS Natl. Earthquake Center, Public Domain

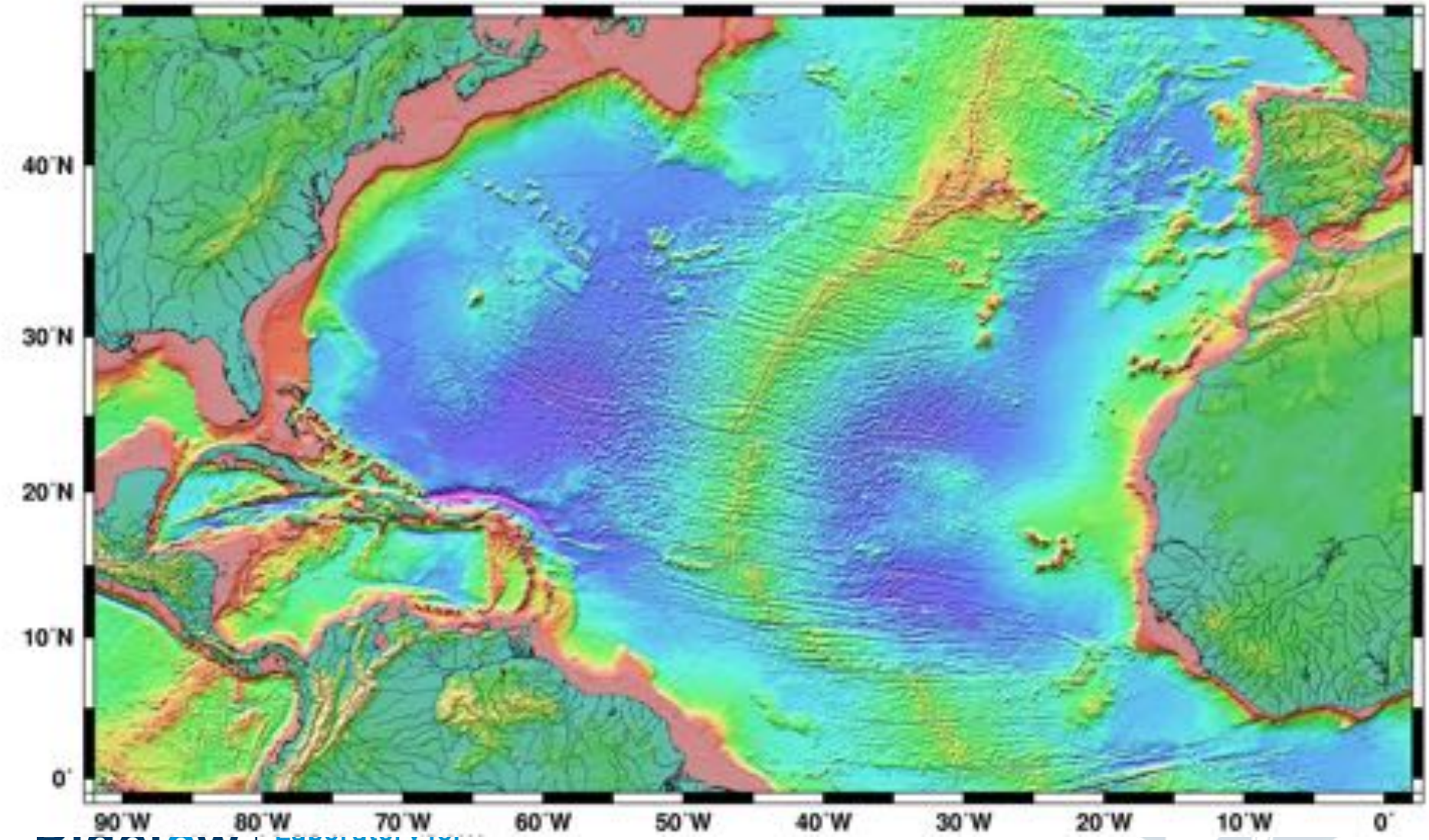
Star shows location of magnitude 8.3 Kurile Eq. 11/15/2006

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.

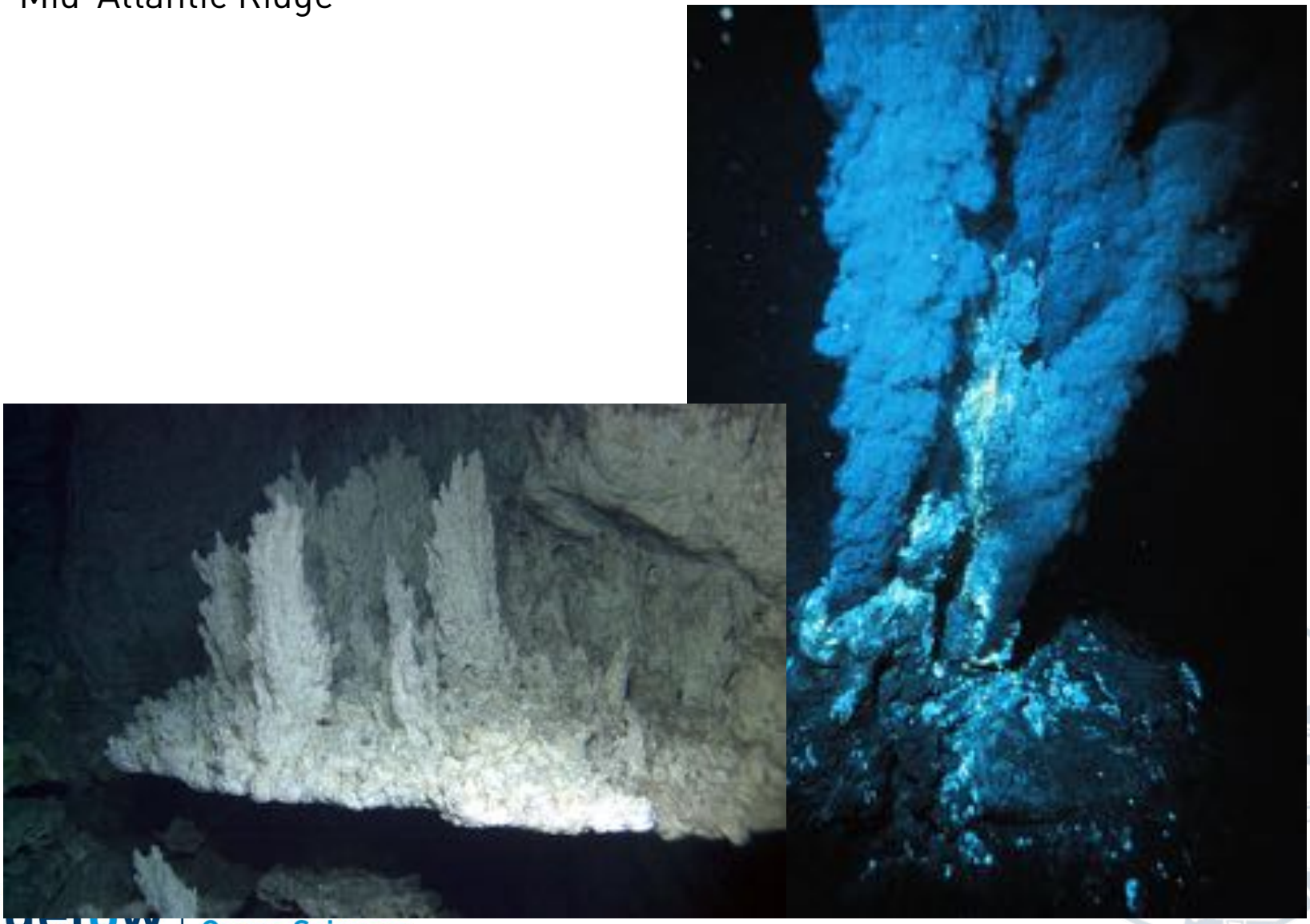
Slide credit: E. Schauble, UCLA

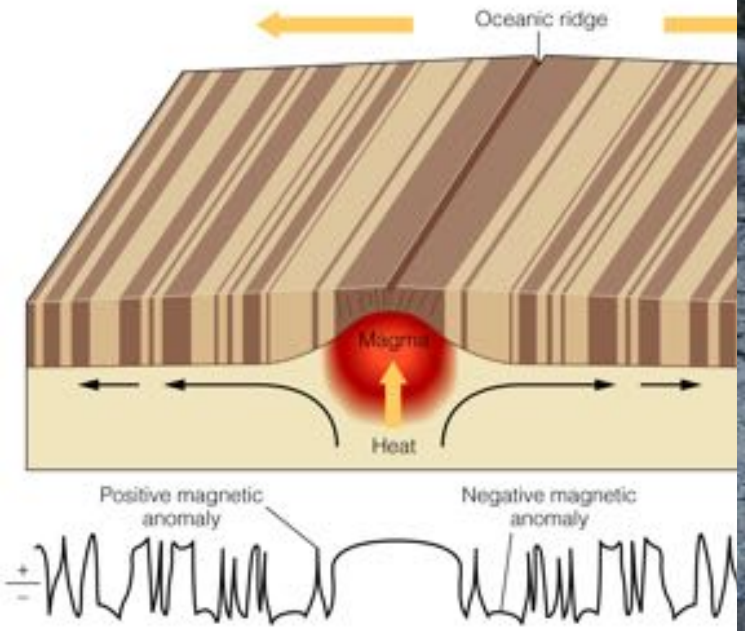
Evidence #2
Magnetic record

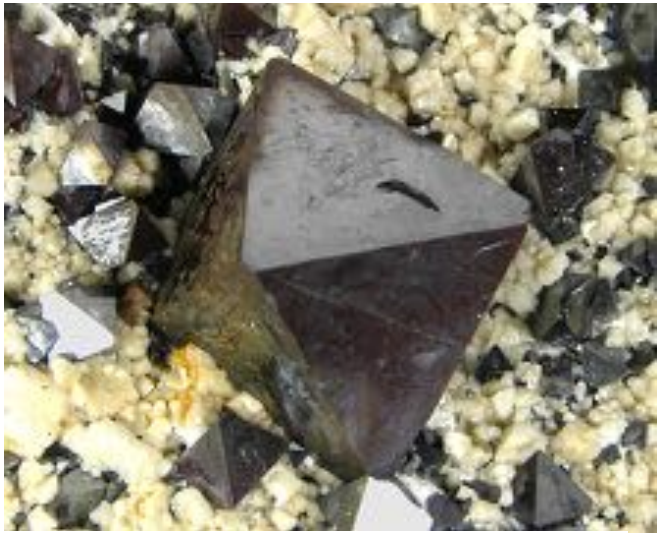
What's happening at the Mid-Atlantic Ridge?



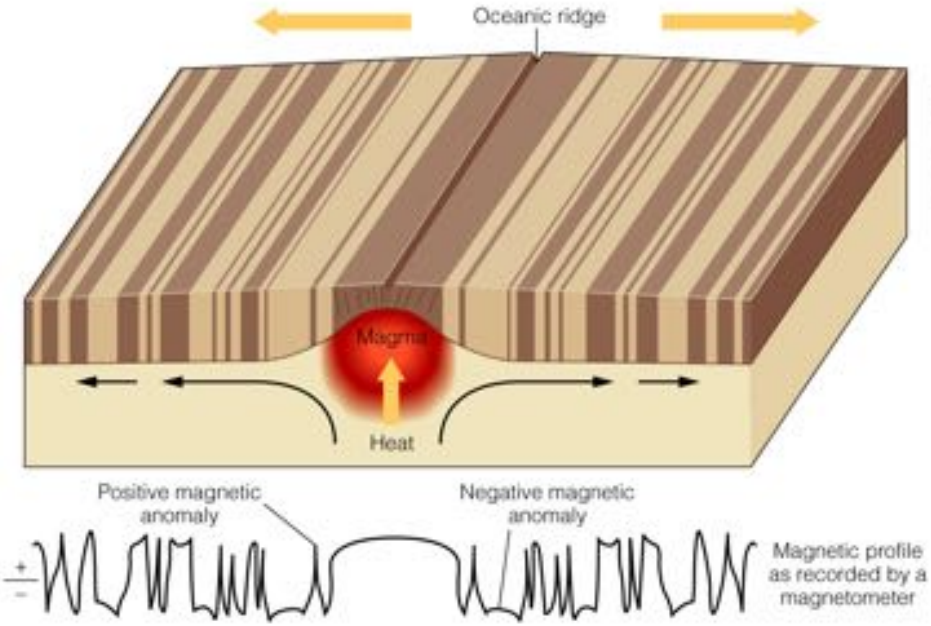
Mid-Atlantic Ridge

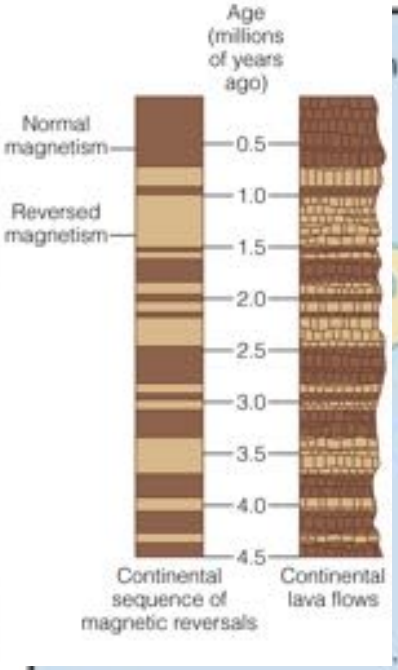


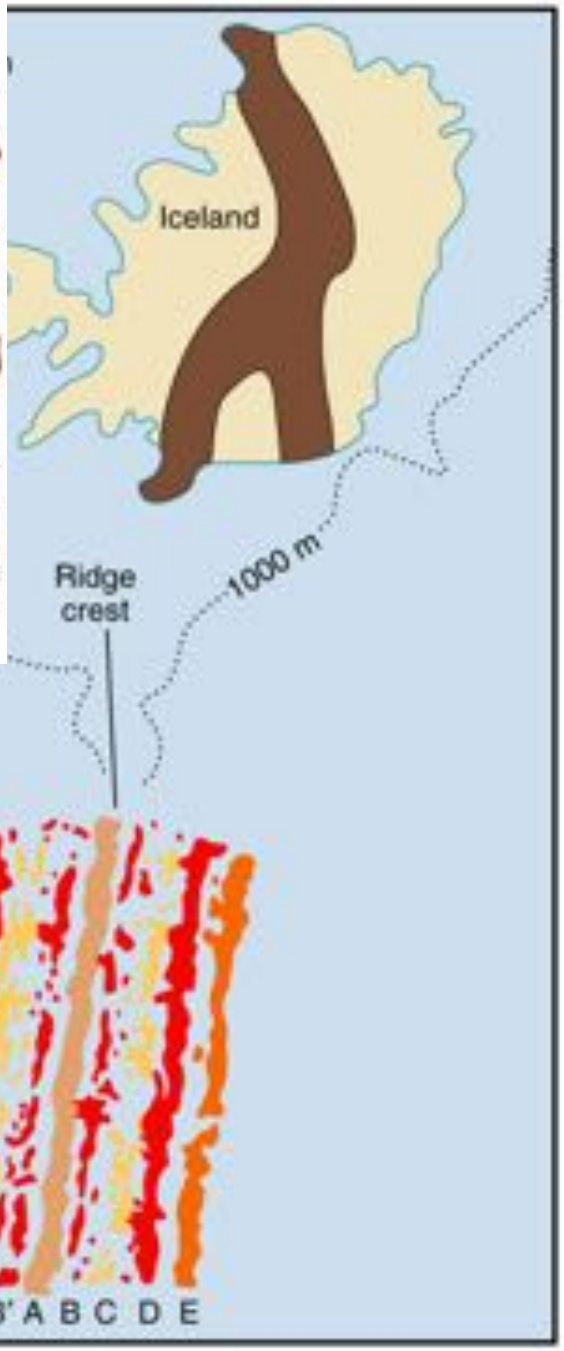


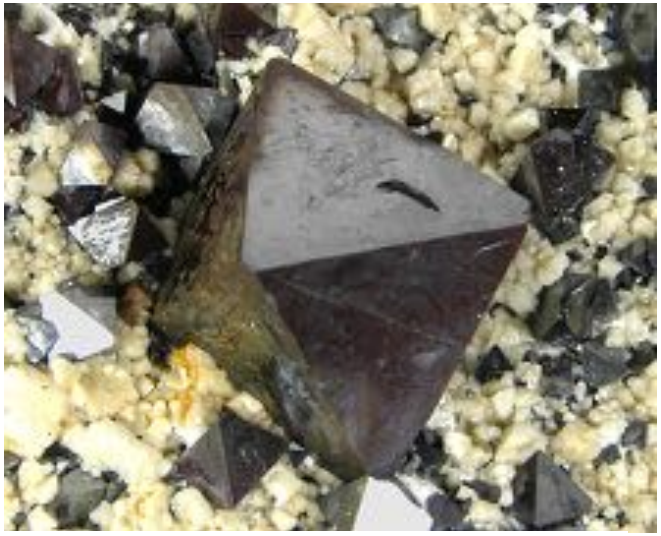


Magnetite Rob Lavinsky, iRocks.com









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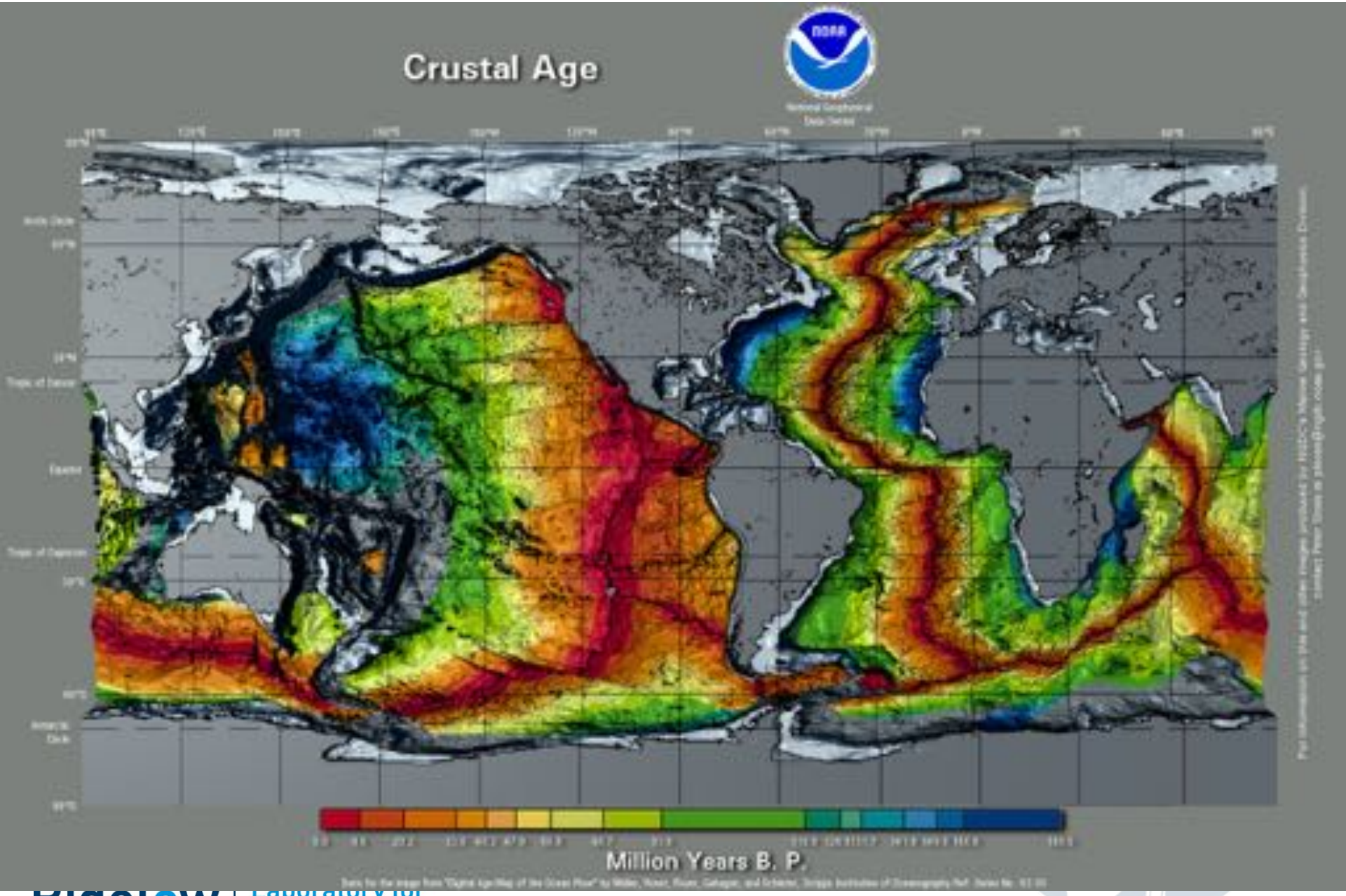

