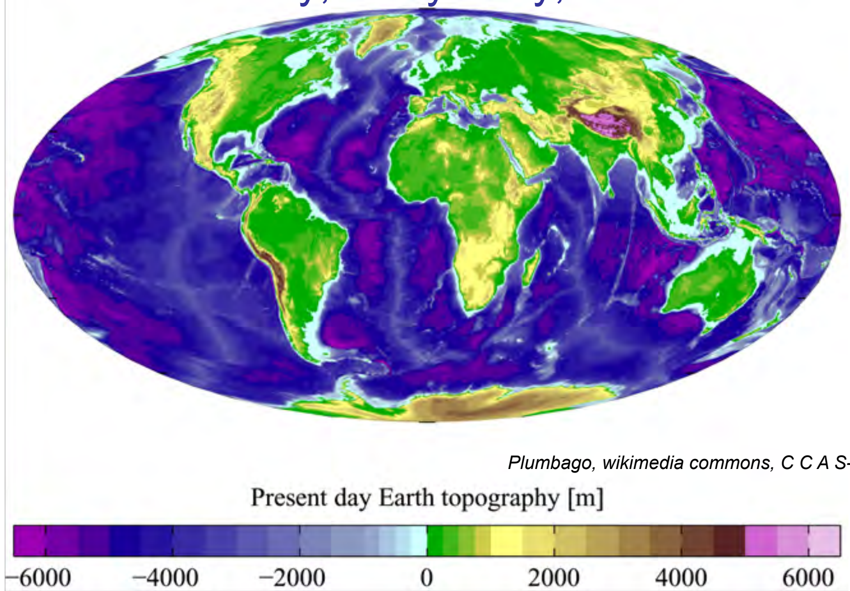
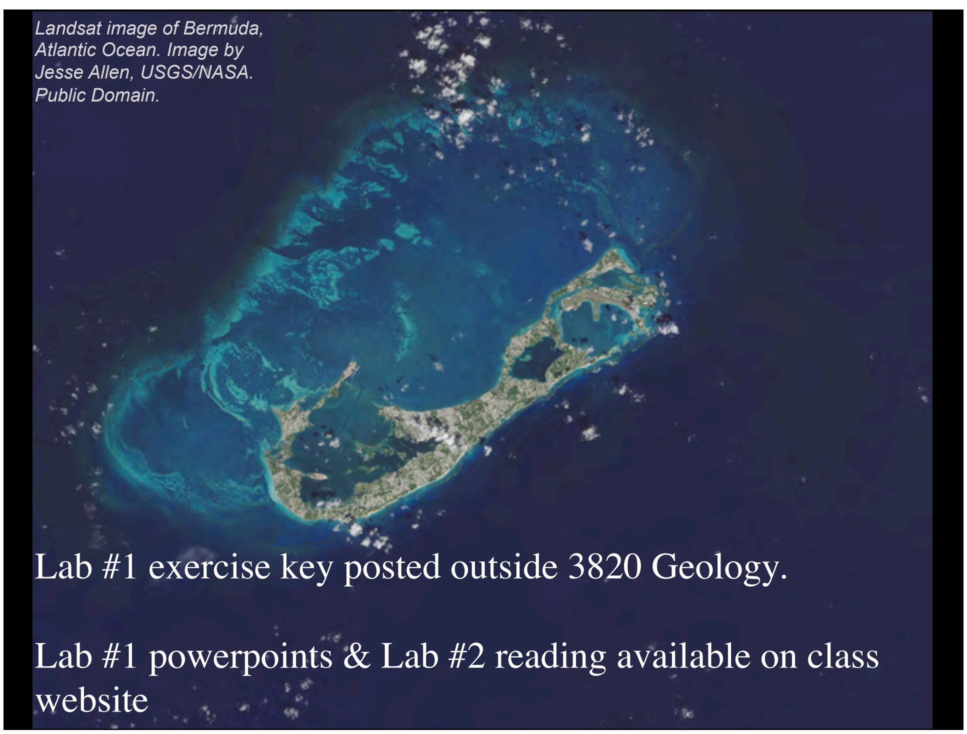
Introduction to Oceanography

Lecture 3: Isostasy, bathymetry, Plate Tectonics



Plumbago, wikimedia commons, C C A S-A 3.0



Landsat image of Bermuda, Atlantic Ocean. Image by Jesse Allen, USGS/NASA. Public Domain.

Lab #1 exercise key posted outside 3820 Geology.

Lab #1 powerpoints & Lab #2 reading available on class website

The Big Picture: Bimodal Distribution

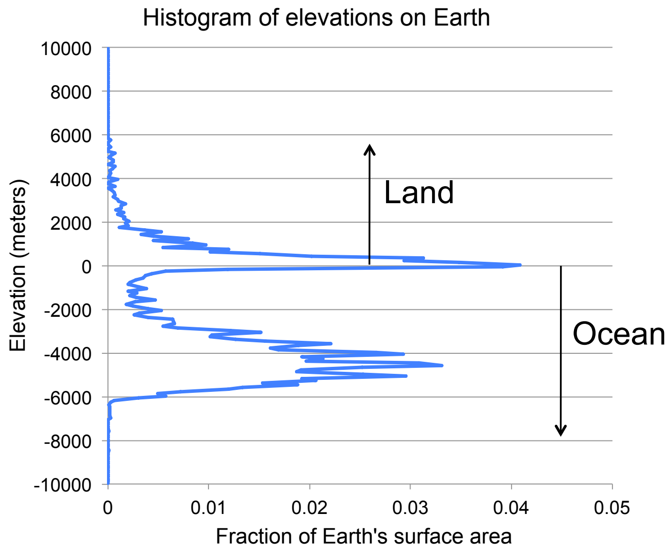


Figure by E. Schauble based on ETOPO5 data (NOAA), as sampled by S.L. Goldstein and S. Hemming, Columbia U. Bin heights are 100m.