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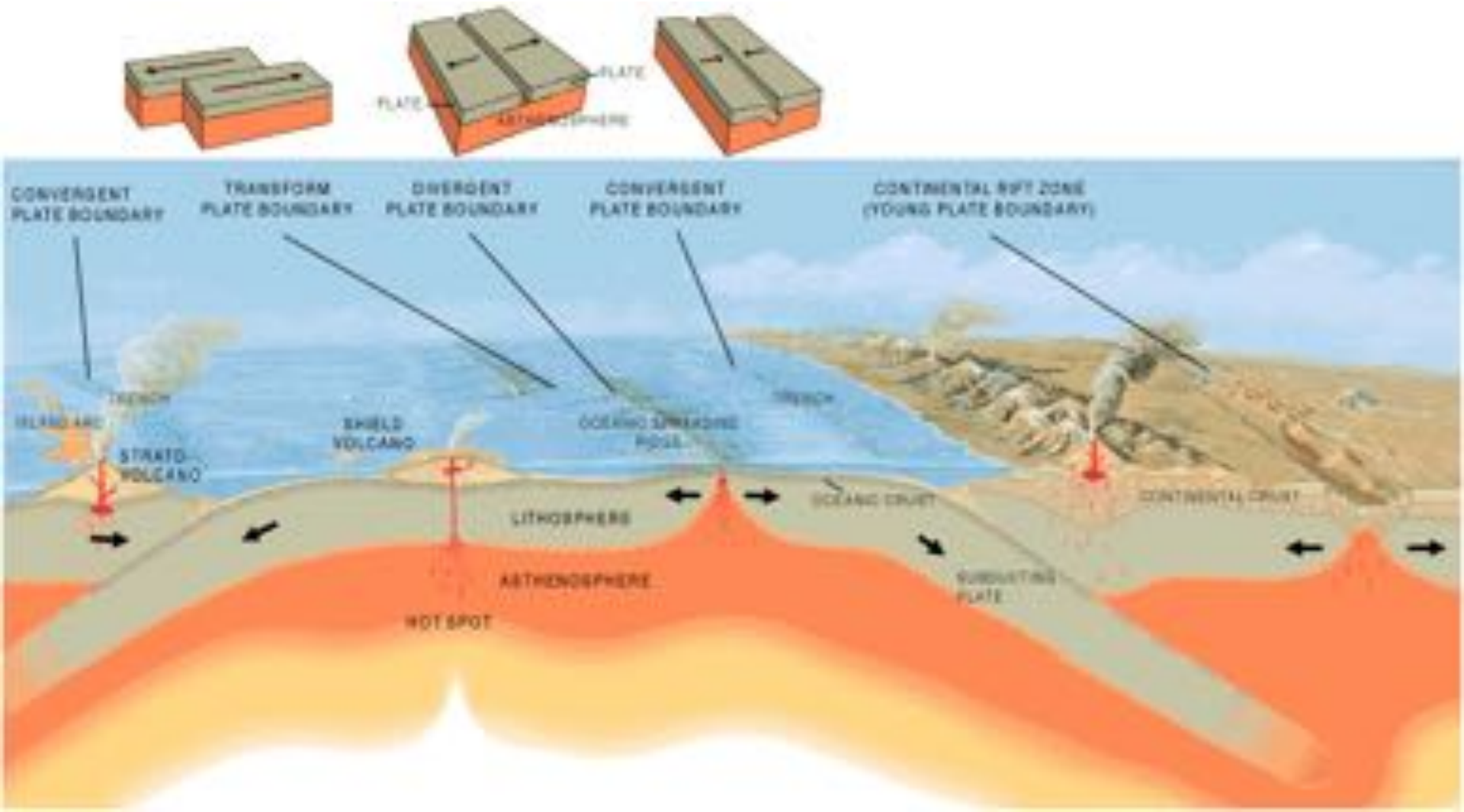
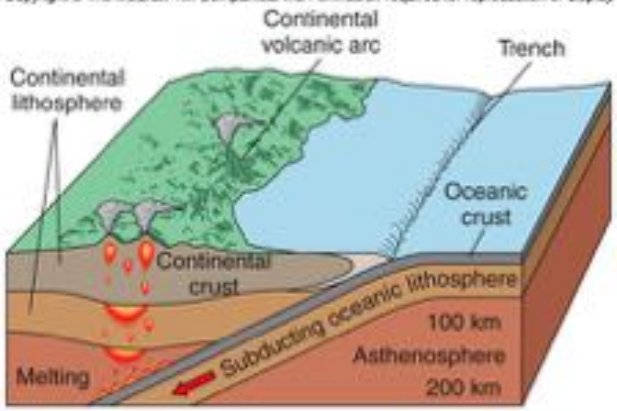
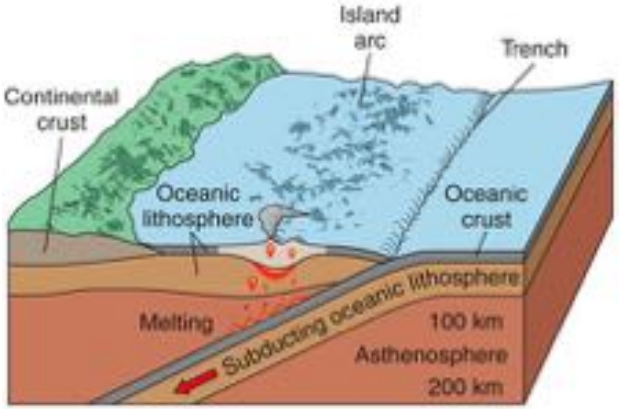
Three types of boundaries



CONVERGENT



(a)



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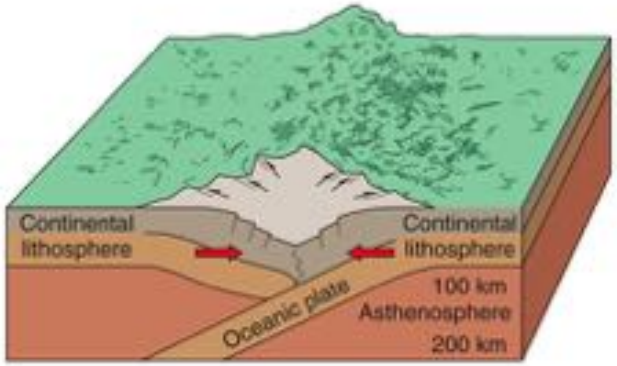
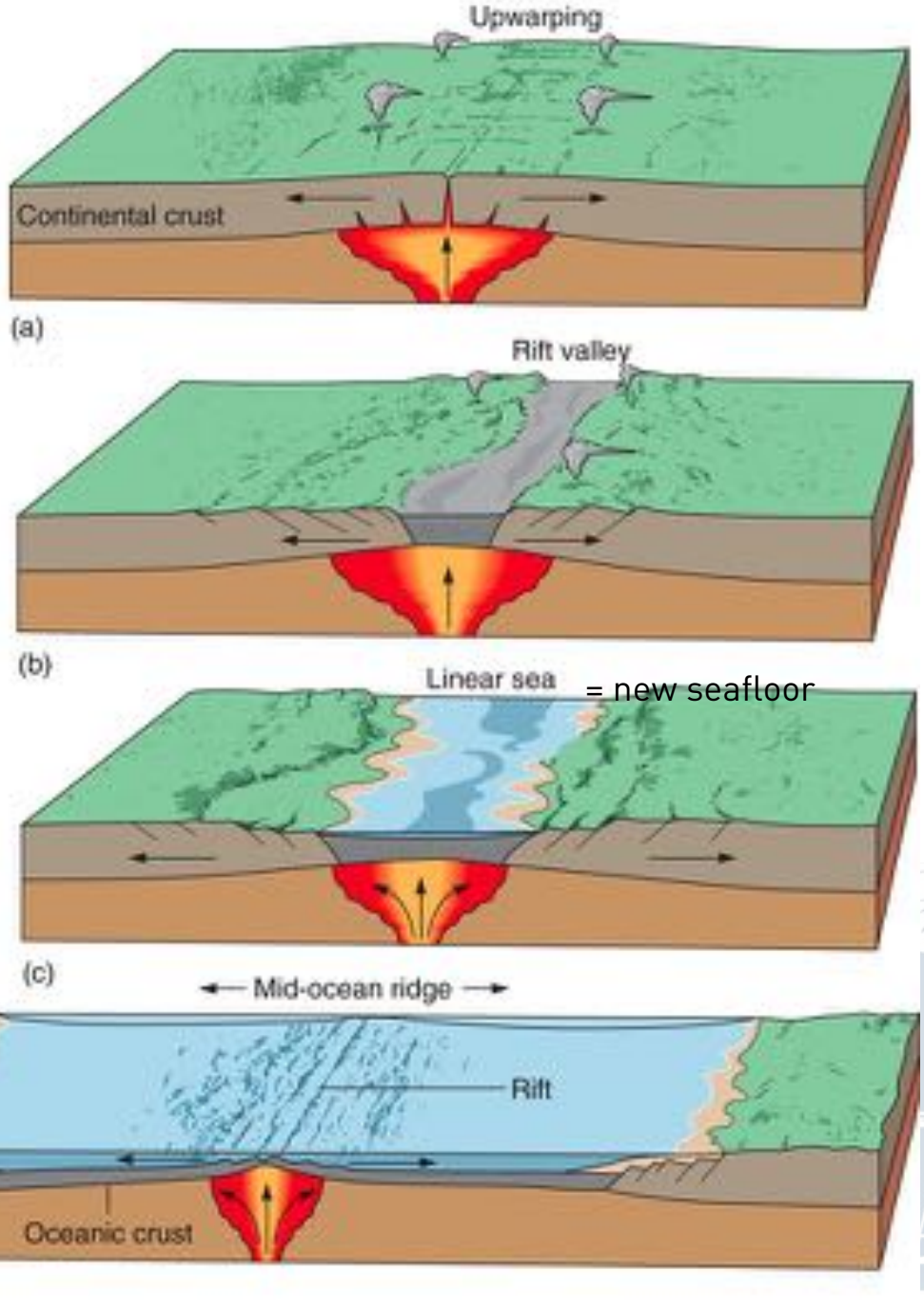


(c)

DIVERGENT

Continental rifting



today:

East African Rift Valley

Red Sea

Atlantic Ocean

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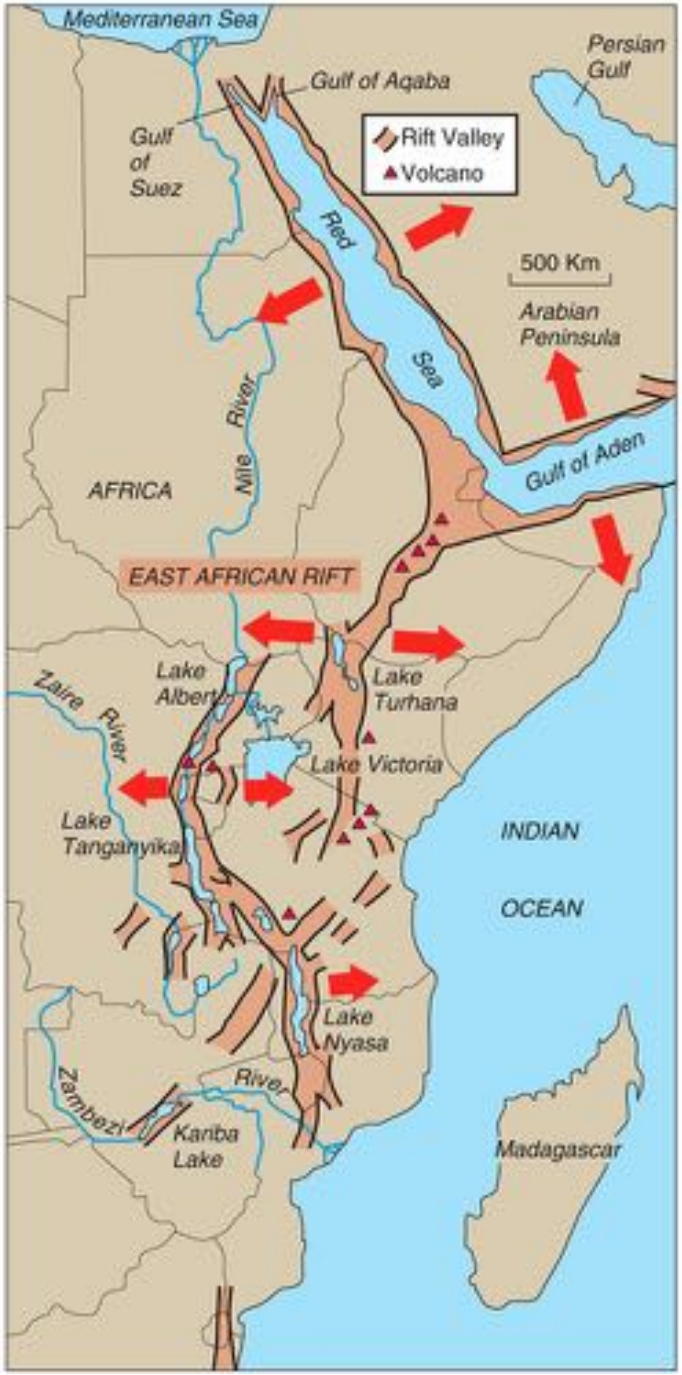
DIVERGENT



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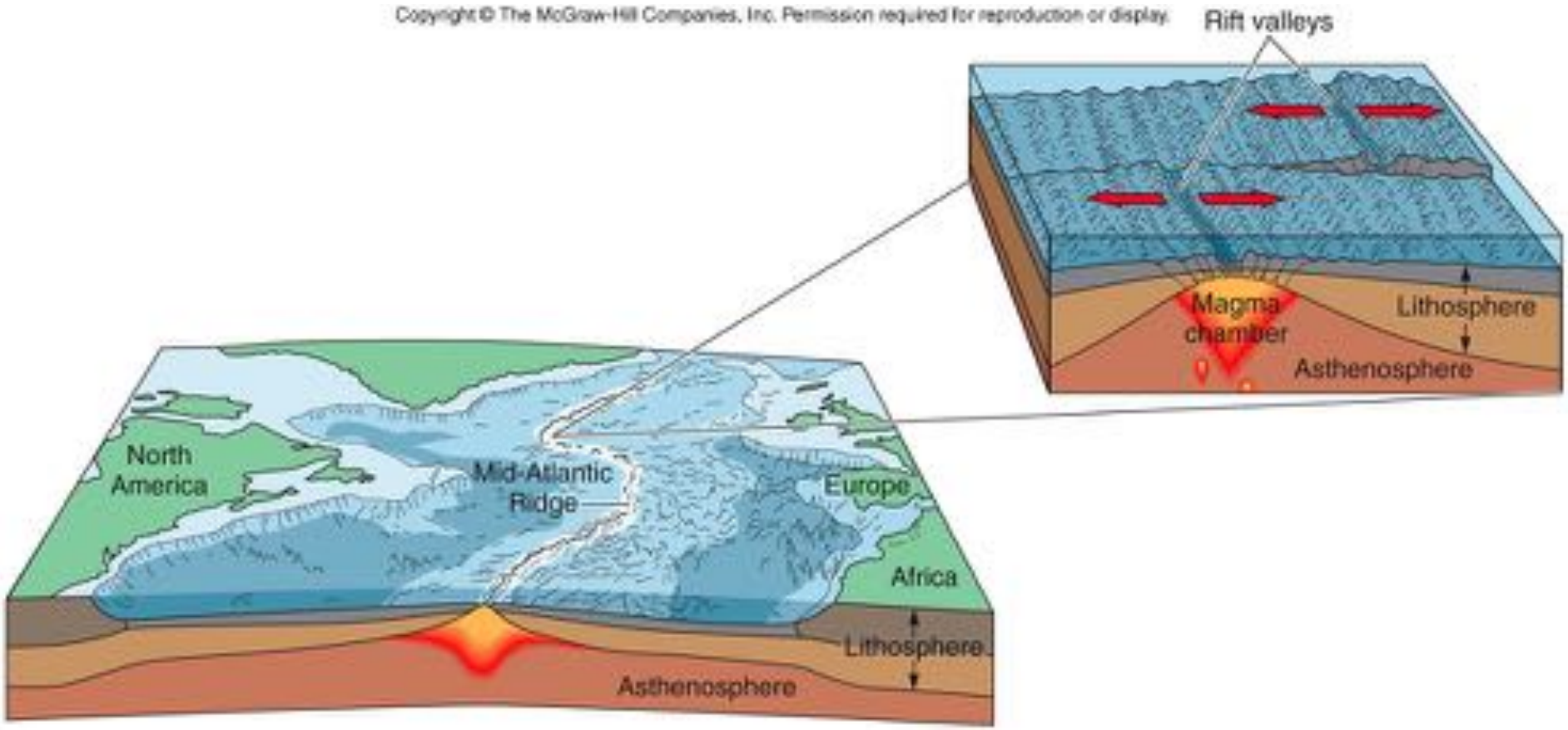
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Rift valleys
Magma chamber
Lithosphere
Asthenosphere
North America
Mid-Atlantic Ridge
Europe
Africa
Lithosphere
Asthenosphere

TRANSFORM / DIVERGENT

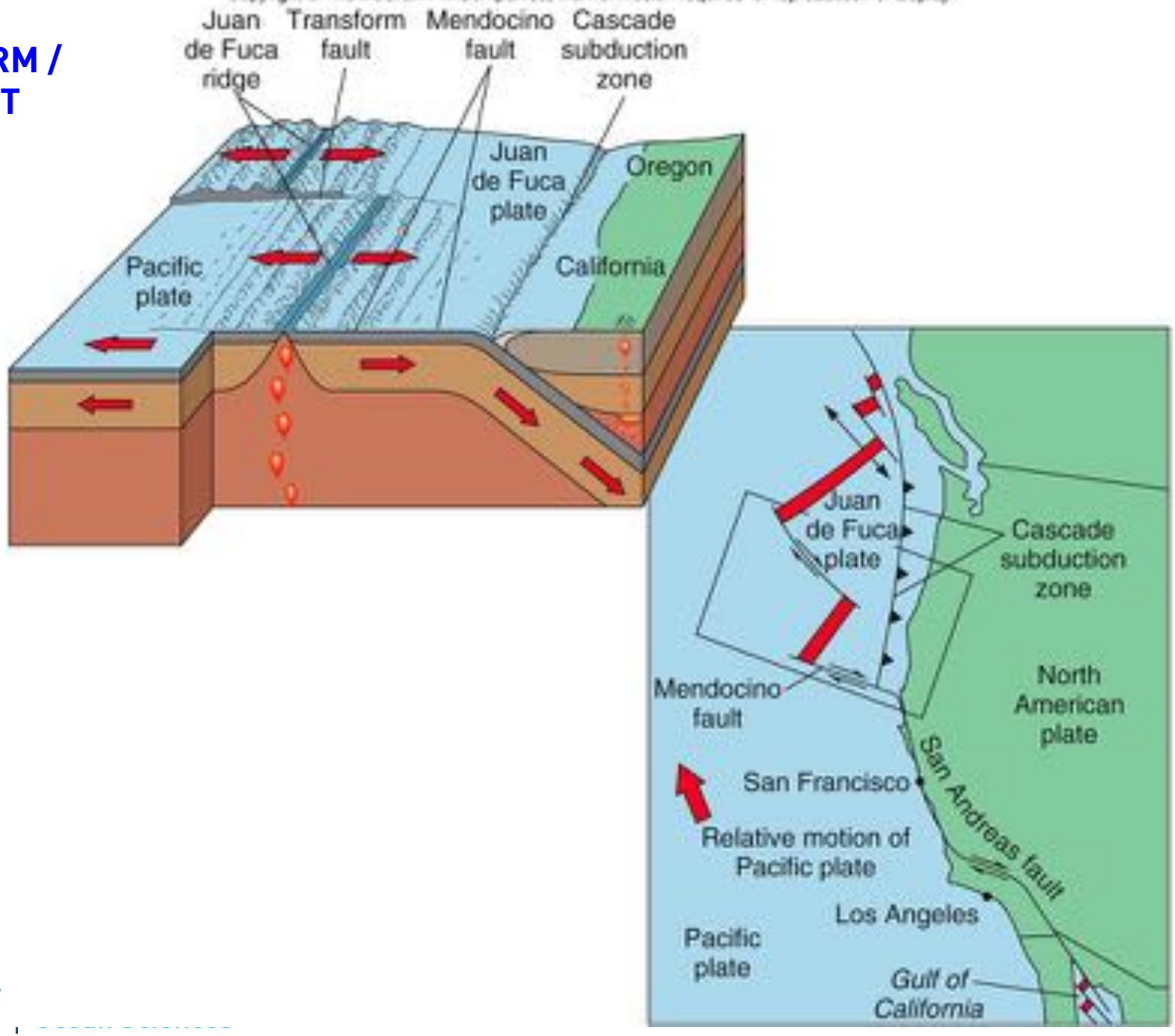
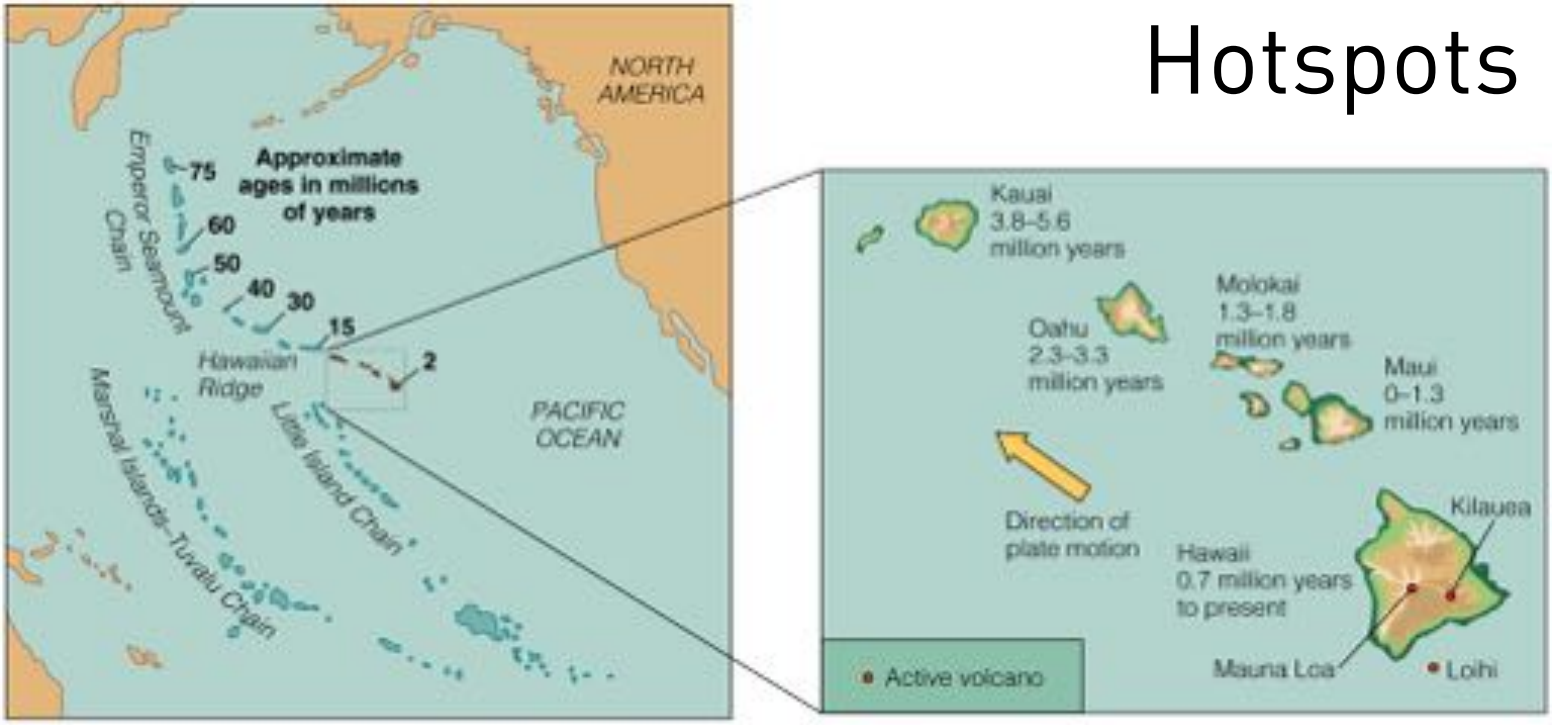


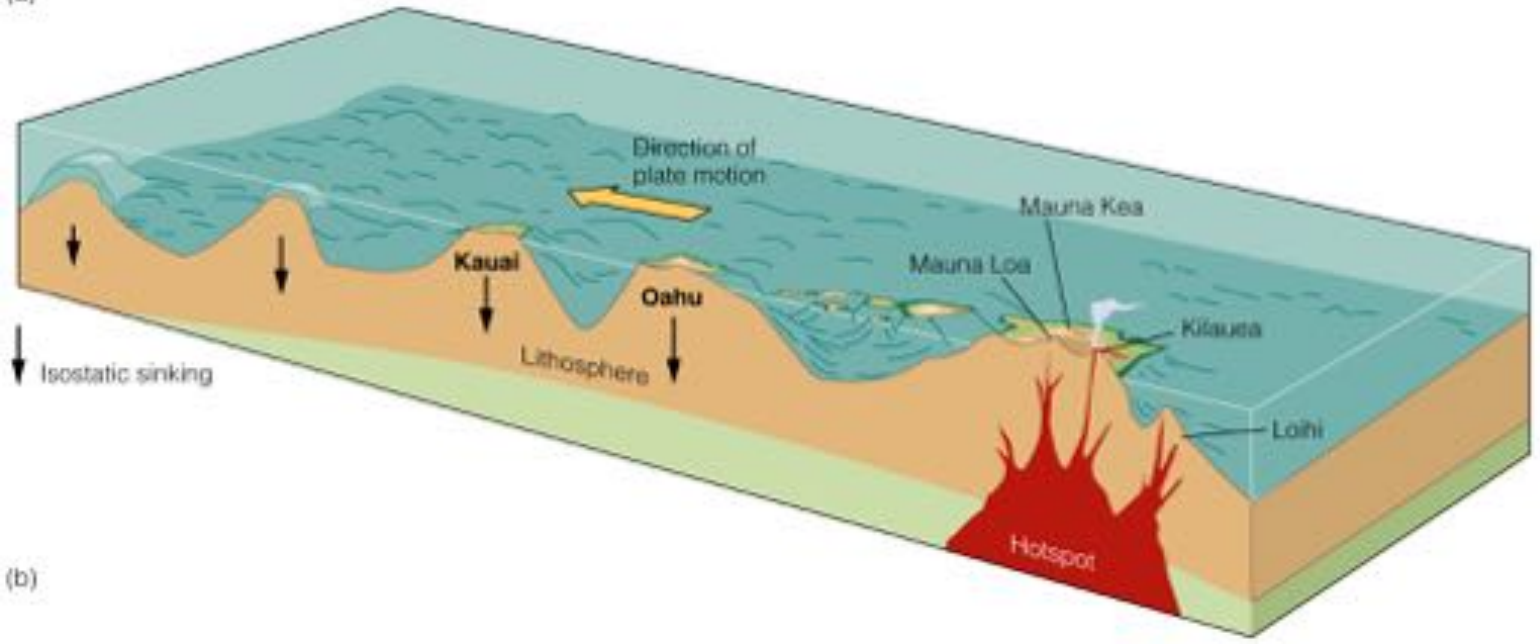
Table 3.4 Types and Characteristics of Plate Boundaries

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

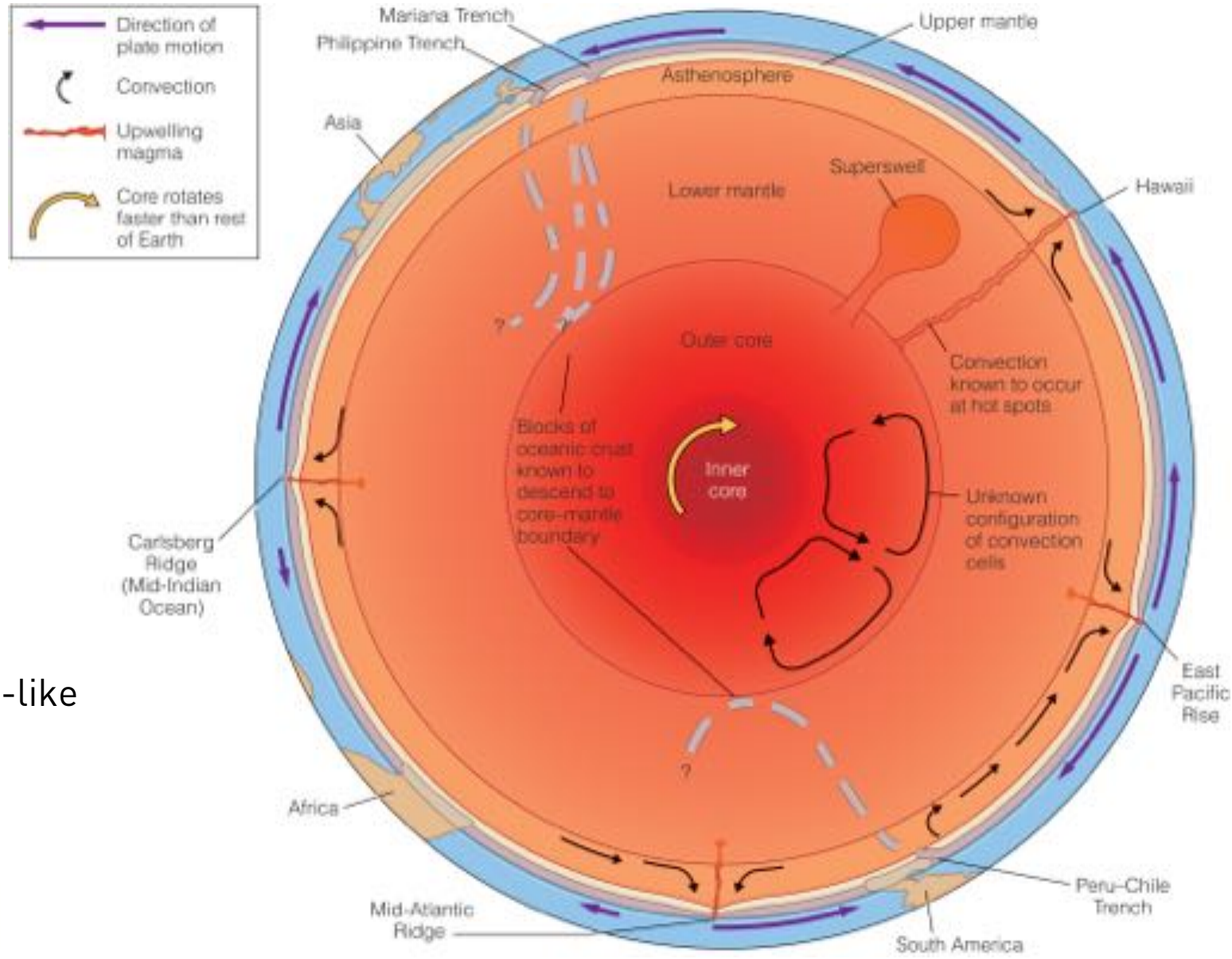

NORTH AMERICA
Approximate ages in millions of years
75
60
50
40
30
15
2
Emperor Seamount Chain
Hawaiian Ridge
Marshall Islands–Tuvalu Chain
Line Island Chain
PACIFIC OCEAN
Kauai 3.8–5.6 million years
Oahu 2.3–3.3 million years
Molokai 1.3–1.8 million years
Maui 0–1.3 million years
Direction of plate motion
Hawaii 0.7 million years to present
Kilauea
Mauna Loa
Loihi
Active volcano

(a)


Direction of plate motion
Kauai
Oahu
Mauna Kea
Mauna Loa
Kilauea
Loihi
Lithosphere
Isostatic sinking
Hotspot

(b)

Putting the picture together



Convection-like process

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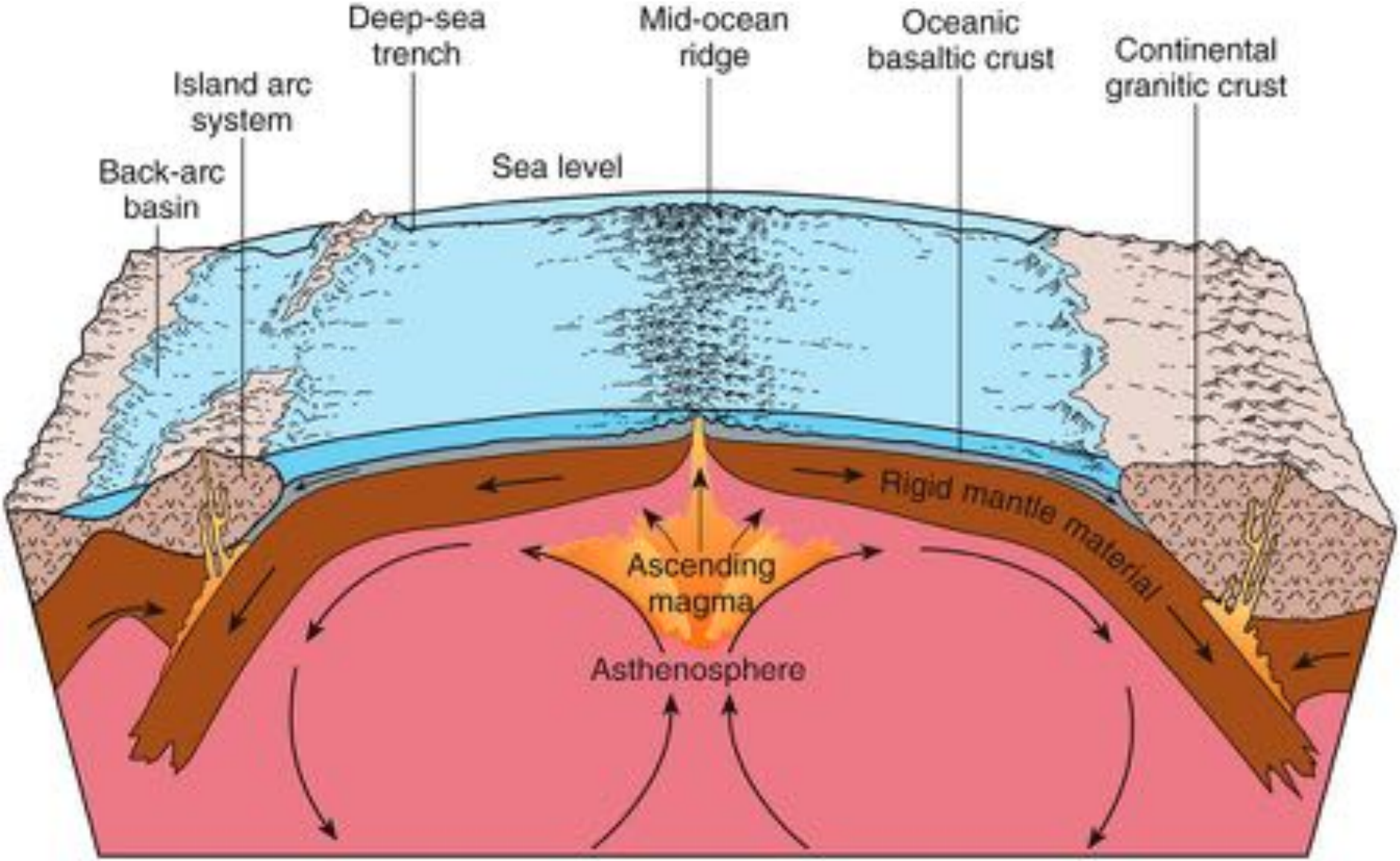
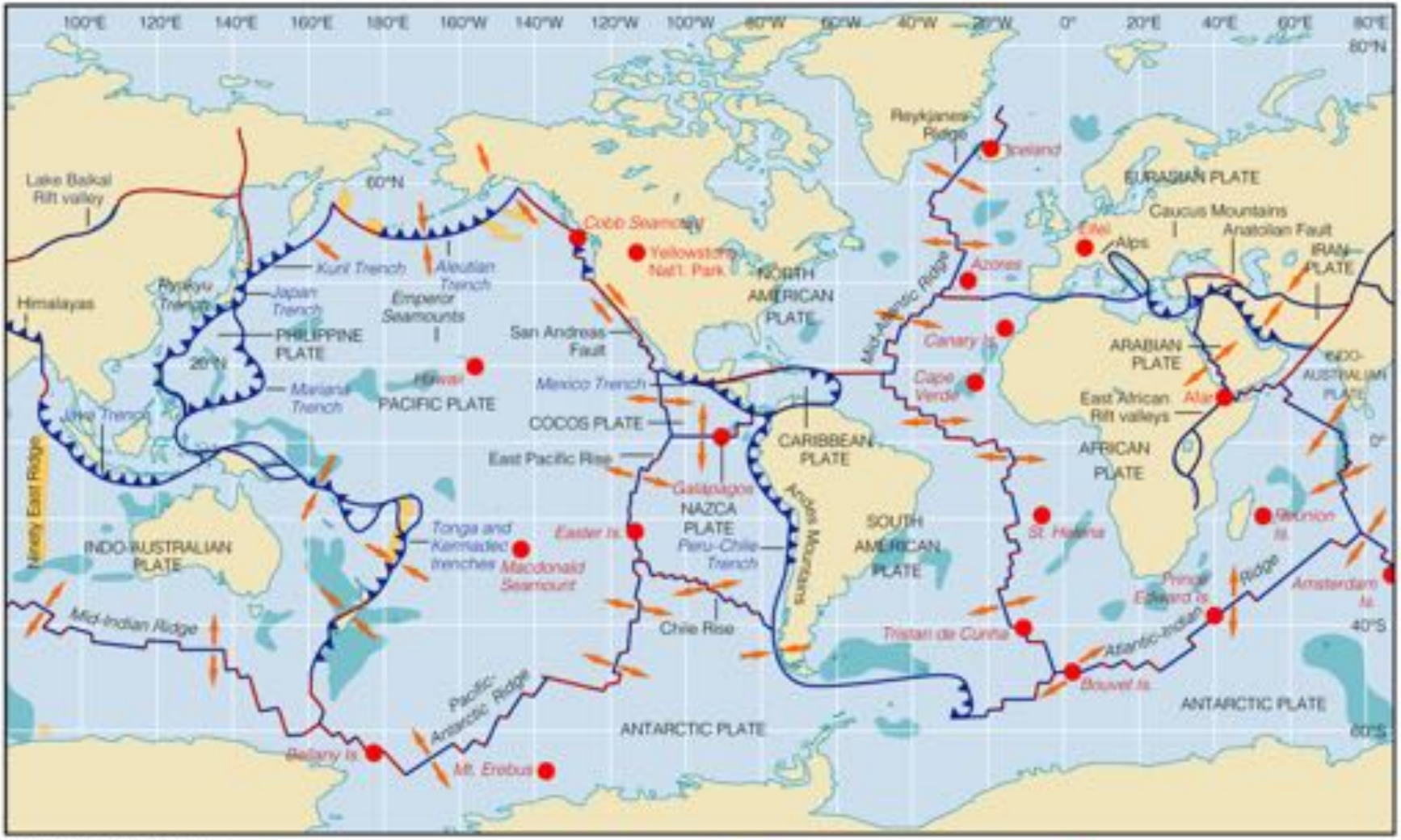
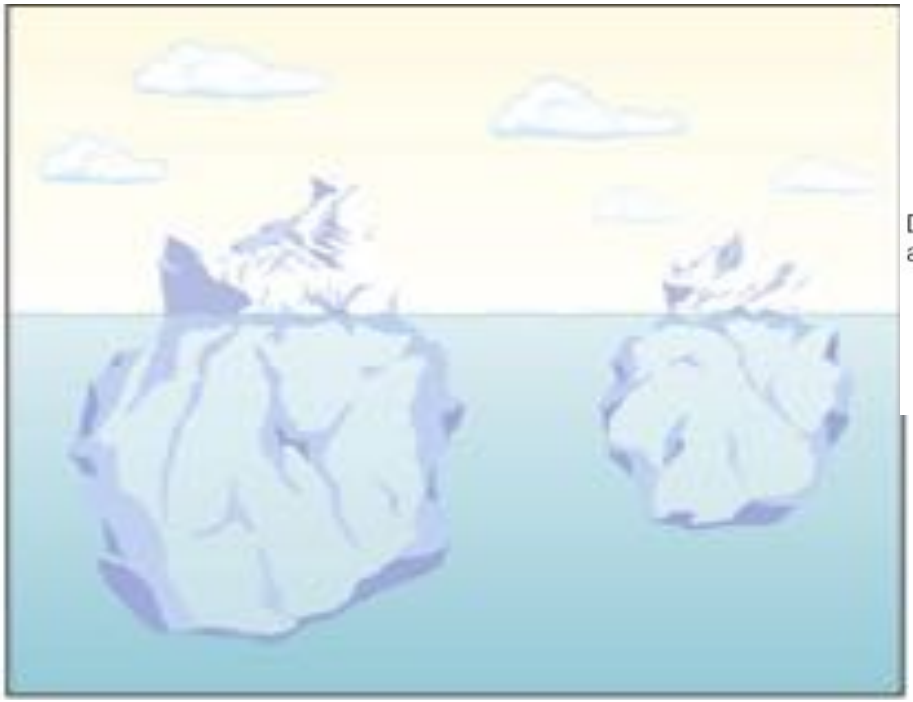
Continental Drift Theory

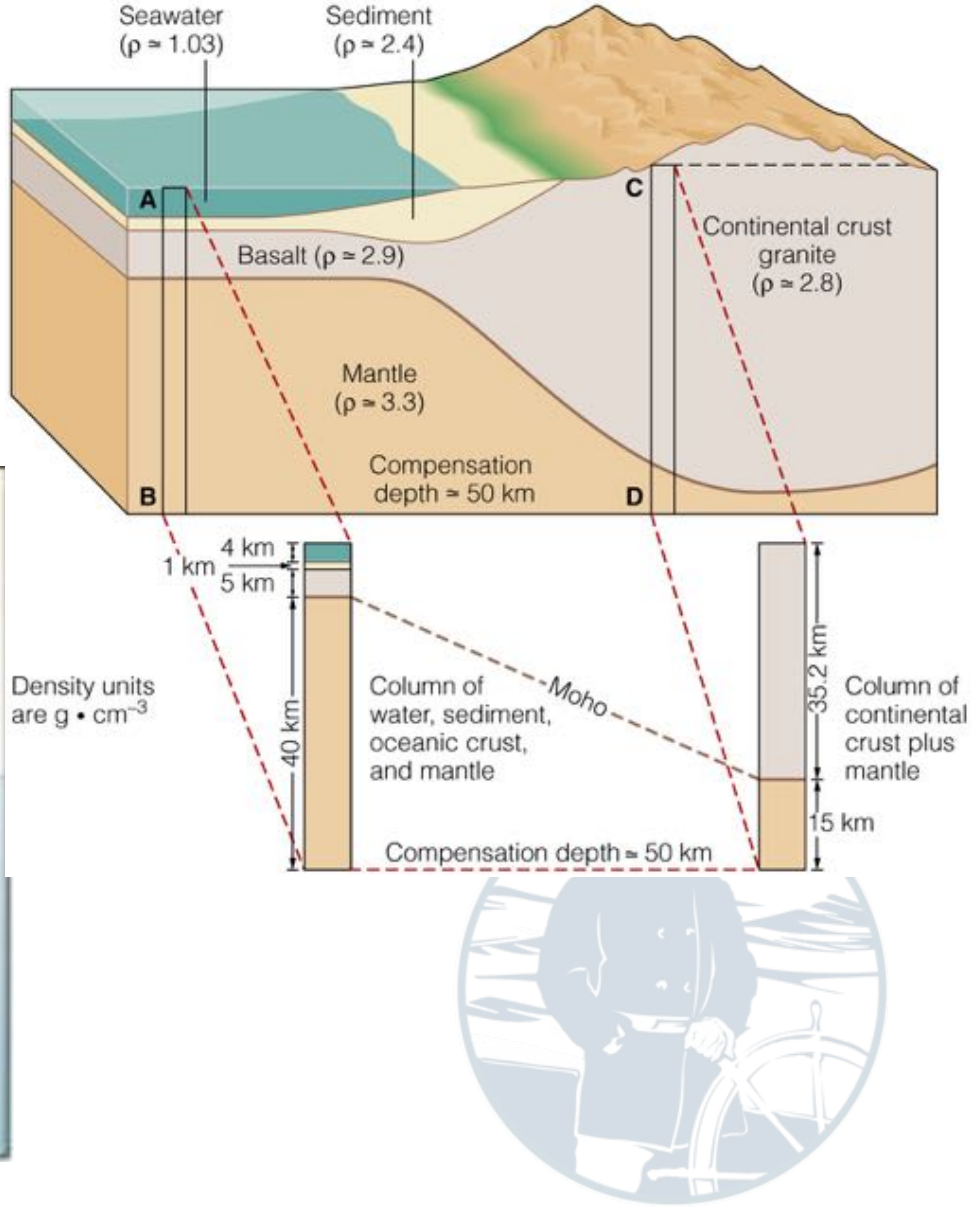



100°E
120°E
140°E
160°E
180°E
160°W
140°W
120°W
100°W
80°W
60°W
40°W
20°W
0°
20°E
40°E
60°E
80°E
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
Lake Baikal Rift valley
Himalayas
Ryukyu Trench
Kuril Trench
Japan Trench
Aleutian Trench
Emperor Seamounts
PHILIPPINE PLATE
Mariana Trench
Yap Trench
Palau Trench
Nansy East Ridge
INDO-AUSTRALIAN PLATE
Mid-Indian Ridge
Tonga and Kermadec trenches
Macdonald Seamount
PACIFIC PLATE
Hawaii
Coop Seamount
Yellowstone Nat'l. Park
San Andreas Fault
Mexico Trench
COCOS PLATE
East Pacific Rise
Galapagos
NAZCA PLATE
Peru-Chile Trench
Easter Is.
Chile Rise
Andes Mountains
CARIBBEAN PLATE
NORTH AMERICAN PLATE
SOUTH AMERICAN PLATE
Pacific-Antarctic Ridge
Balleny Is.
Mt. Erebus
ANTARCTIC PLATE
Reykjanes Ridge
Iceland
Mid-Atlantic Ridge
Azores
Canary Is.
Cape Verde
St. Helena
Tristan da Cunha
Bouvet Is.
Atlantic-Indian ridge
Prince Edward Is.
Reunion Is.
Amsterdam Is.
EURASIAN PLATE
Caucus Mountains
Anatolian Fault
Alps
Etna
IRAN PLATE
ARABIAN PLATE
East African Rift valleys
Afar
AFRICAN PLATE
INDO-AUSTRALIAN PLATE
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).