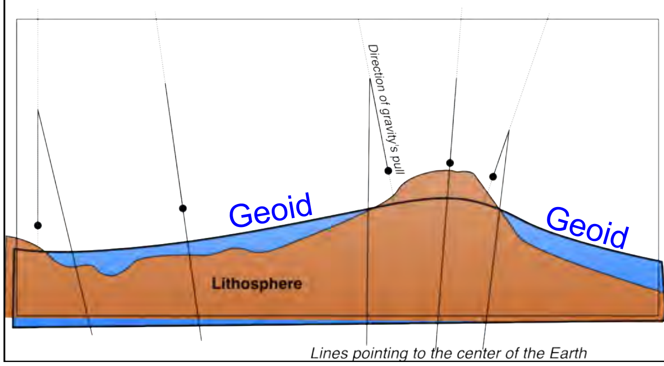
Satellite radar mapping (gravity)

Painting of JASON-2, http://sealevel.jpl.nasa.gov/mission/images/OSTM-06.jpg, Public Domain

Satellites (like TOPEX-Poseidon and Jason-1&2) can measure their distance from the sea surface.

Knowing this distance and the orbit of the satellite, we can determine the topography (shape) of the ocean surface.

Any extra mass on the seafloor will exert extra gravity on the ocean, causing a "hump" in the sea surface.

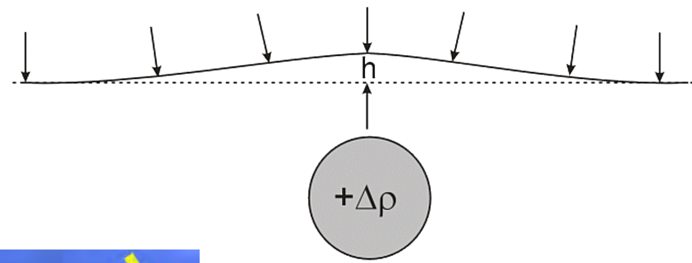


Thus it is possible to extract the seafloor topography

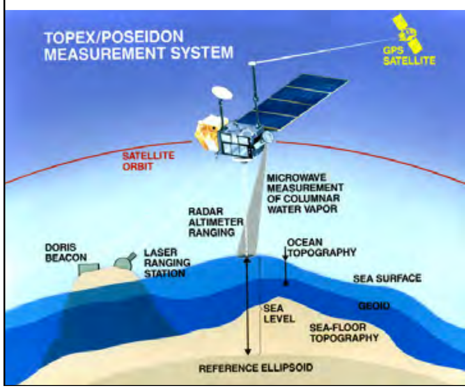
Great spatial coverage, lower resolution & precision (far away).

Modified by E. Schauble from original by MesserWoland, Wikimedia Commons, http://en.wikipedia.org/wiki/File:Geoida.svg, CC A S-A 3.0

Satellite radar mapping (gravity)



http://principles.ou.edu/earth_figure_gravity/geoid/geoid.gif



NASA/JPL image, Public Domain. http://topex-www.jpl.nasa.gov/technology/technology.html

Isostatic Balance

- Blocks of lithosphere (crust + uppermost mantle, ca. 100 km thick) **float** atop the plastic asthenosphere

Which is more like continental lithosphere?

Which is more like oceanic lithosphere?

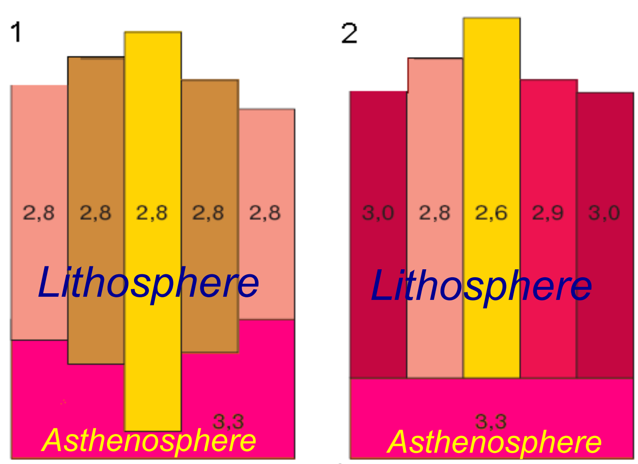
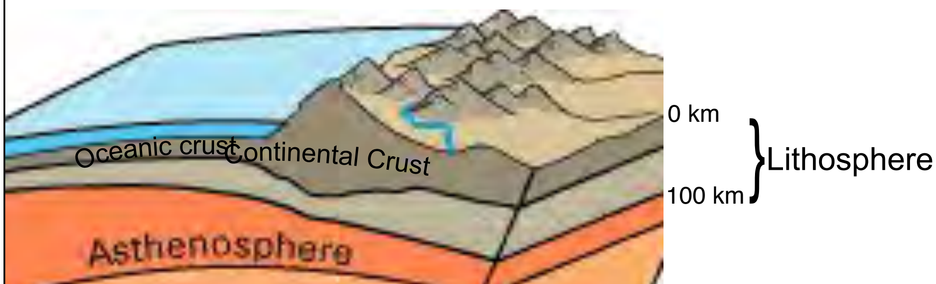


Figure by Kurgus, Wikimedia Commons, Public Domain

Elevation of Continents vs. Oceans



Oceanic Crust: Thinner & Denser

Continental Crust: Thicker & Lighter

Adapted from USGS image, Public Domain

Morphology of the Oceans

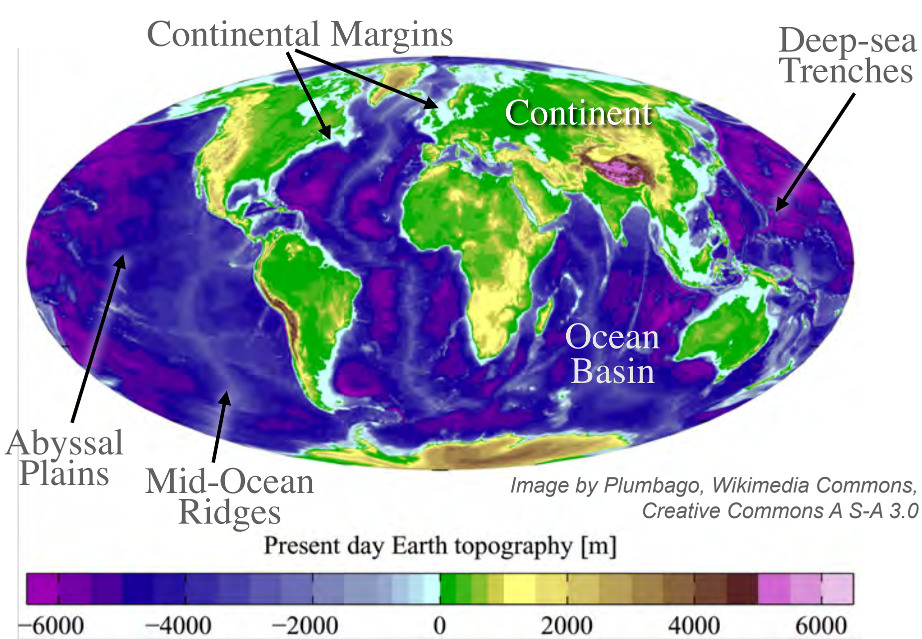


Image by Plumbago, Wikimedia Commons, Creative Commons A S-A 3.0

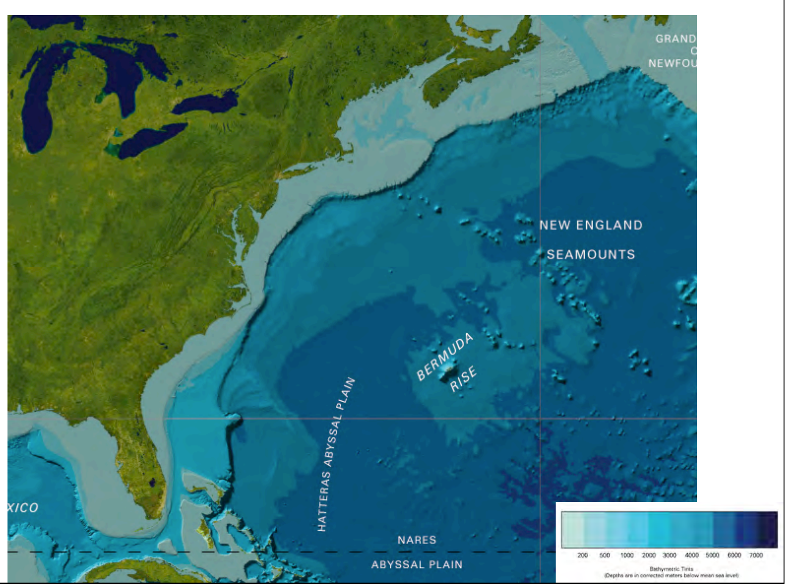
Continental Margins

- Two Types
  - Atlantic style “passive” margins
    - Broad flat shelves
    - Examples are Florida, Virginia
  - Pacific style “active” margins
    - Narrow shelf adjacent to a deep-sea trench
    - Examples are Chile, Japan

Distances and depths of margin features are variable. Active margin features are narrower and extend deeper than on passive margins.

Passive Margins (Atlantic-style)

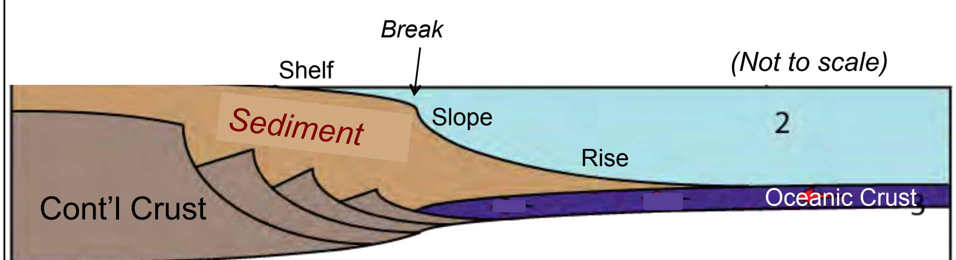
Broad continental shelf, gradual transition to deep ocean.



Bathymetry from GEBCO world map, http://www.gebco.net, educational use expressly allowed.