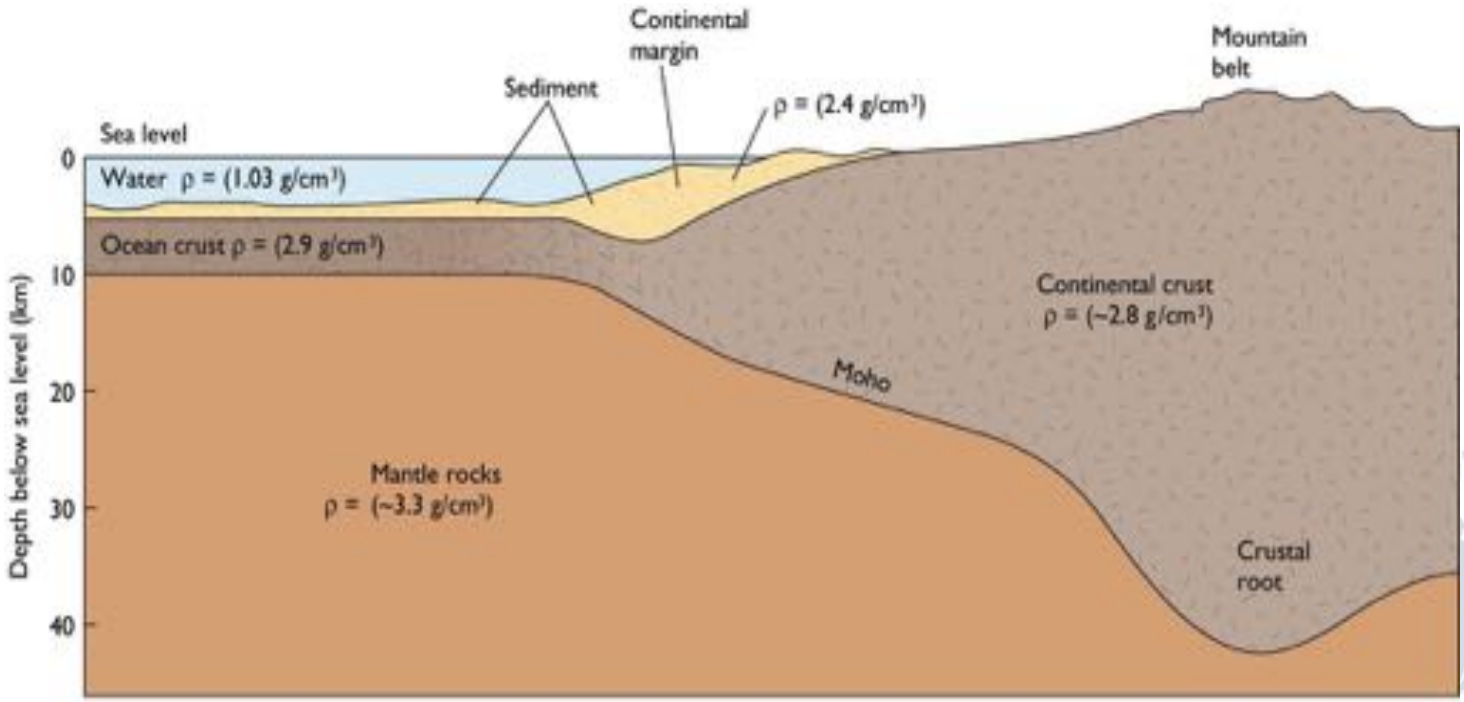


Slide credit: Emanuele Di Lorenzo, Georgia Tech

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

Physical layers of the earth

Table 2.1 Layers of the Earth

Layer	Depth (km)	Thickness (km)	State	Composition	Density (g/cm³)	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

Oceanic crust

- Thin, more dense
  - Mostly basalt
  - mean density ~3.0 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 2.7-2.8 g cm^{-3}
  - Thickness 25-40 km

- Buoyant continents

- Preferentially preserved during plate convergence

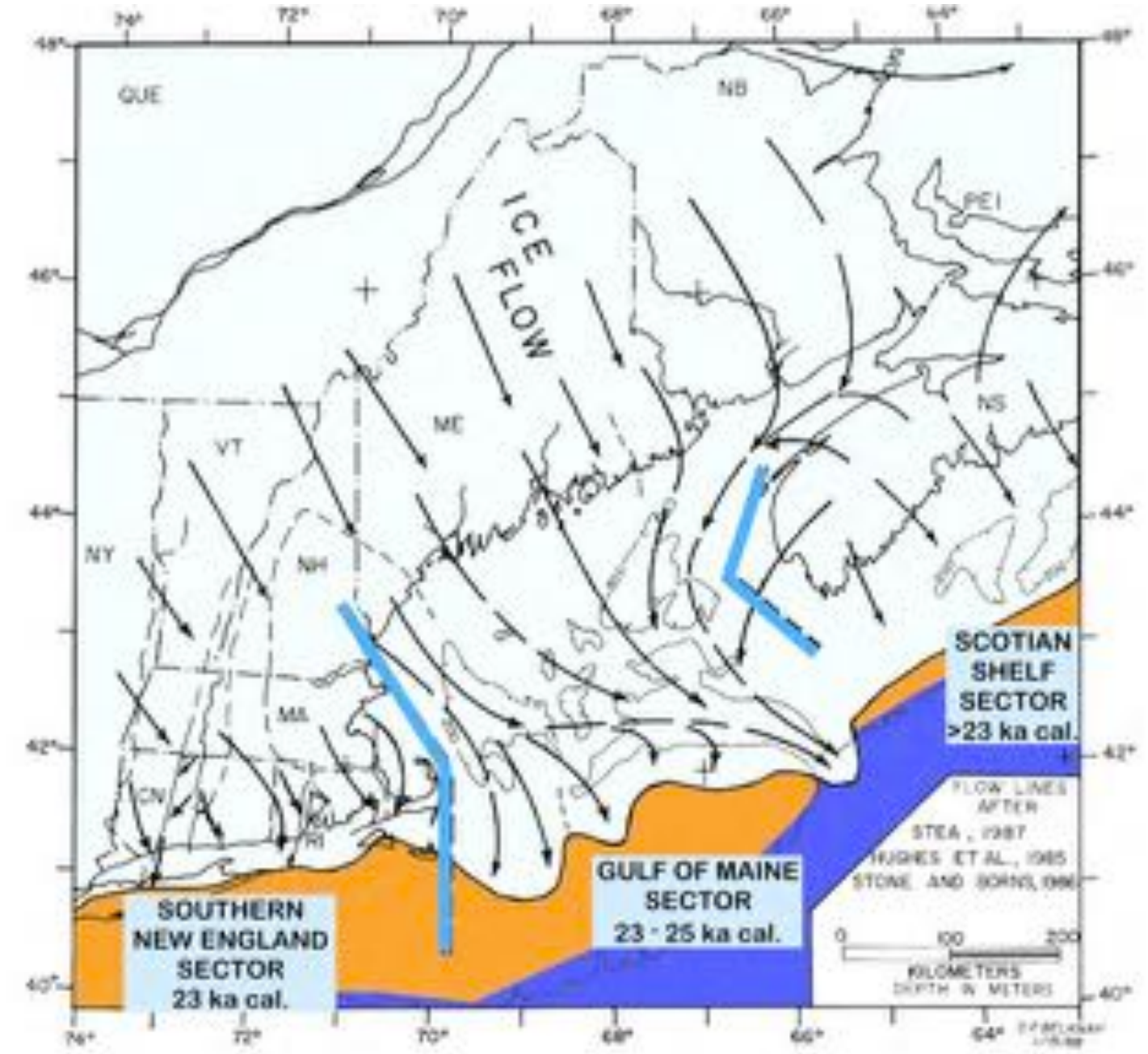
- Old >3500M yrs

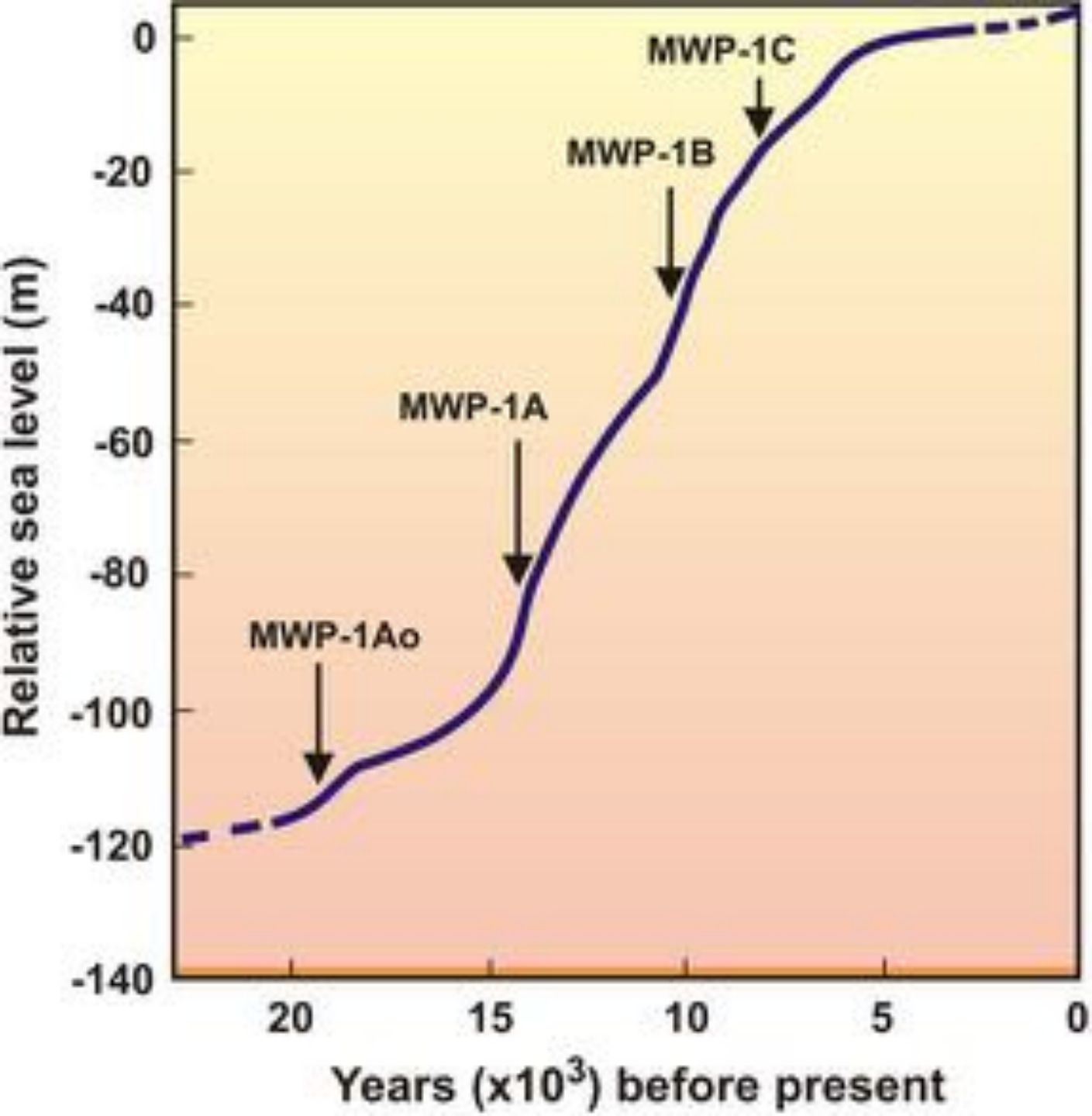
Key Properties and processes

- Density
  - Layering of earth
  - Isostasy of continents

- Convection
  - Overturning within layers
  - Convection-like process moves plates