Passive Continental Margins

- “Drowned” continental sediments pile up adjacent to the continents
- Comprised of:
  - Continental Shelf
  - Shelf Break
  - Continental Slope
  - Continental Rise



Modified from figure by Cidnye, Wikimedia Commons, Public Domain

Continental Shelf

- **Shelf**: terraces of sediment
- Width: variable, ~10 km (active) ~100’s km (passive).
- Slope ≤ 0.5^o
  Very flat
- Ends at the **Shelf Break**
  Occurs at average water depth approx. 140 m (variable)

Figure from NOAA Ocean Explorer, http://oceanexplorer.noaa.gov/technology/tools/mapping/media/GulfofMexico.jpg Public Domain

Continental Slope

- Beyond Shelf Break is the **Continental Slope**
- Much steeper, ~4^{o}
- Depths: to ~3-4 km
- Typical width ~20 km

Figure from NOAA Ocean Explorer, http://oceanexplorer.noaa.gov/technology/tools/mapping/media/GulfofMexico.jpg Public Domain

Continental Rise

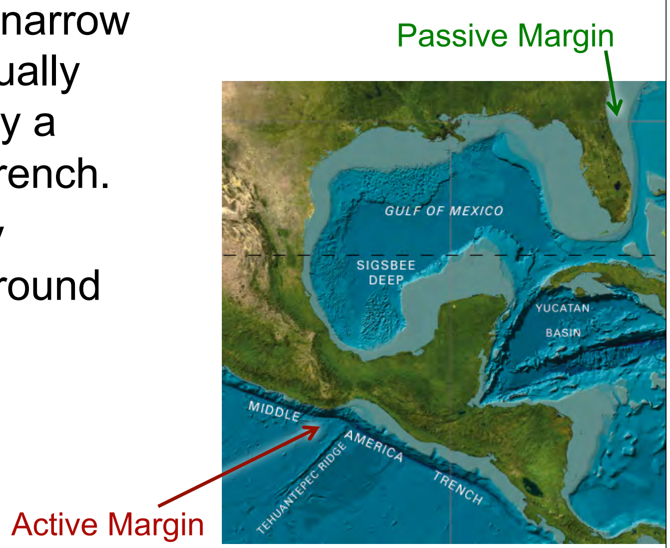
- At the base of the continental slope
- Slope lessens
- Depths: from ~2km - 5km
- Width: ~ 100-1000 km
- Sedimentary "apron" or "fan"

Bathymetry from GEBCO world map, http://www.gebco.net, educational use expressly allowed.

Turbidity currents and the slope

Active Margins

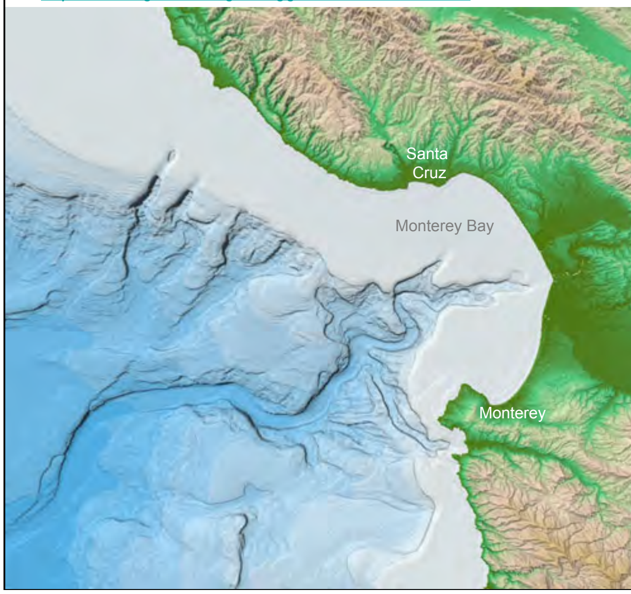
- A steeper, narrow margin, usually bordered by a deep sea trench.
- Particularly common around the Pacific Ocean.



Bathymetry from GEBCO world map, http://www.gebco.net, educational use expressly allowed.

Submarine Canyons

Image from Divins, D.L., and D. Metzger, NGDC Coastal Relief Model, http://www.ngdc.noaa.gov/mgg/coastal/coastal.html. Public Domain

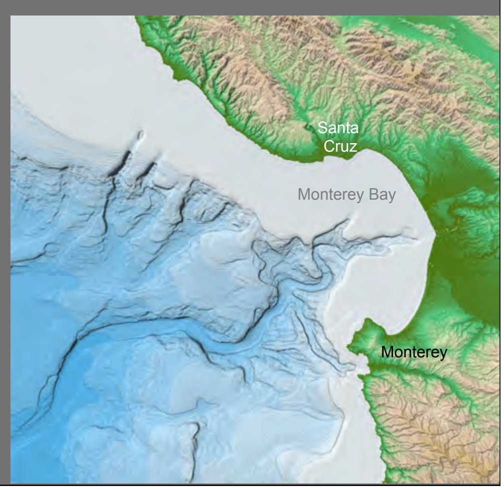


- Erosional incisions through shelf and slope
- Transport sediments from the rise out onto abyssal plains
  - Turbidity currents
    - Transport sediments onto Abyssal Plains

Submarine Canyons, carved by debris flows and turbidity currents, not rivers

Movie by AGU & Lai et al. Morphohydraulics Imaging Laboratory, National Cheng Kung University, Taiwan. http://blogs.agu.org/geospace/2016/05/24/watch-underwater-canyons-take-shape-real-time/

Image from Divins, D.L., and D. Metzger, NGDC Coastal Relief Model, http://www.ngdc.noaa.gov/mgg/coastal/coastal.html. Public Domain



Deep-Sea Trenches

Depths: 5 - 11 km

Widths: 30 - 100 km

Associated with volcanism and island arcs

- i.e., the Andes and the Aleutians, respectively

Also associated with the strongest and deepest earthquakes on the planet

Including last week's Chile earthquake

Passive Margin

Same image credit as prevous slide.