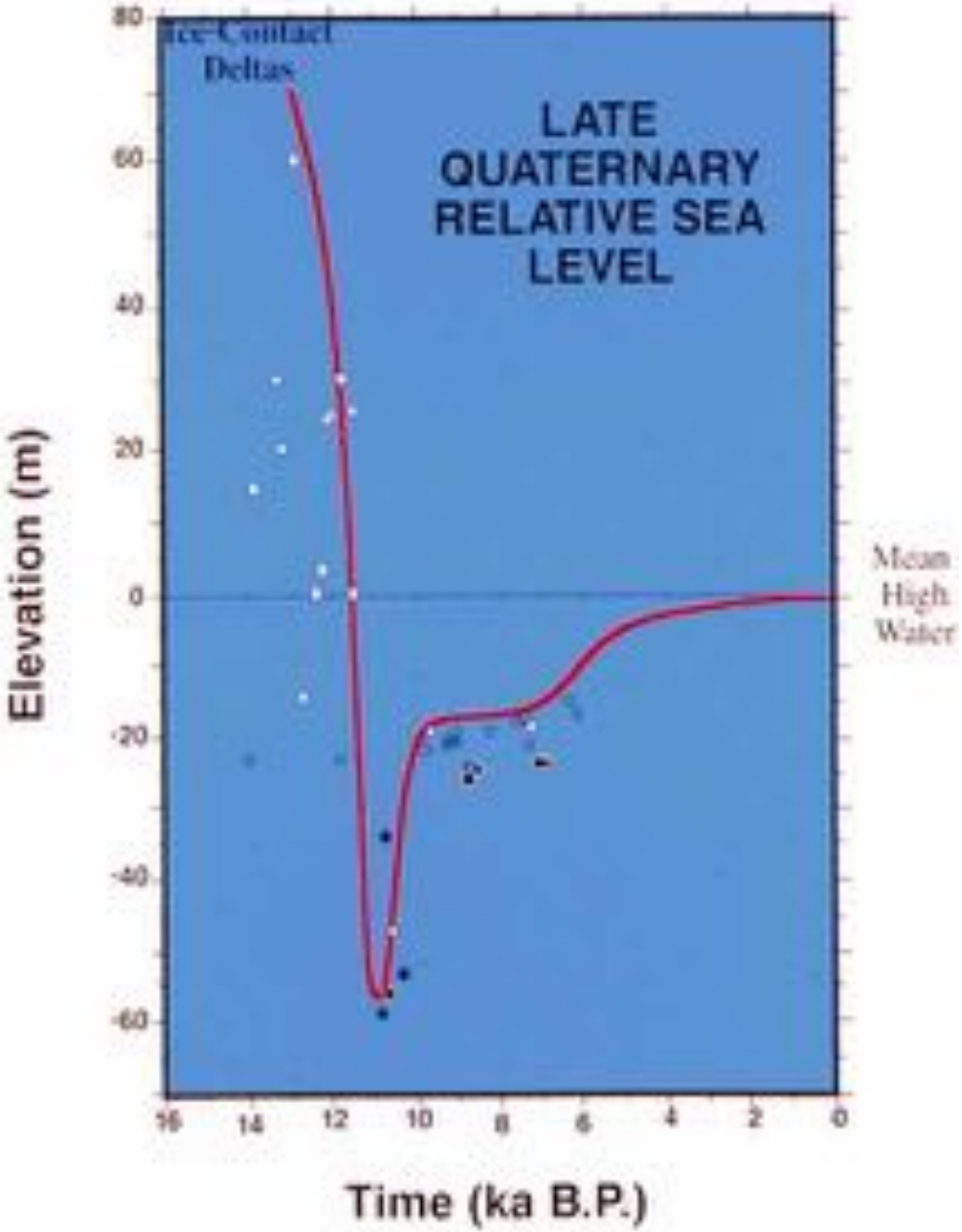
A local note on isostacy



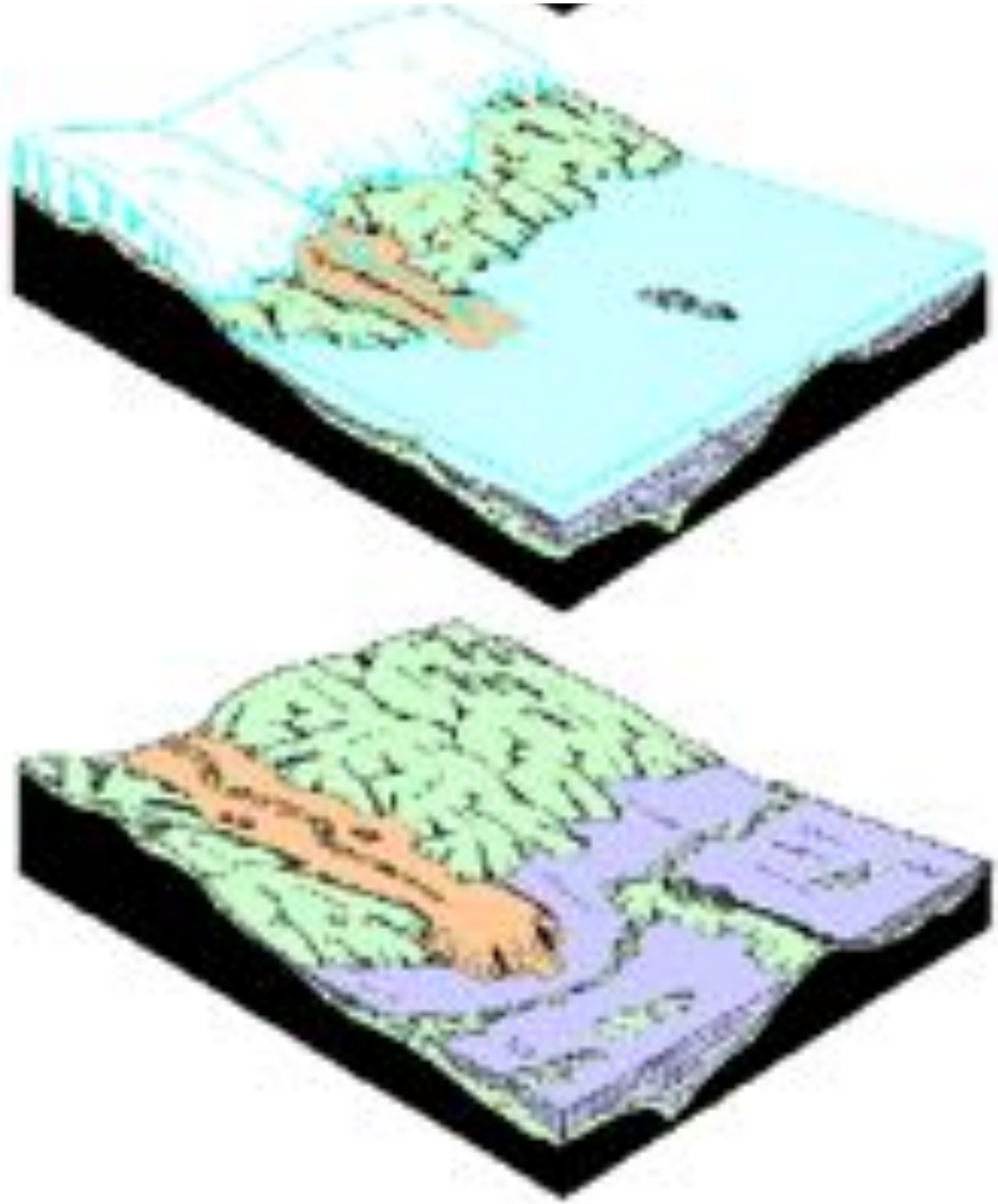


Global sea level rise since last ice age

Image credit: NASA



Maine sea level rise since last ice age



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

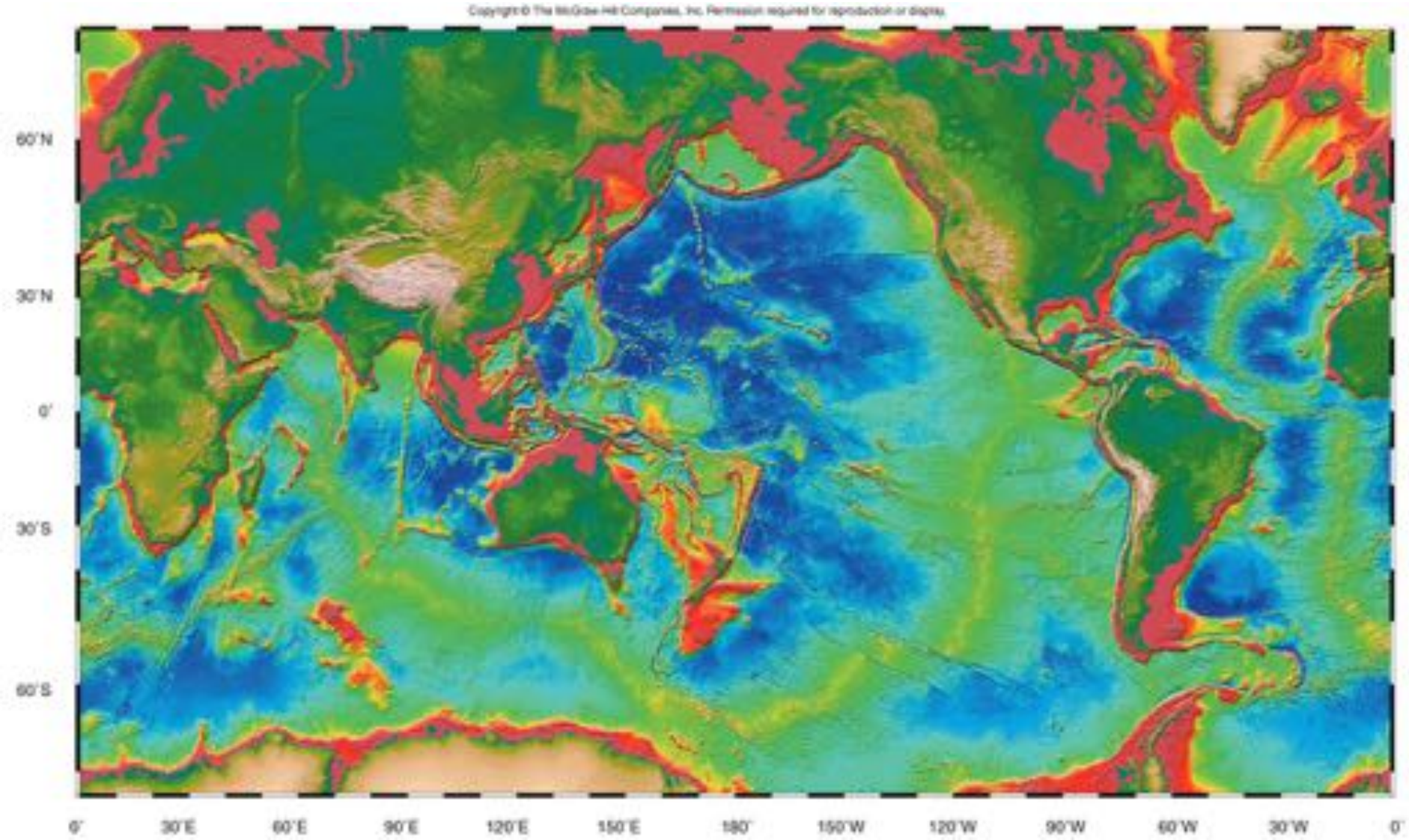
The Sea Floor

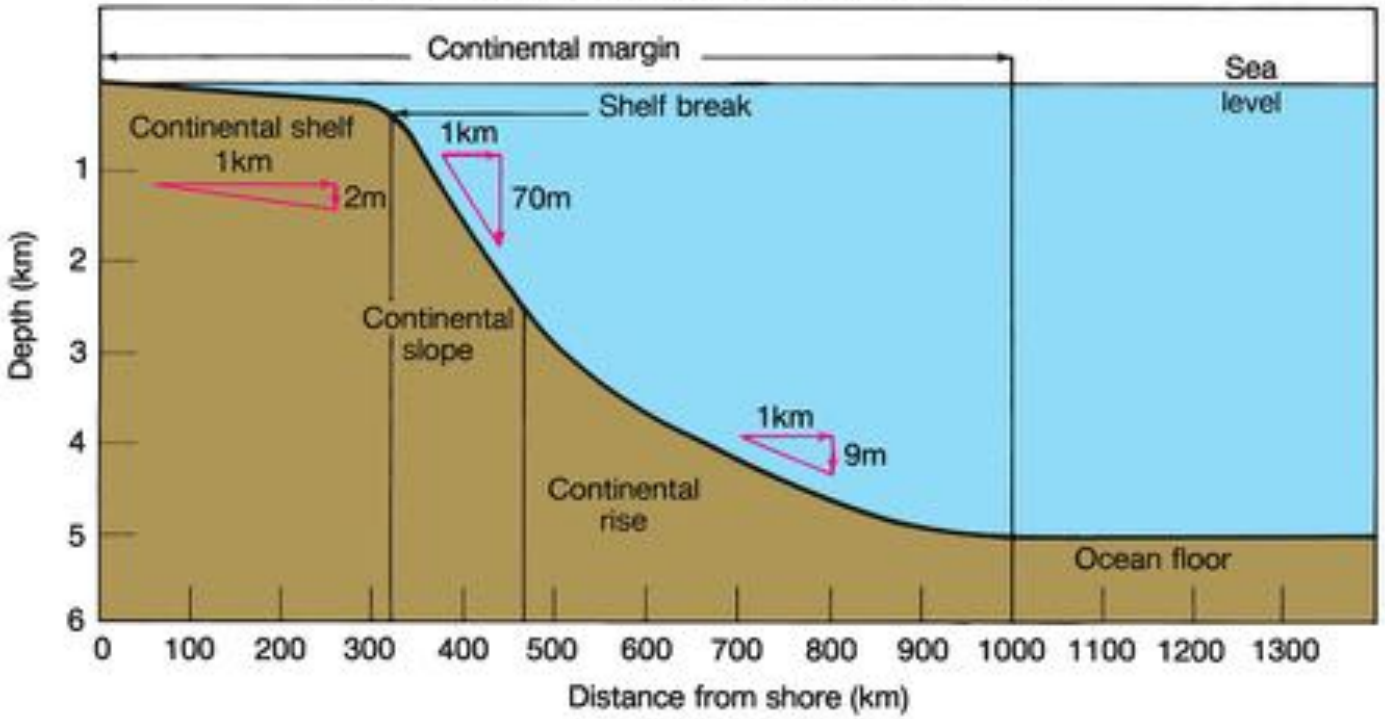
Bigelow | Laboratory for Ocean Sciences

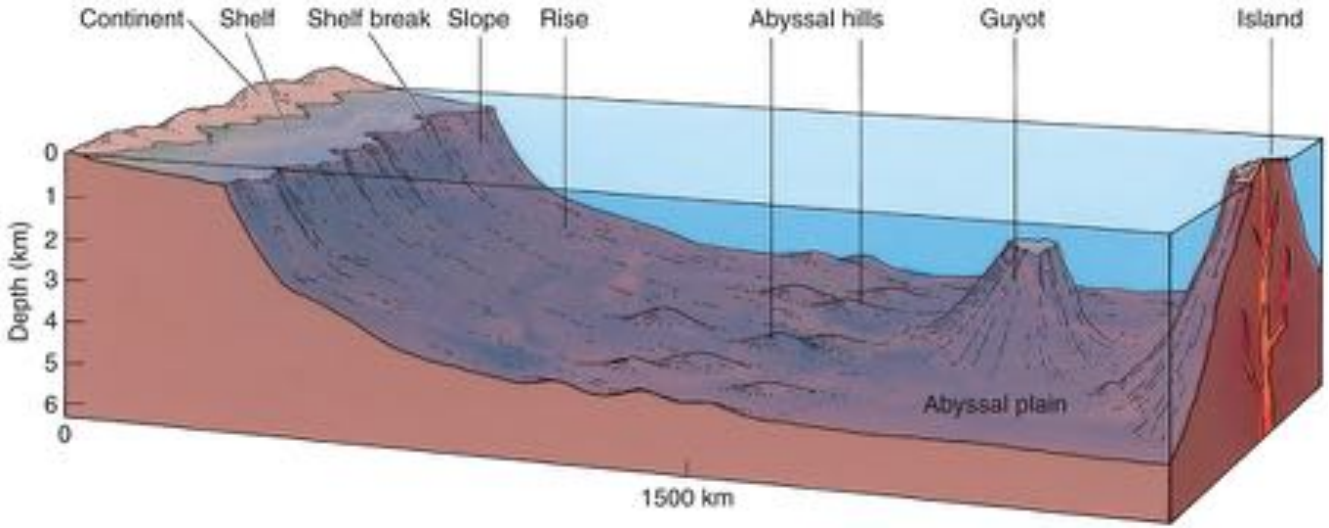
Topography of the sea floor

- 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

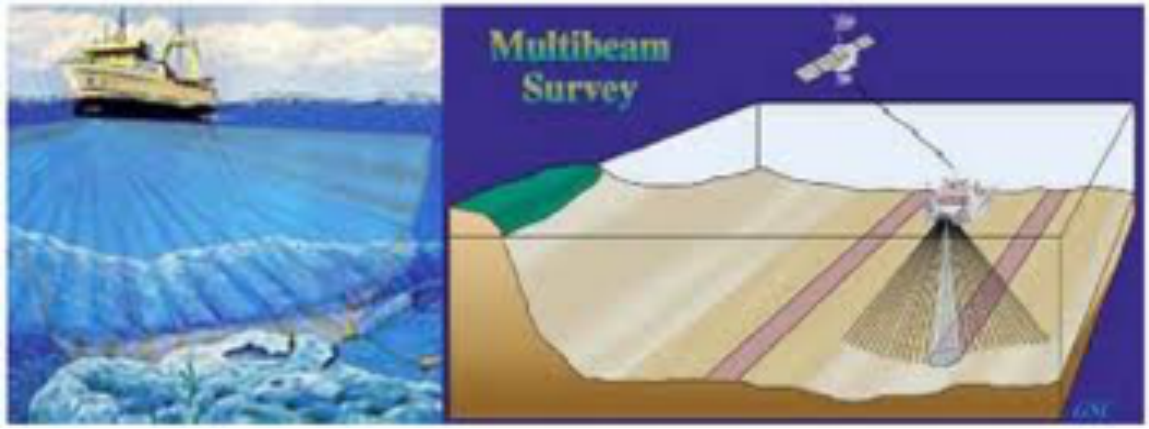




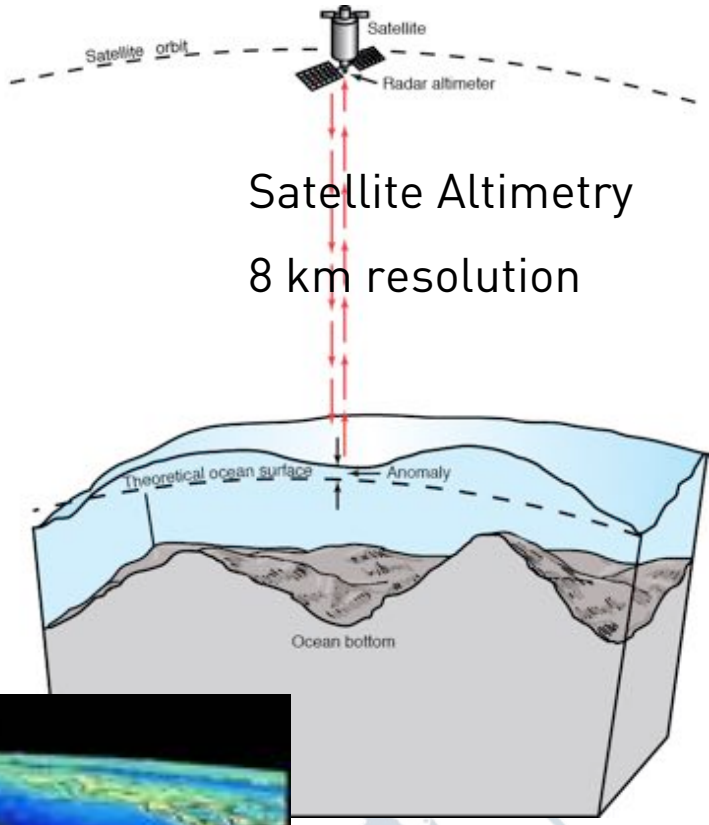


Determining bottom topography

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

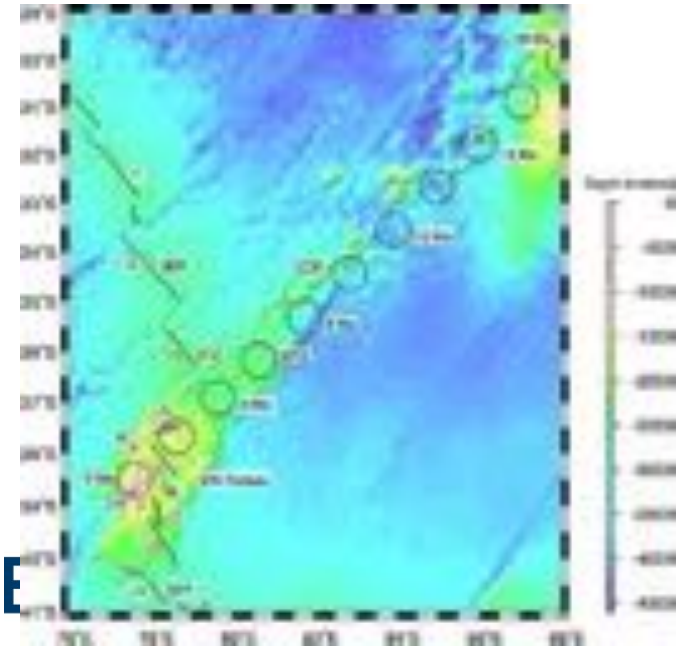


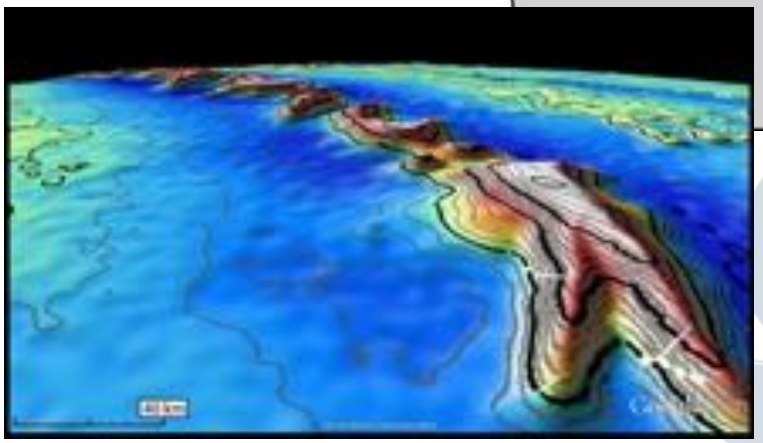
NOAA/NGDC



Satellite Altimetry

8 km resolution





Maia, M., et al. (2011), *J. Geophys. Res.*, 116

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)

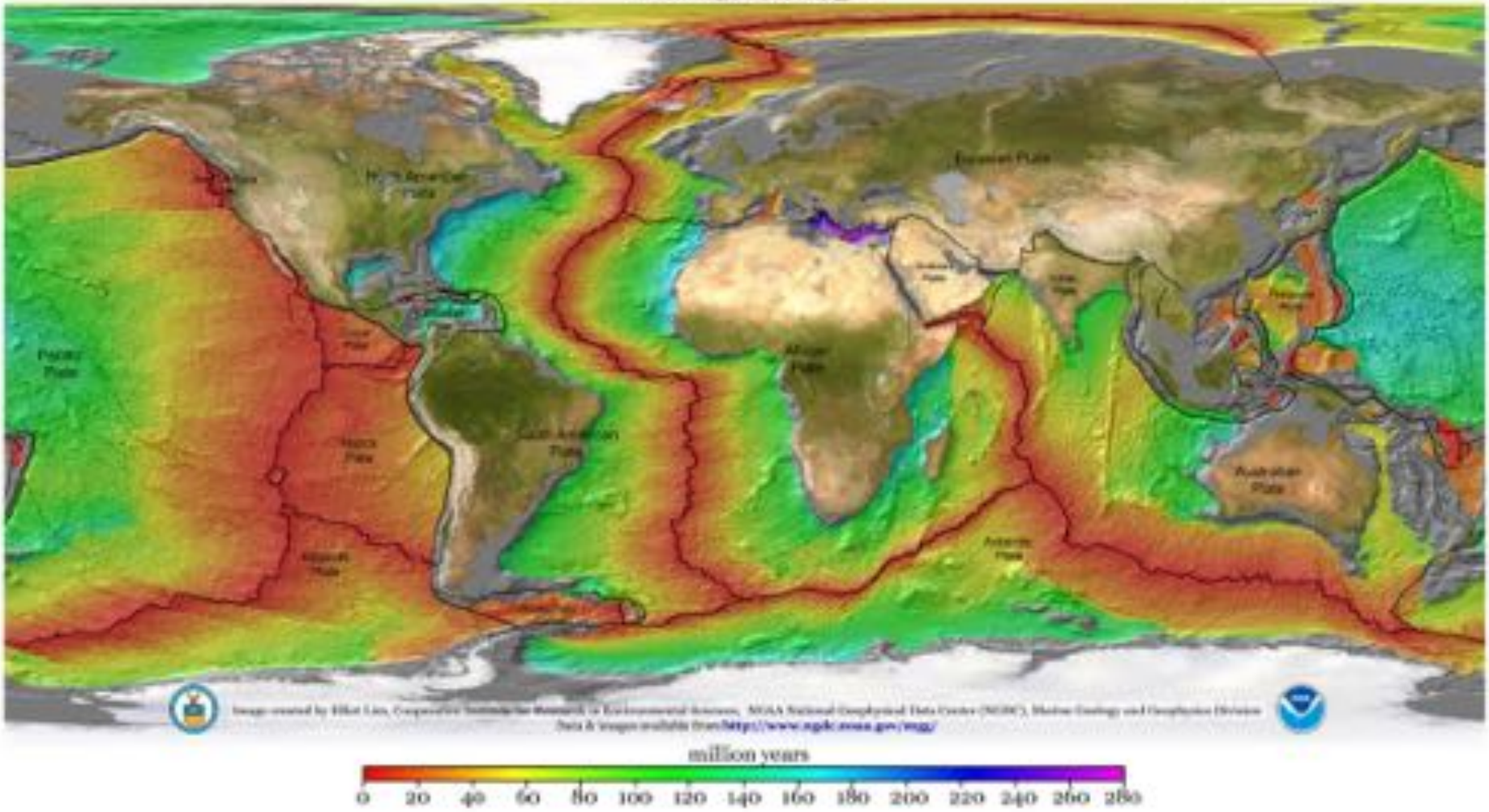
Sedimentation rate ≠ Accumulation rate

***Note**: marine sedimentation is the major way carbon is buried*

Age of Oceanic Lithosphere (m.y.)

Data source:

Müller, R.D., M. Sdrolias, 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.



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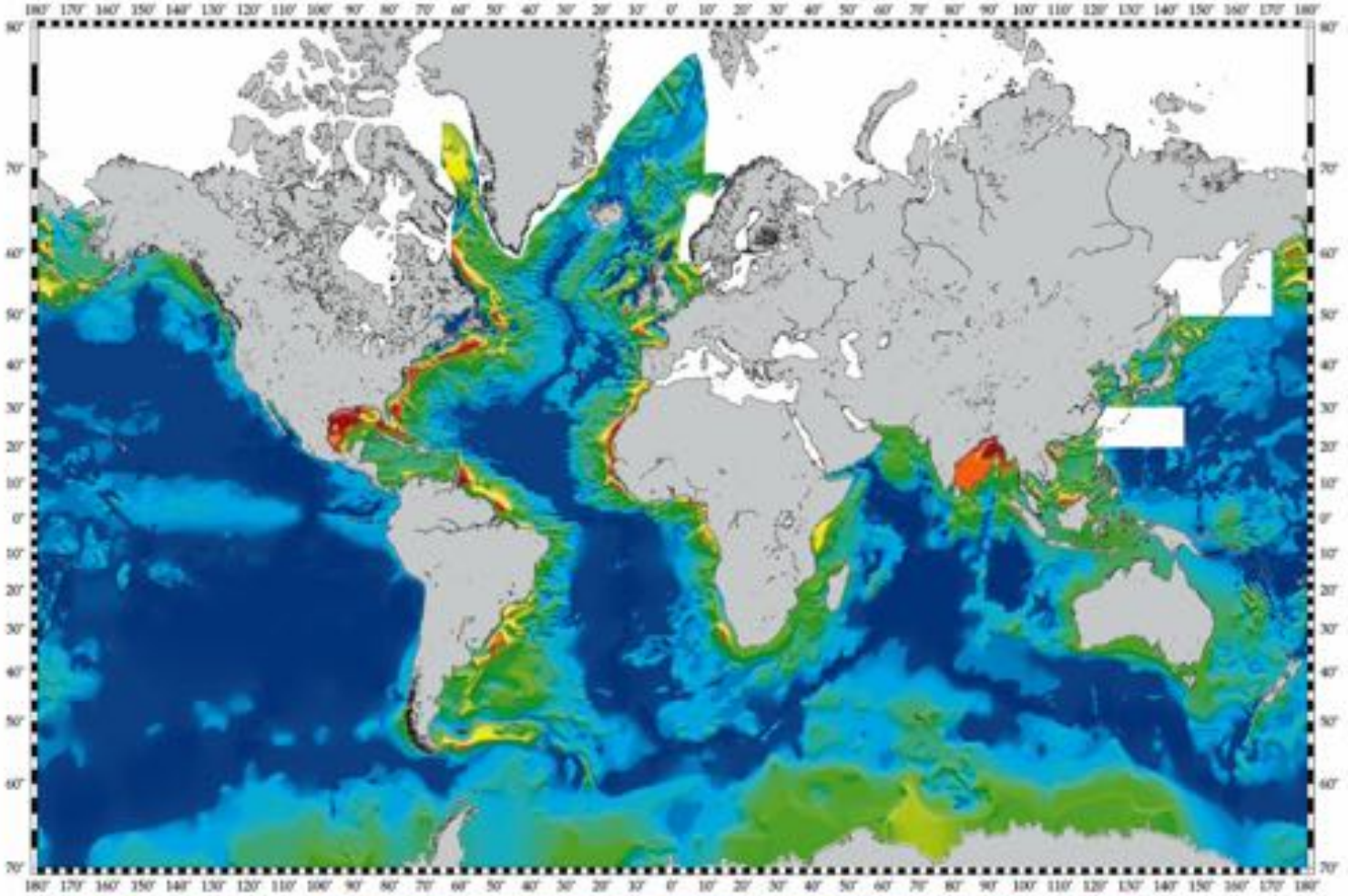
Total Sediment Thickness of the World's Oceans & Marginal Seas



0 500 1000 5000 10000 20000

Thickness in Meters

A digital total sediment thickness database for the world's oceans and marginal seas is being compiled by the National Geophysical Data Center (NGDC) ,Marine Geology & Geophysics Division. The data are gridded with a spacing of 5 arc-minutes by 5 arc-minutes. Sediment thickness data were compiled from three principle sources: previously published isopach maps; ocean drilling results, both ODP and DSDP; and seismic reflection profiles archived at NGDC as well as seismic data and isopach maps available as part of the IOC's Geological/Geophysical Atlas of the Pacific (GAP'N) project.

The distribution of sediments in the oceans is controlled by five primary factors:
1) Age of the underlying crust
2) Tectonic history of the ocean crust
3) Structural trends in basement
4) Nature and location of sediment sources, and
5) The nature of the sedimentary processes delivering sediments to depocenters

The data values are in meters and represent the depth to acoustic basement. It should be noted that acoustic basement may not actually represent the base of the sediments. These data are intended to provide a minimum value for the thickness of the sediment in a particular geographic region.

http://www.ngdc.noaa.gov/mgg/sedthick/sedthick.html

Bige

Classification Exercise

Which one is a Florida beach?