Active Margin

Deep-Sea Trenches

The Ring of Fire – Trenches, earthquakes and volcanoes concentrated along the Pacific, including active margins.

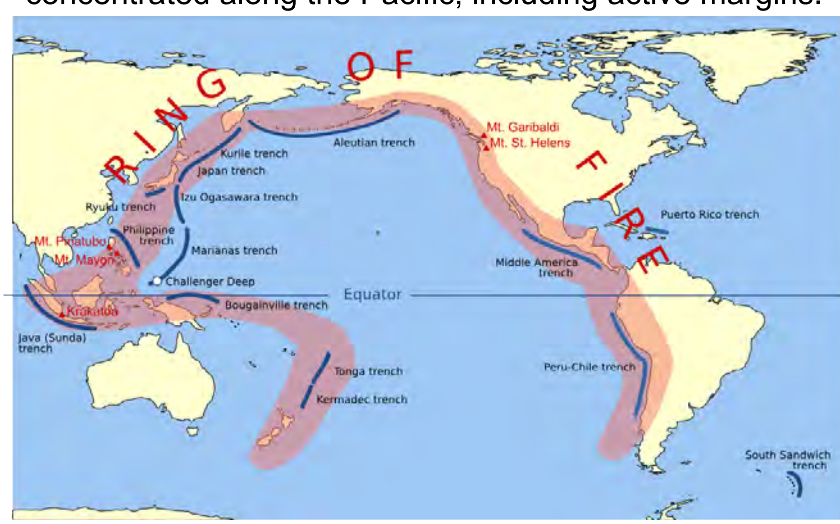
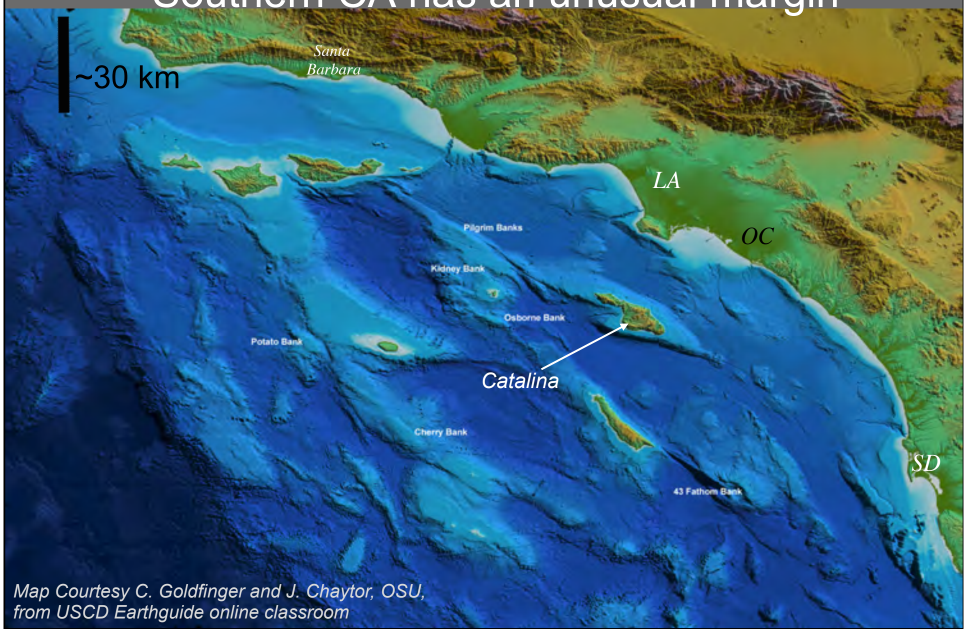


Figure by Gringer, Wikimedia Commons, Public Domain, http://en.wikipedia.org/wiki/File:Pacific_Ring_of_Fire.svg

Southern California Margin

- Southern CA has an unusual margin

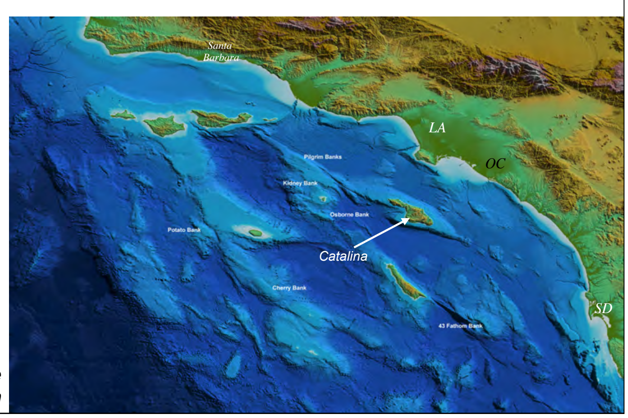


Map Courtesy C. Goldfinger and J. Chaytor, OSU, from USCD Earthguide online classroom

Southern Californian Borderland

- Pervasive active faulting and tectonics
  - No broad flat shelf region
  - Instead, fault bounded ridges and basins
  - Ridges can form islands (i.e., Catalina)
  - Basins can be 1 - 2 km deep
  - Continental slope ~80-100 km west

Los Angeles sits on a silted up basin!



Map Courtesy C. Goldfinger and J. Chaytor, OSU, from USCD Earthguide online classroom

Deep Ocean Basins

What about in the very center of the ocean basins?

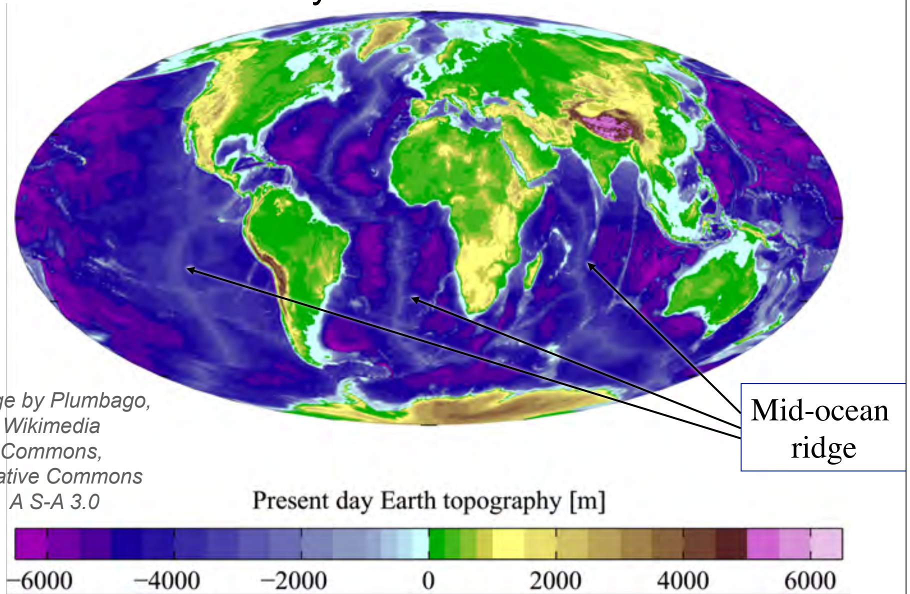
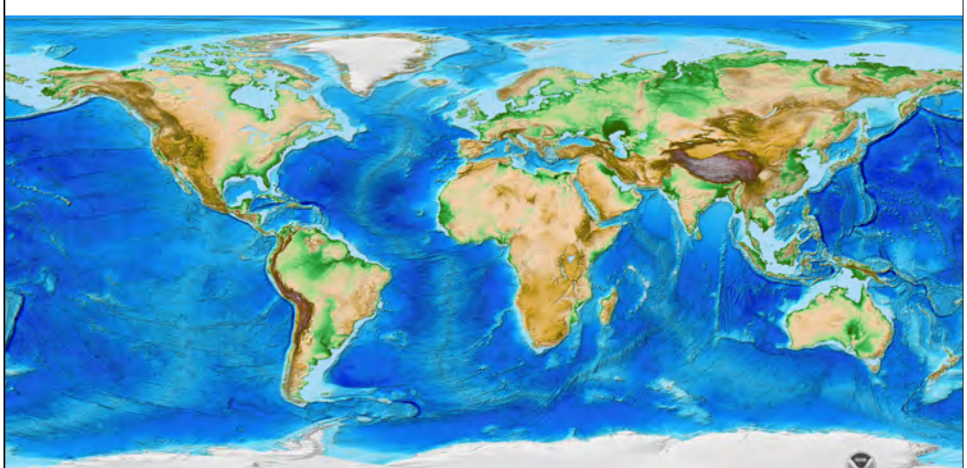


Image by Plumbago, Wikimedia Commons, Creative Commons A S-A 3.0

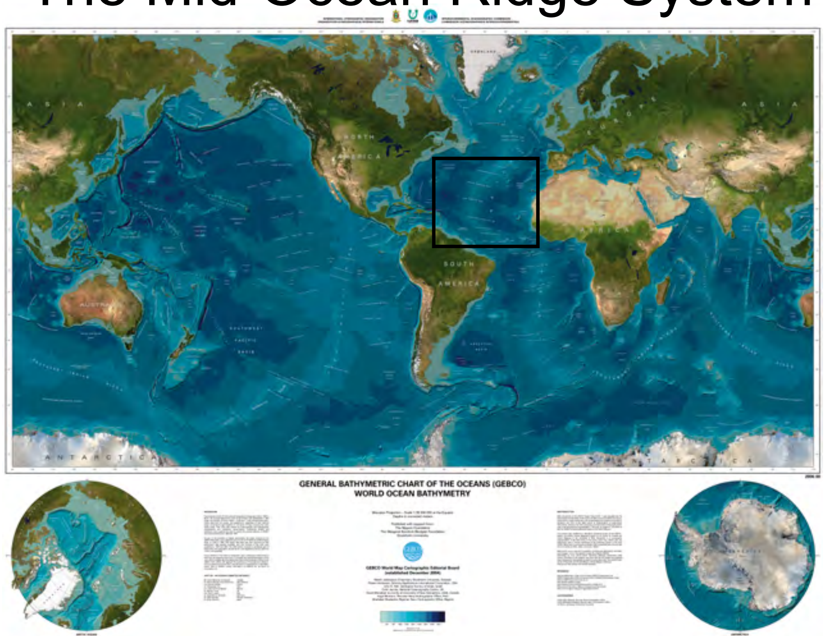
Mid-Ocean Ridges

- Earth's longest continuous mountain chain
  - ~ 60,000 km long, ~1/3 of ocean floor area
  - Relief: ~ 2-3 km above abyssal plains