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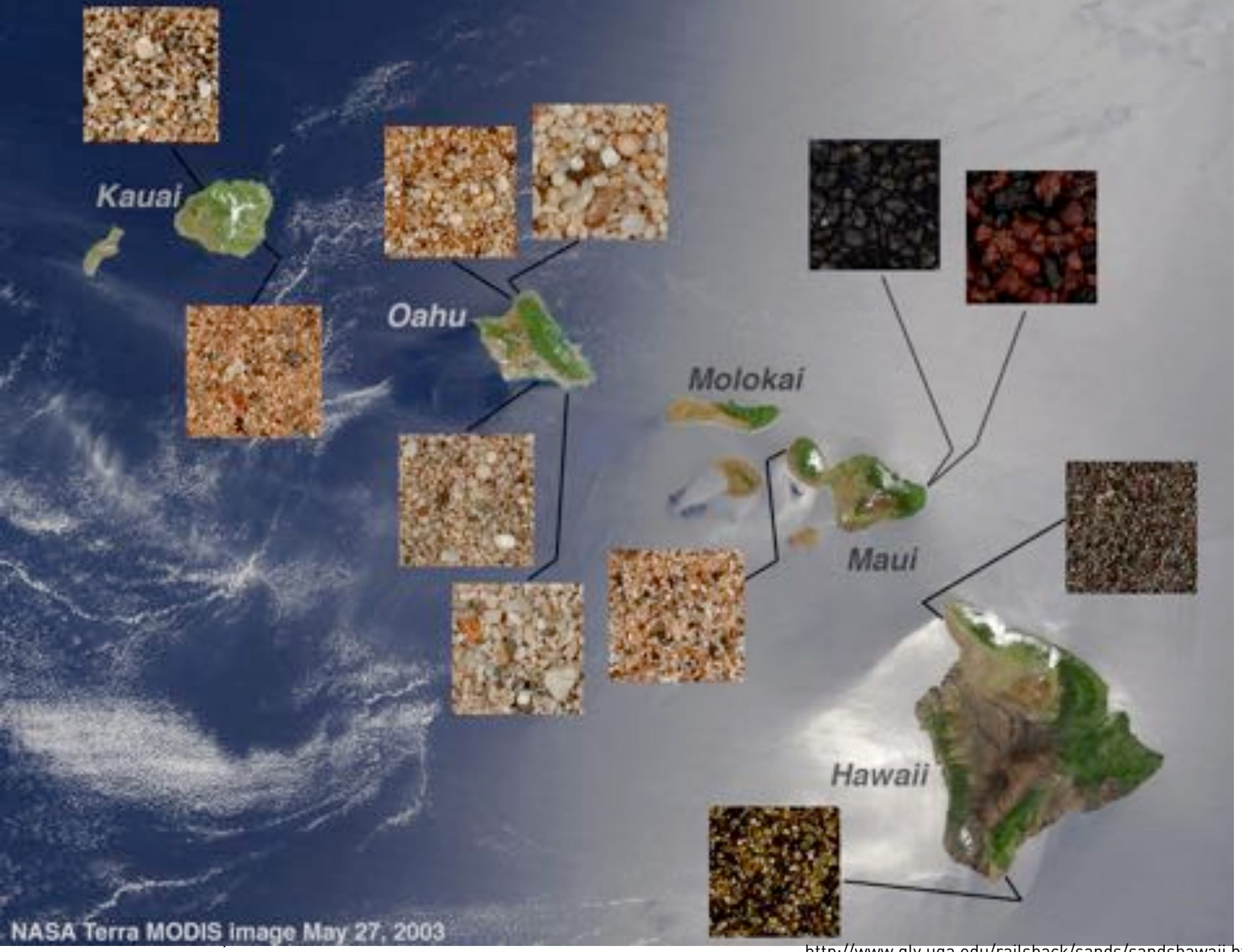
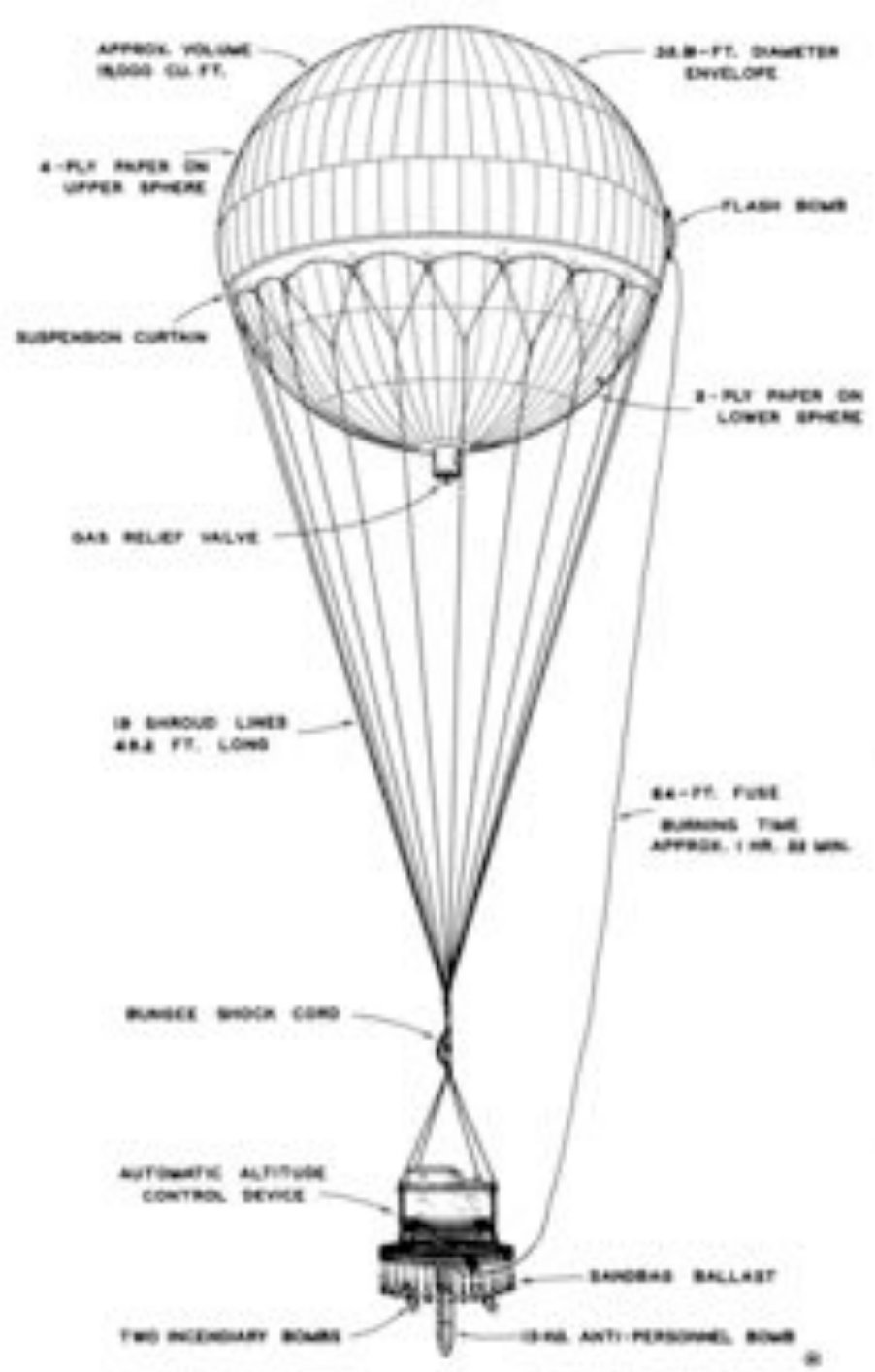
http://www.gly.uga.edu/railsback/sands/sandstitle.html

Kennair & Railsback
University of Georgia



http://www.gly.uga.edu/railsback/sands/sandshawaii.html



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%20vengenance%20bombs%20new.htm

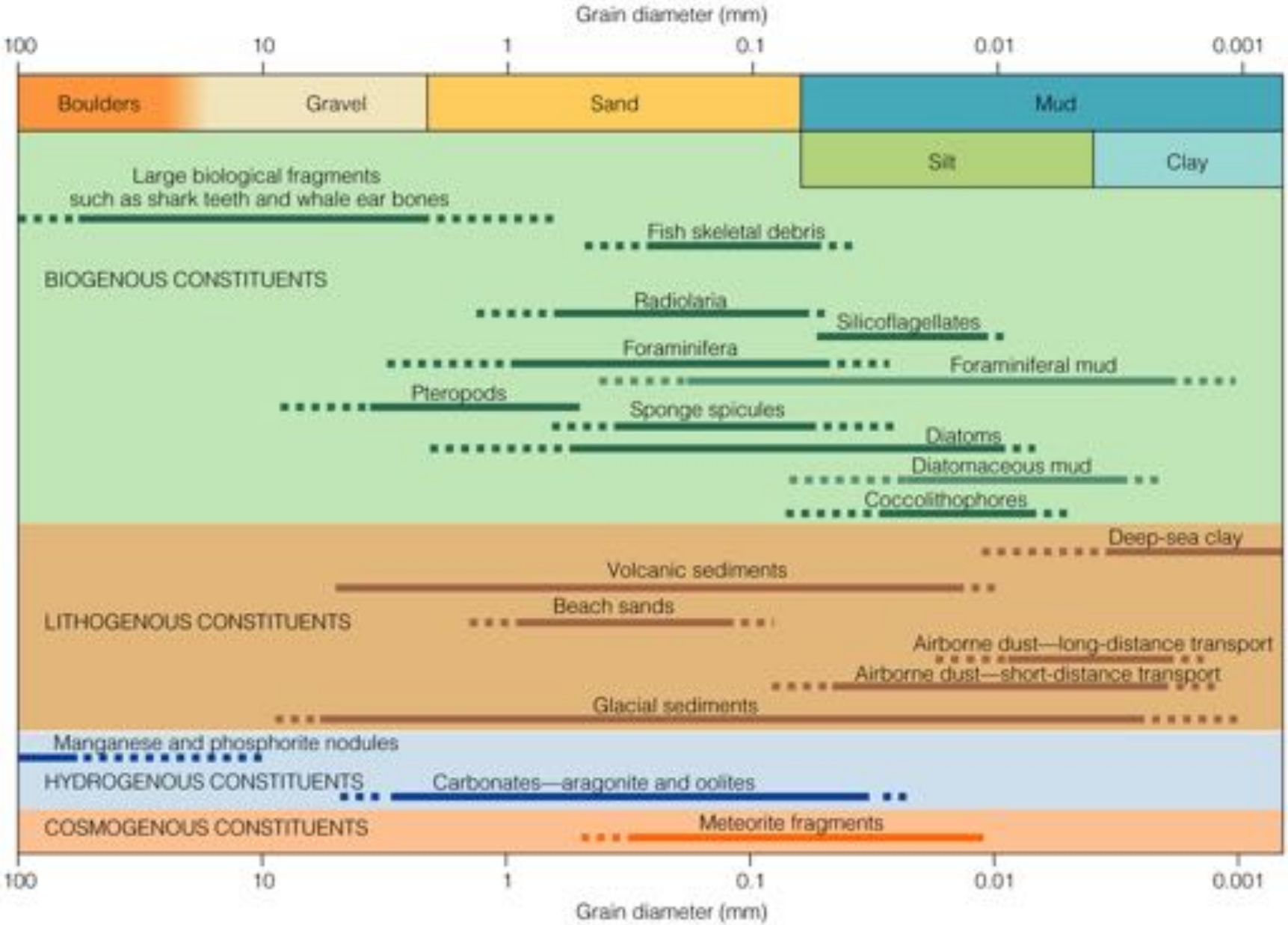
Two classifications: (1) **Classification by grain size**

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**

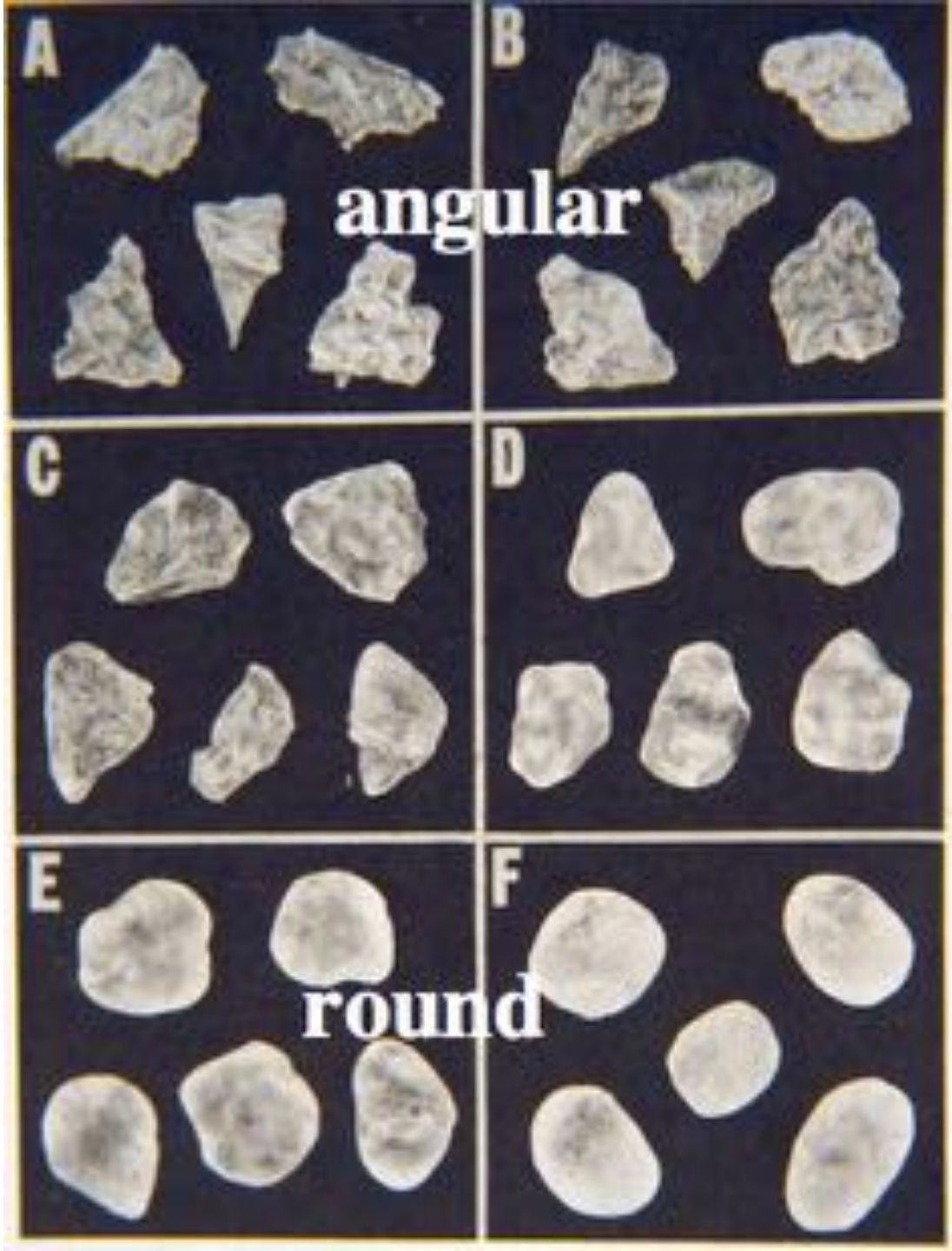
Lithogenous—fragments of rock from terrestrial sources

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

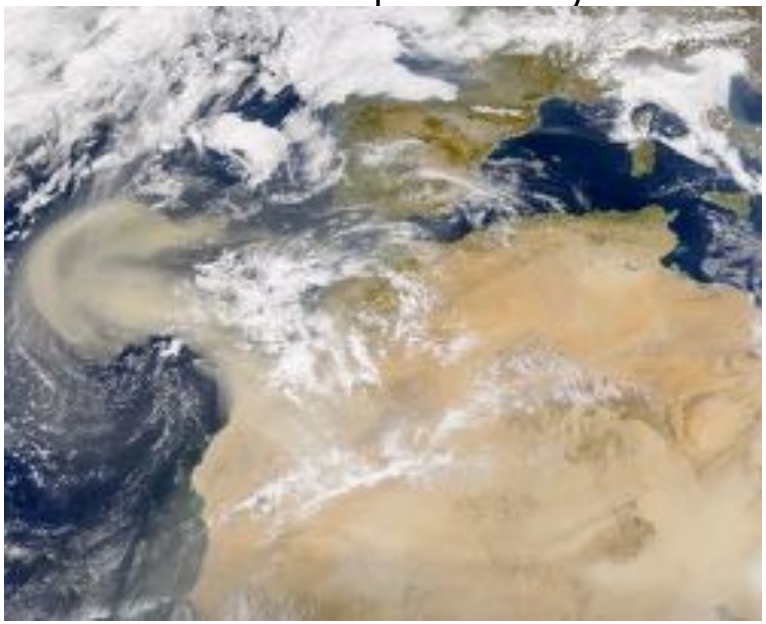
Images: D. Belknap

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

$CaCO_3$

shallow, warm

Ucl.ac.uk

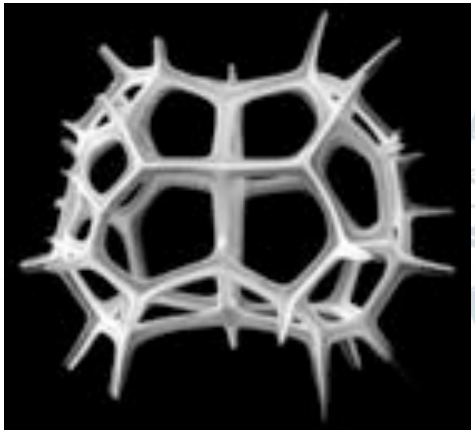
wikipedia.com

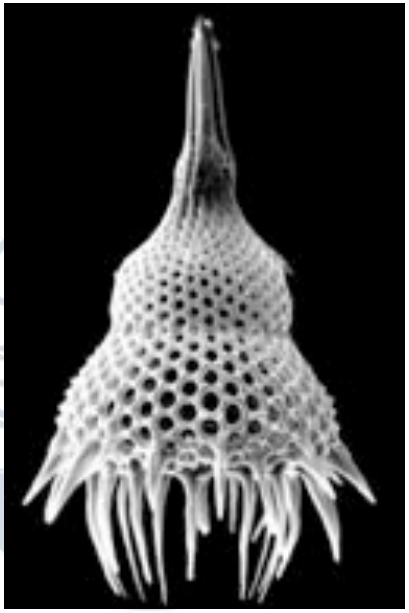
Siliceous oozes

SiO_2

colder, deeper water

micrographia.com

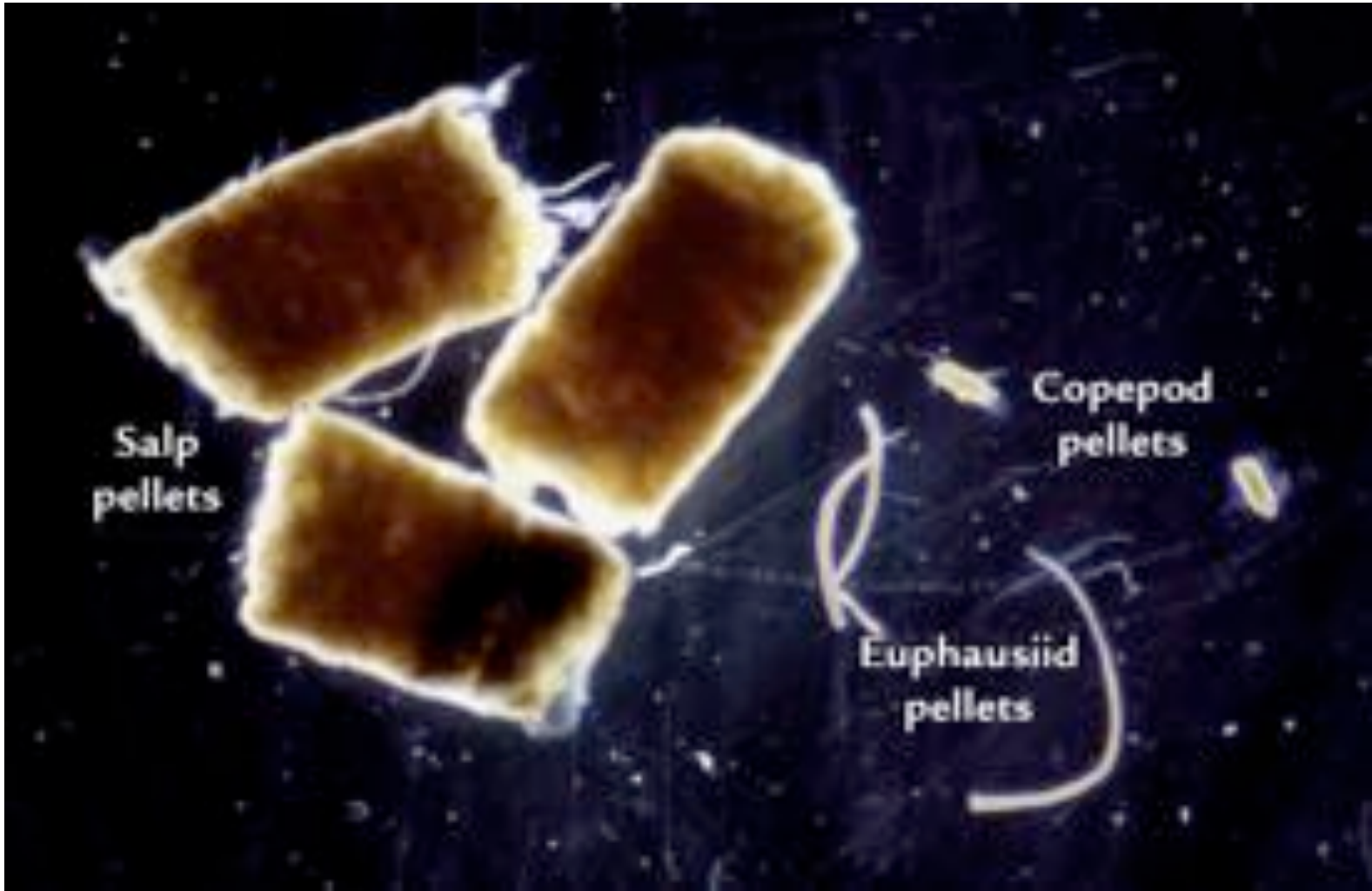




radiolarians.org

Biogenous

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



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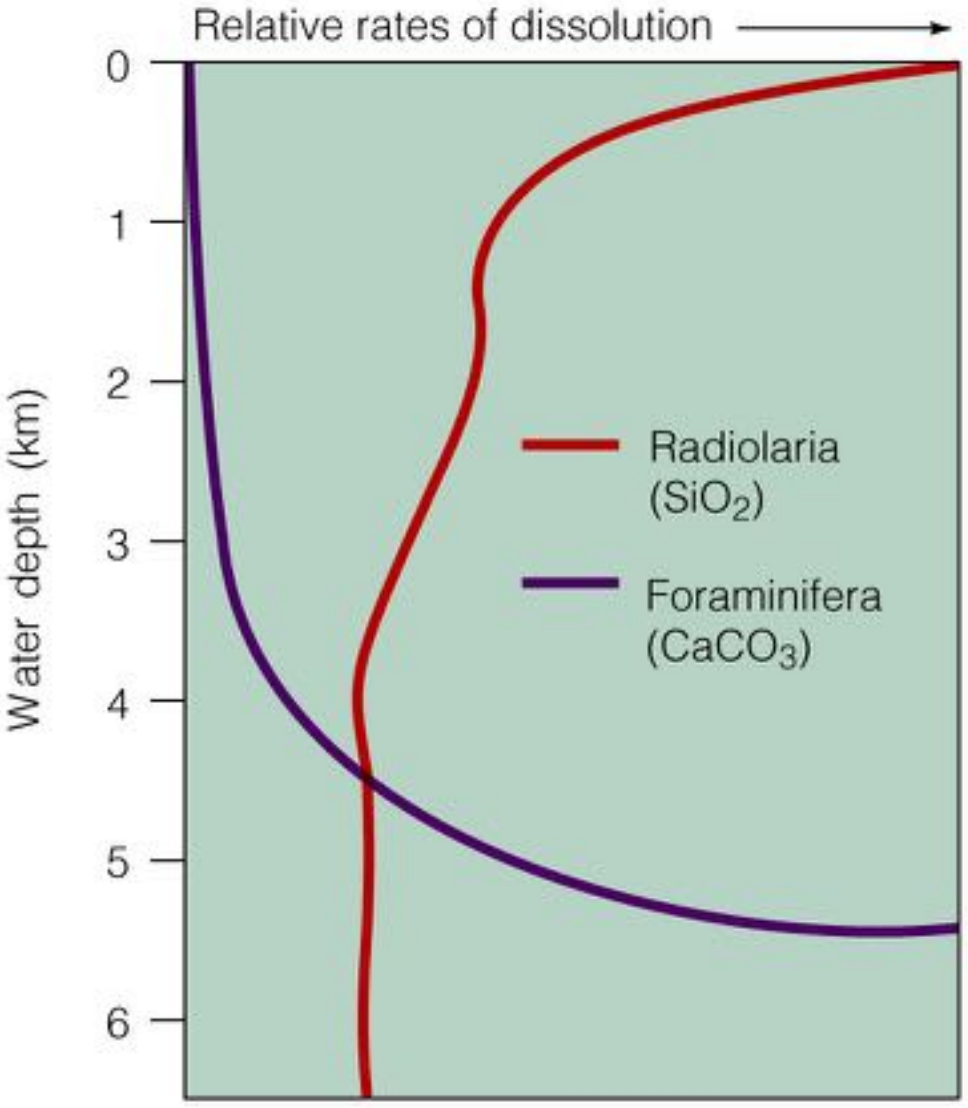
Carbonate Compensation Depth (CCD)

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

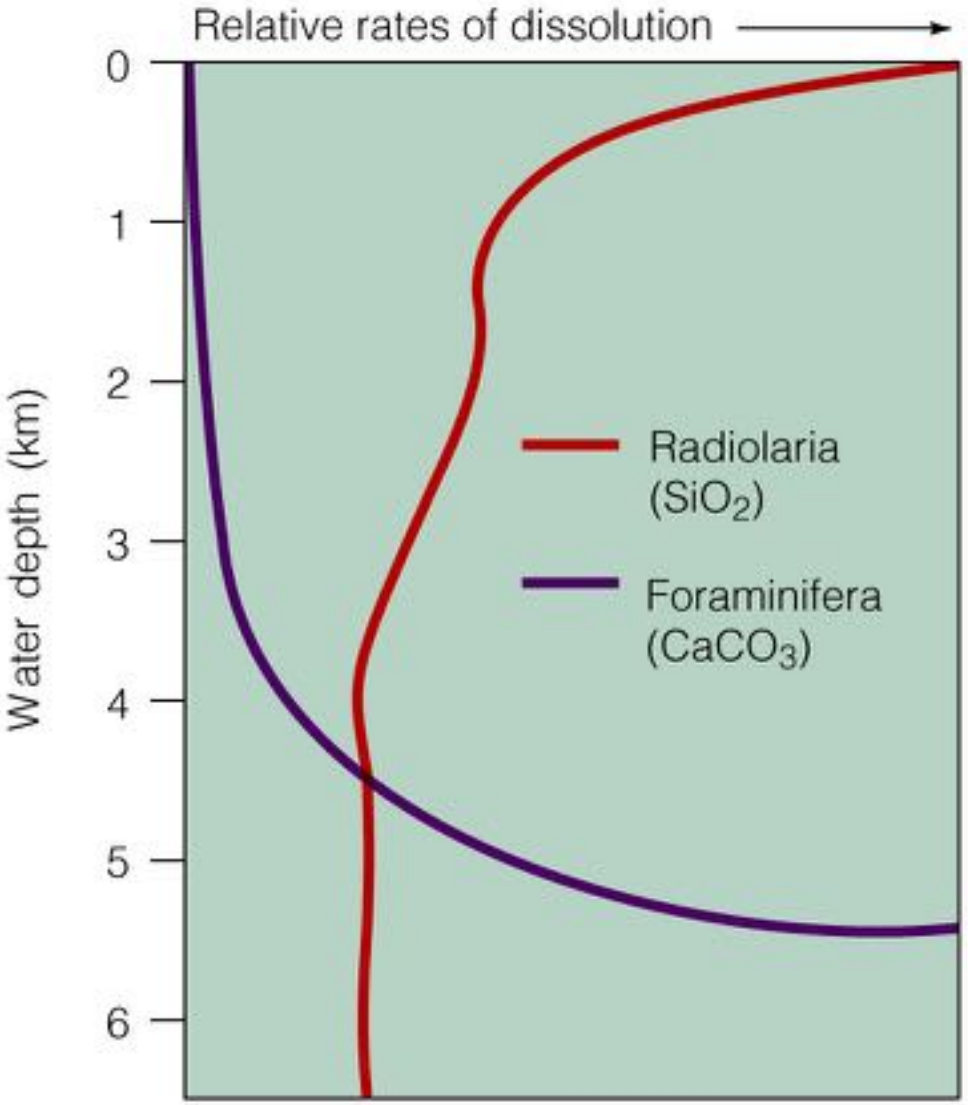


Carbonate Compensation Depth (CCD)

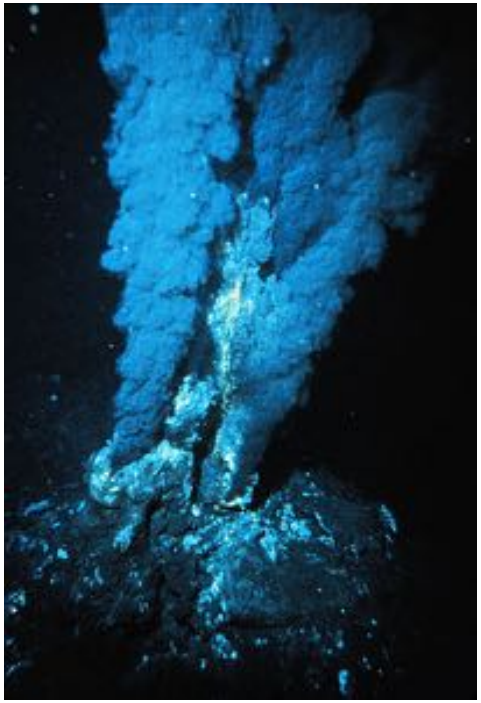
The CCD depends on pressure and temperature, the concentration of dissolved carbon dioxide, and the pH

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.



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)

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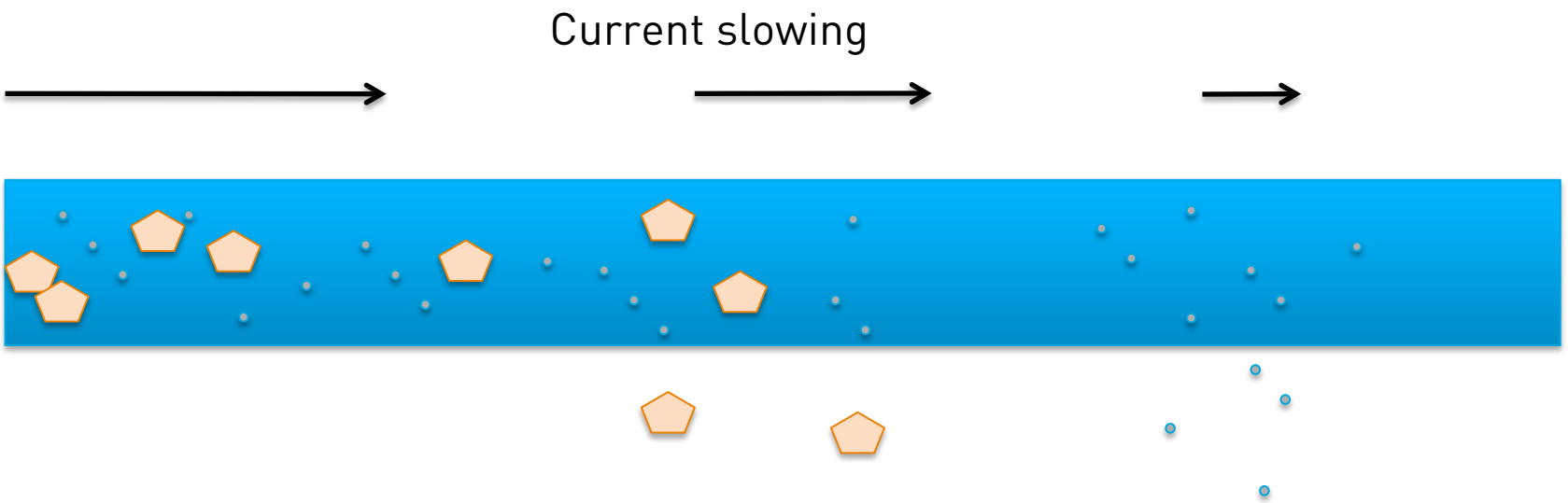
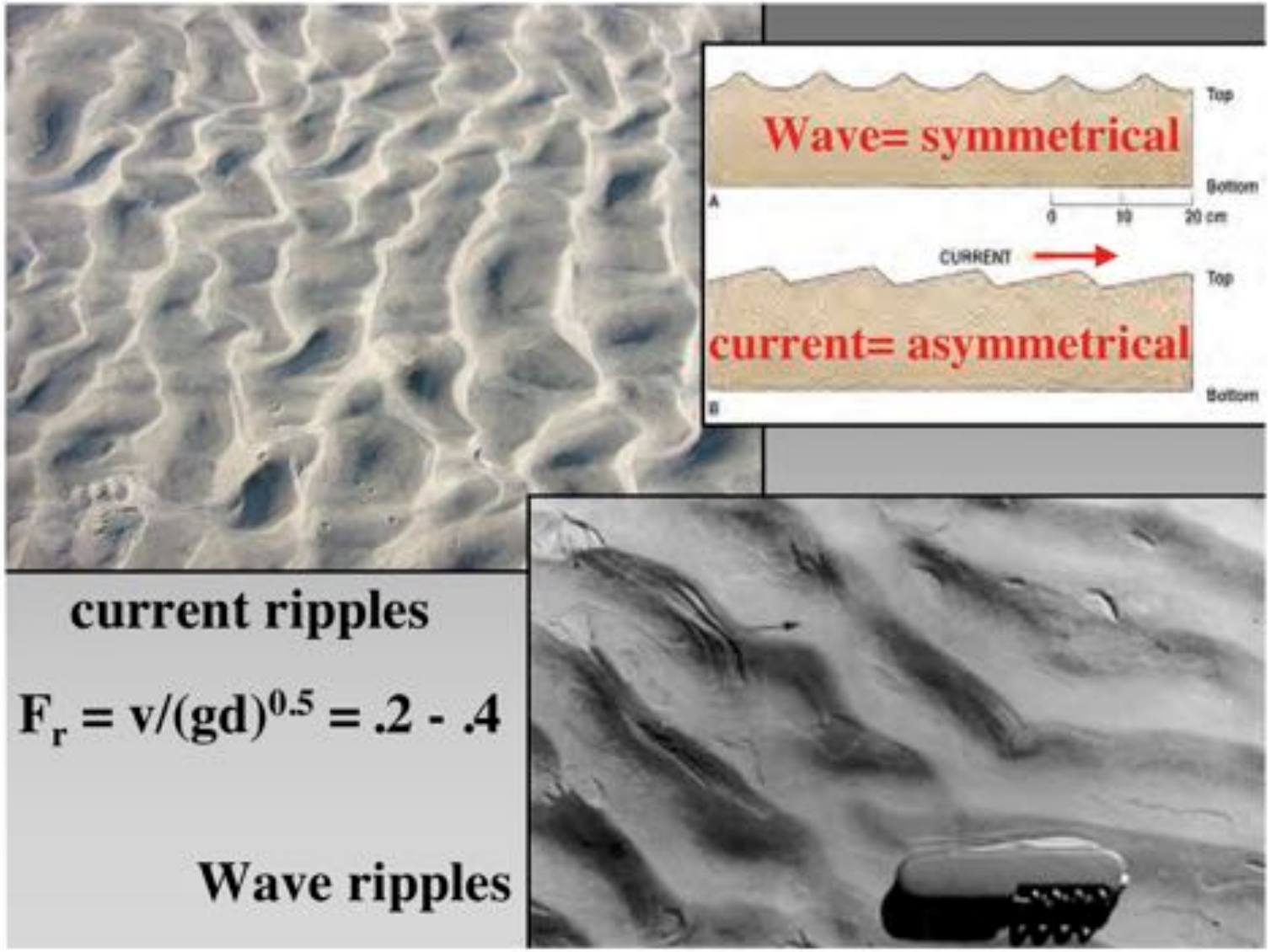
How sediment is moved

Ocean Currents

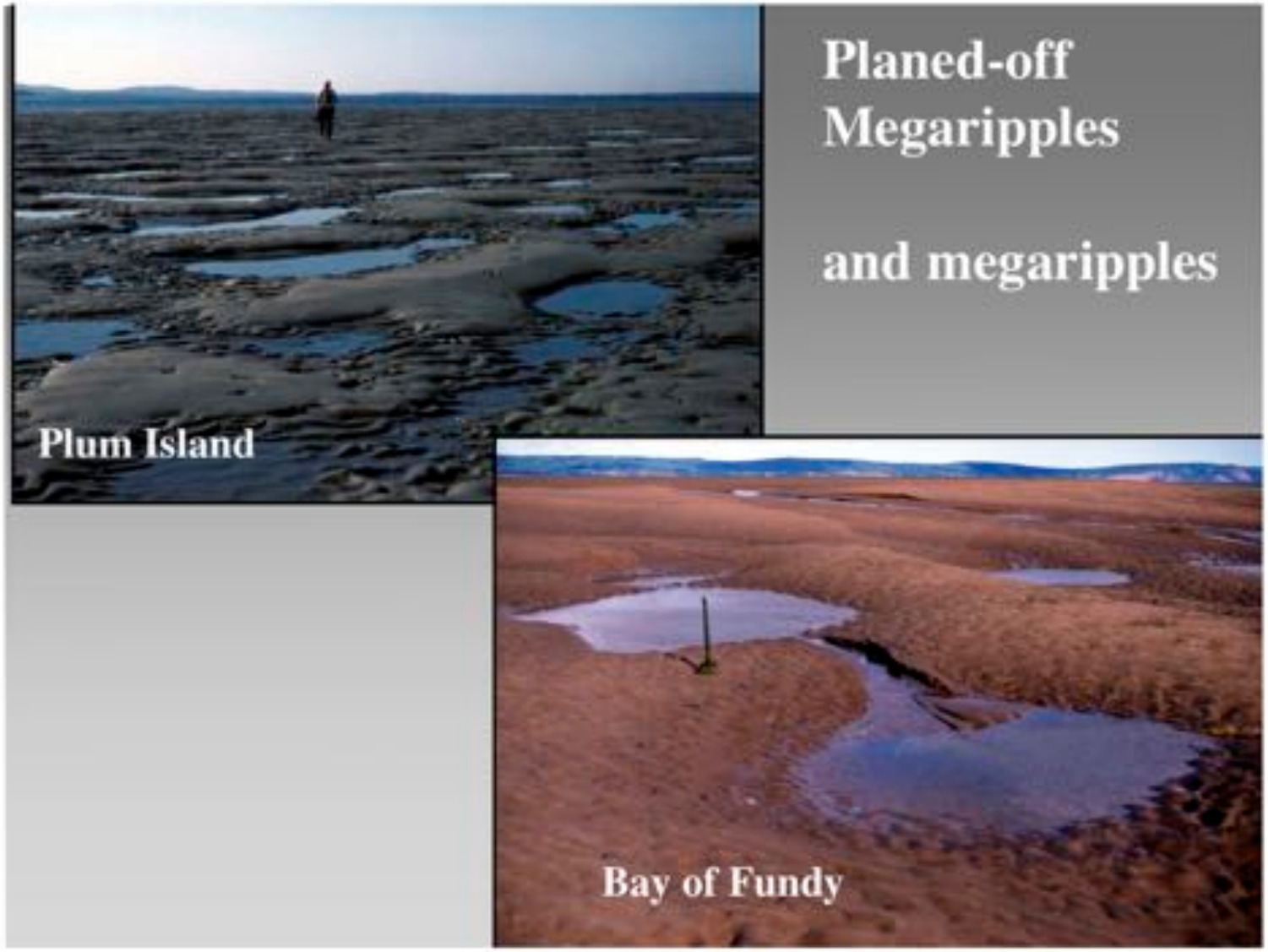


How sediment is moved



Images: D. Belknap

How sediment is moved



Images: D. Belknap

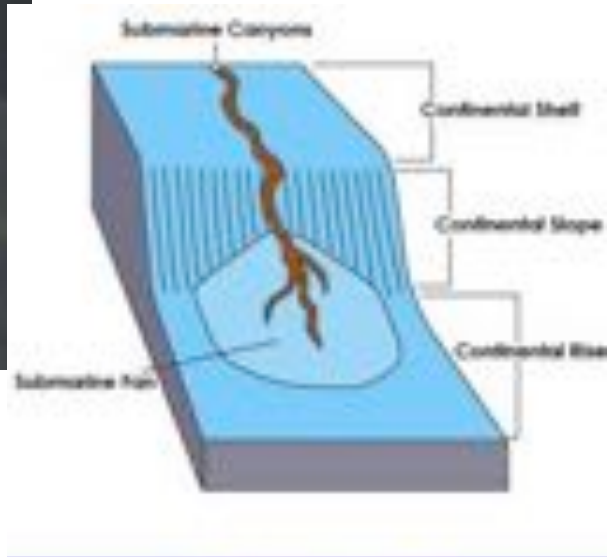
How sediment is moved

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

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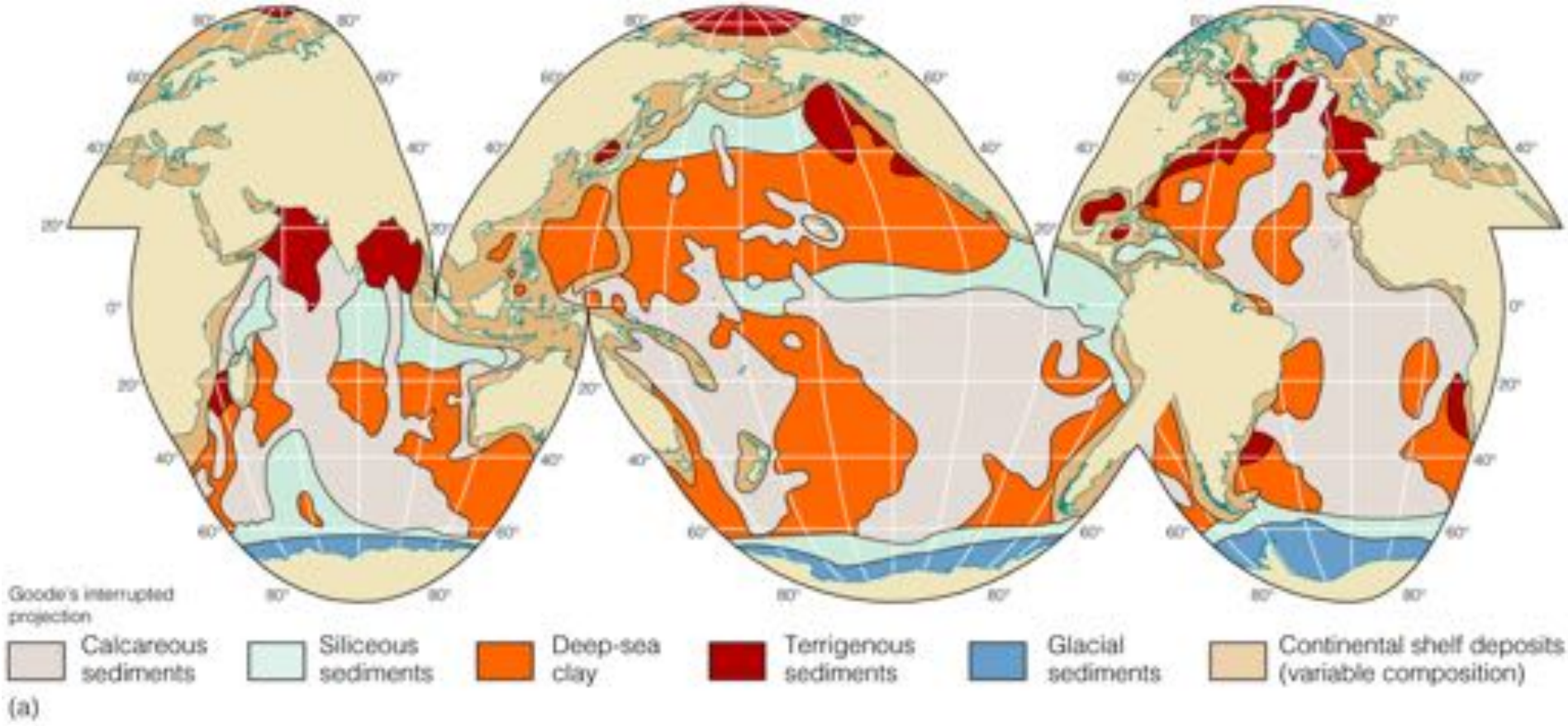
Surface Sediment Distribution