NOAA global relief map, Public Domain

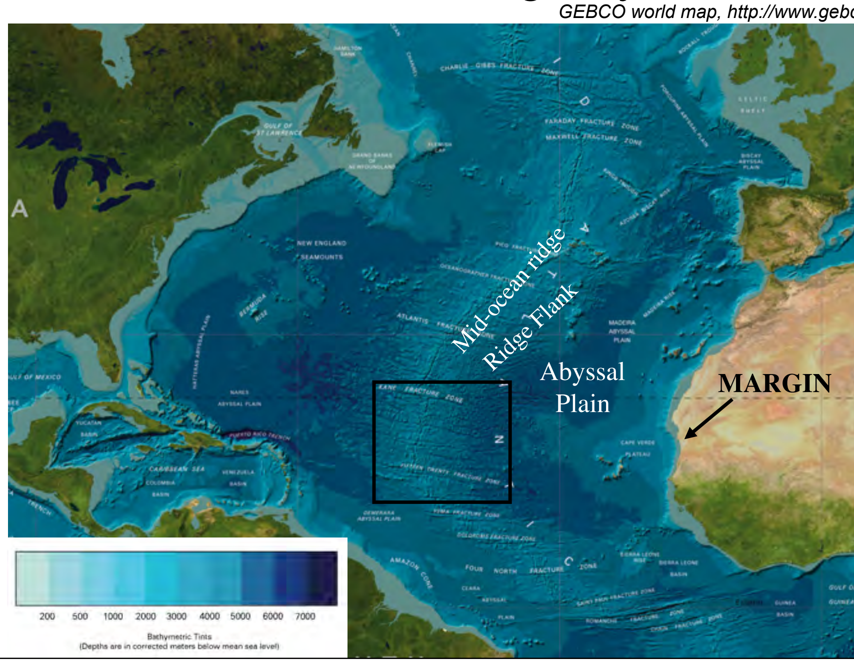
The Mid-Ocean Ridge System



Bathymetry from GEBCO world map, http://www.gebco.net, educational use expressly allowed.

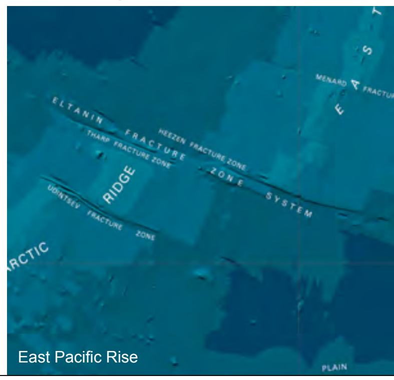
The Mid-Ocean Ridge System

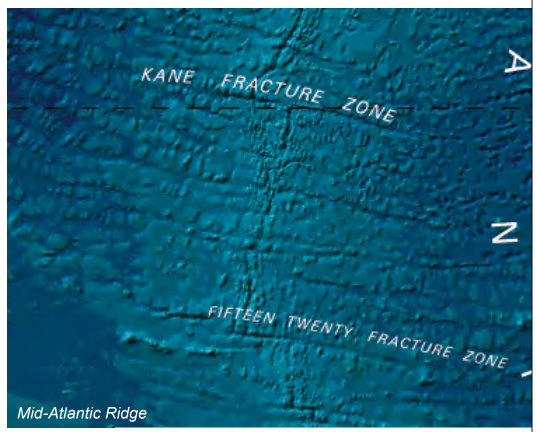
GEBCO world map, http://www.gebco.net

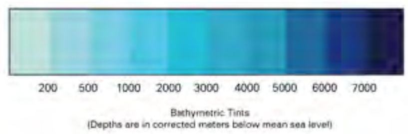


Mid-Ocean Ridge Features

- Ridge Axis Rift Valley
  - Depth ~ 1 km, Width ~ 10 -20 km
  - Widespread volcanism
  - Shallow earthquakes
  - Perpendicular fractures



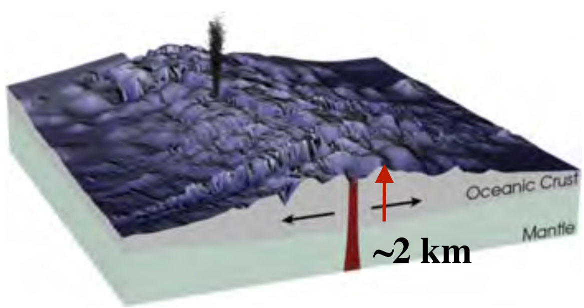




Both images from GEBCO world map, http://www.gebco.net, education use allowed.

Mid-Ocean Ridges & Isostasy

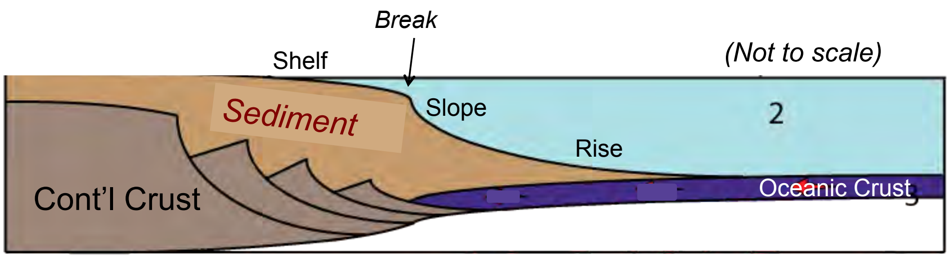
- Keeping isostasy in mind, why do mid-ocean ridges stand up so high above the ocean bottom?



NASA art, http://en.wikipedia.org/wiki/File:Ridge_render.jpg, Public Domain

Questions?

- Why do we have oceanic and continental crusts?
- Why are there deep-sea trenches, mid-ocean ridges and long seamount chains?