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

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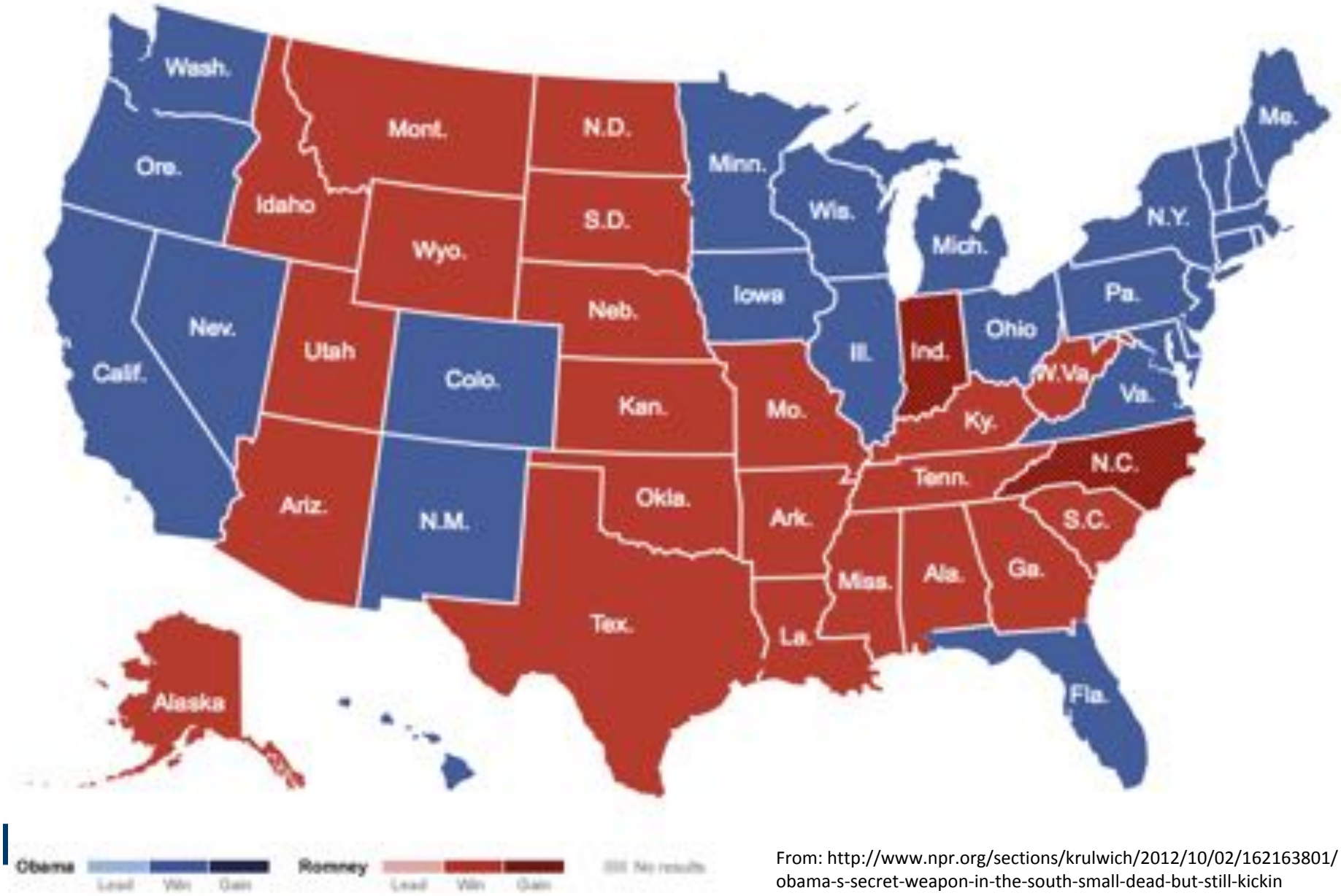
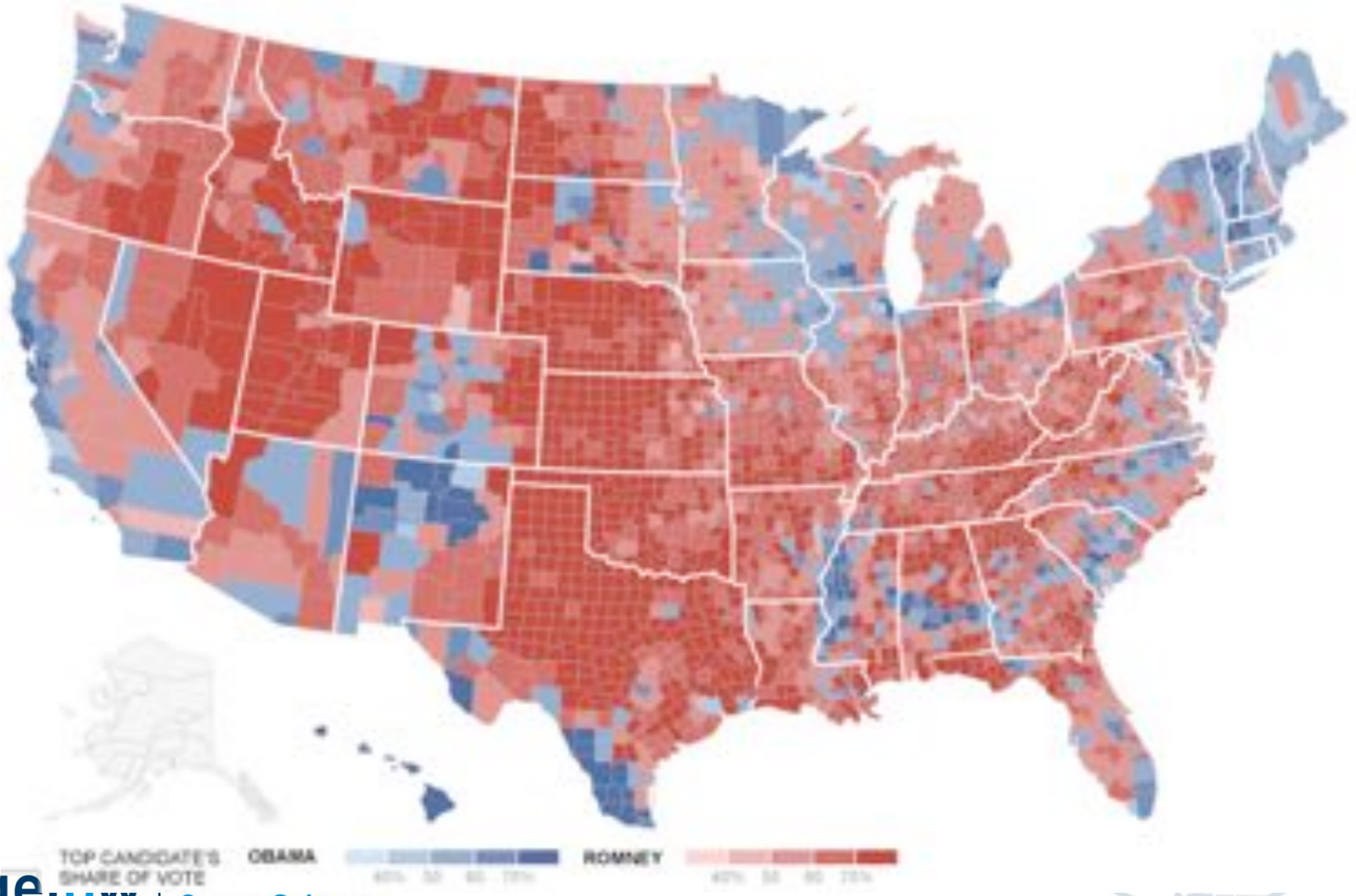
Crossing disciplines: Sedimentation and politics

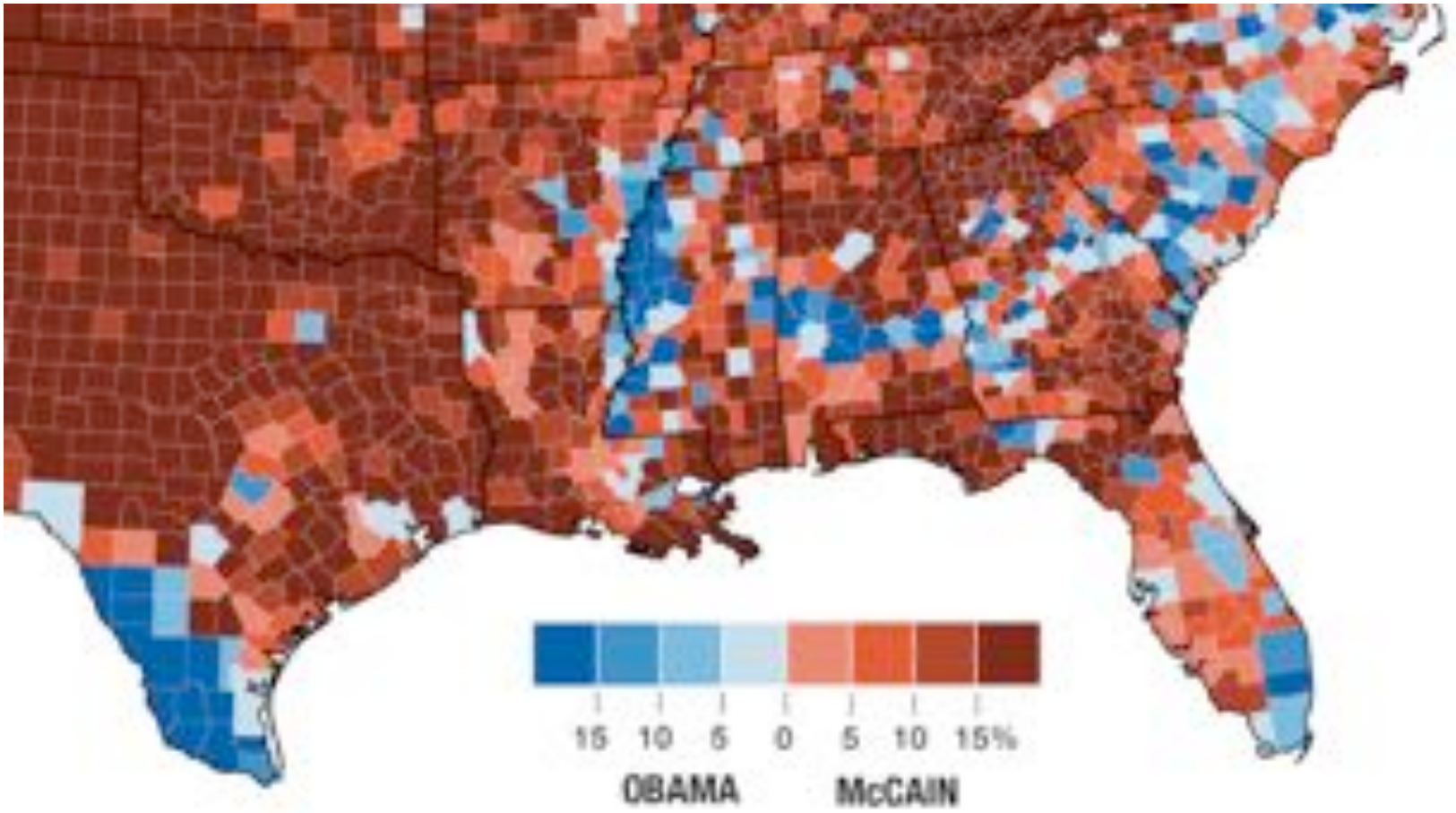


From: http://www.npr.org/sections/krulwich/2012/10/02/162163801/obama-s-secret-weapon-in-the-south-small-dead-but-still-kickin

U.S. Election 2012

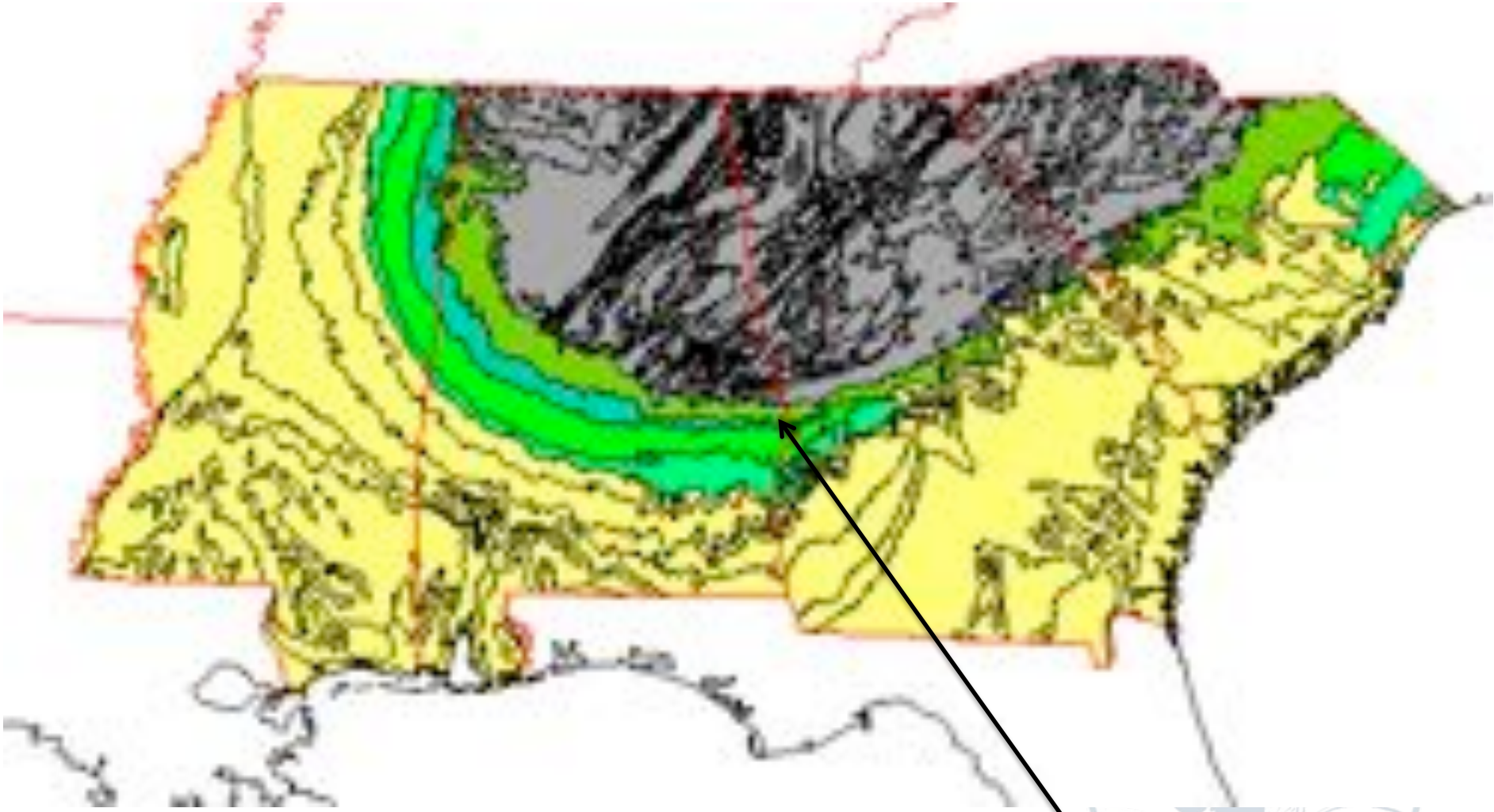


US Election 2008



Late Cretaceous
85 mya

U.S. Election and ancient oceans



The "Black Belt" - Fertile Cretaceous soils
Formed by plankton

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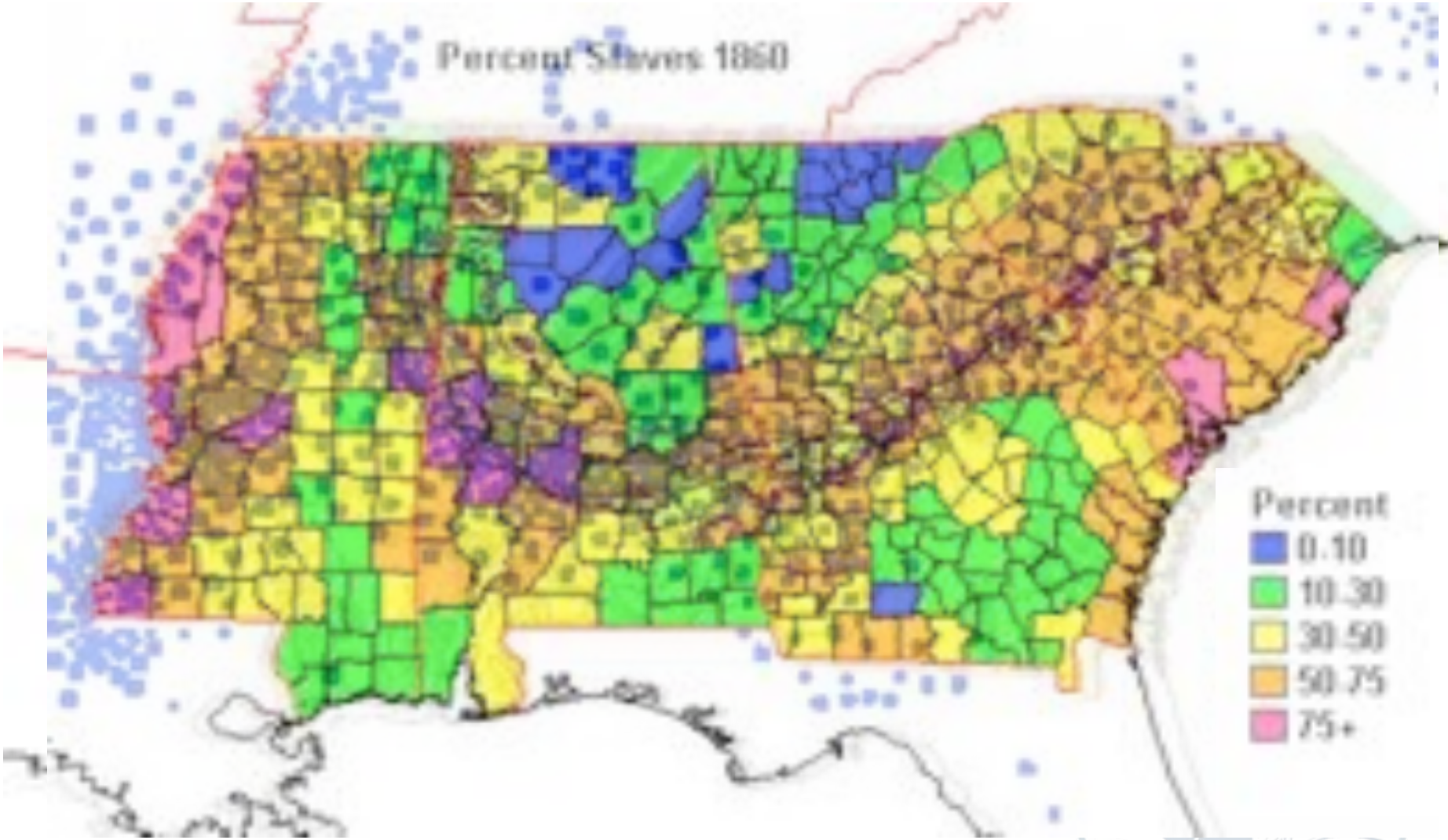
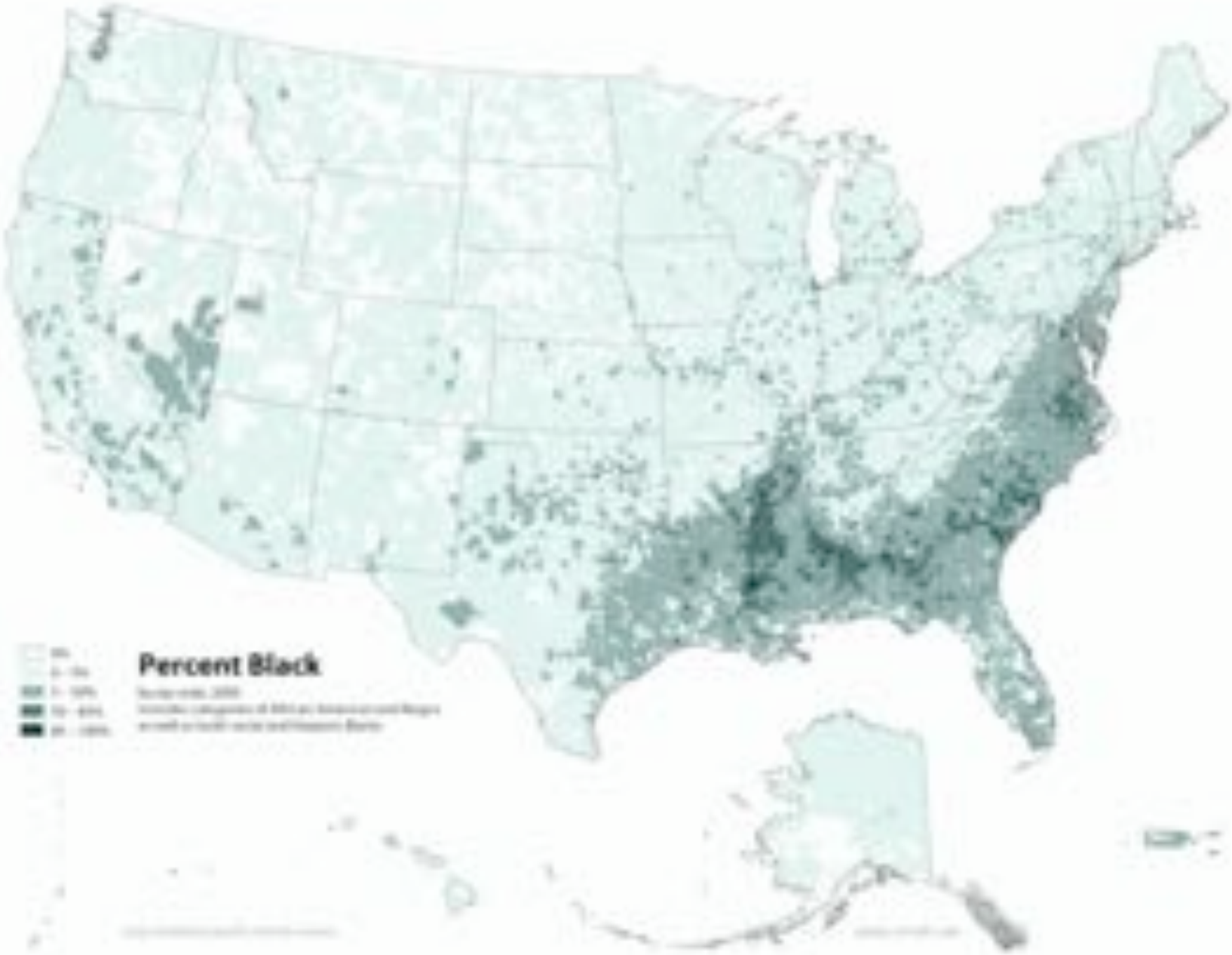
U.S. Election and ancient oceans

U.S. Election and ancient oceans




Percent Black