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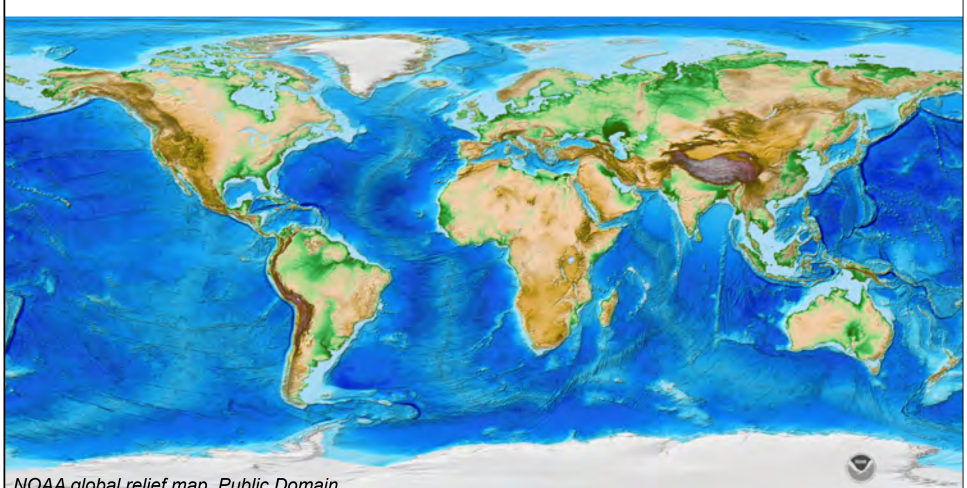
Introduction to Plate Tectonics



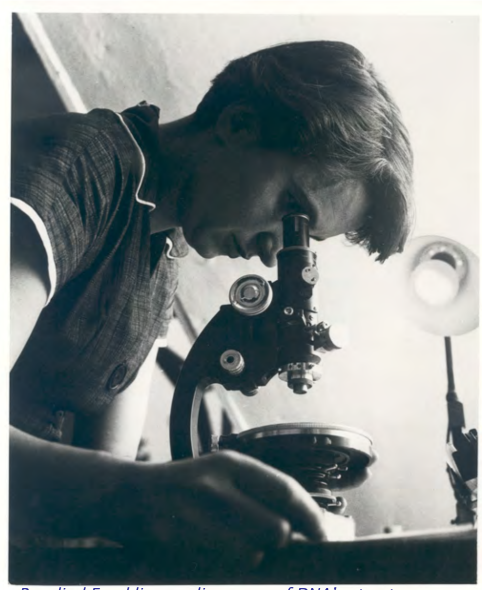
NOAA global relief map, Public Domain

History of Plate Tectonic Theory

- Plate tectonics is a fundamental, unifying theory in all of the Earth Sciences.
- Explains locations of most earthquake zones, volcanoes, the age of the sea floor, and the shape of the Earth's surface.
- Plate tectonic theory has only been accepted for ~40 years
  - more recent than evolution (Biology - late 1800's), quantum mechanics (Phys/Chem - early 1900's).
- Why? – the best evidence is under water!

The Scientific Method

- The process whereby scientists build accurate models of natural phenomena
  - Accurate: consistent and non-arbitrary
  - Empirical: based on observation and measurement



Rosalind Franklin, co-discoverer of DNA's structure. Image from NIH, http://profiles.nlm.nih.gov/KR/B/B/H/K/, Henry Grant Archive/Museum of London, Public Domain

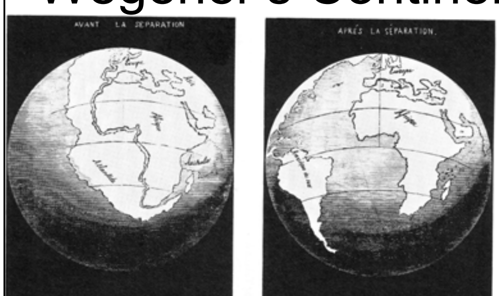
Alfred Wegener, 1930, image from Alfred Wegener Institute, Public Domain

The Scientific Method

- 1) **Observe** phenomenon
- 2) Generate a **<u>testable</u>** **hypothesis** to explain phenomenon
  - – Untestable hypotheses cannot become scientific theories
  - – Earliest hypothesis of Plate Tectonics proposed by Alfred Wegener (1912): *<u>Continental Drift</u>*
- 3) Test hypothesis

What did Wegener observe?

Wegener's Continental Jigsaw Puzzle

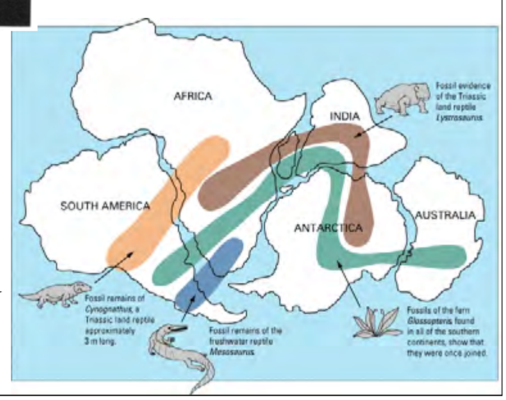


Observation: 1. The coastlines of the continents around the Atlantic Ocean appear to fit together (particularly South America and Africa).
Australia, India, Antartica and Madagascar also seem to fit together.

Opening of the Atlantic, Antonio Snider-Pellegrini, 1858, Public Domain

Observation 2: When the continents are fit together, many geologic features line up across the boundaries.

Examples include mountain belts, types of fossils, belts of ~200 million year old and older rocks)



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

Distribution of *Eurydesma*

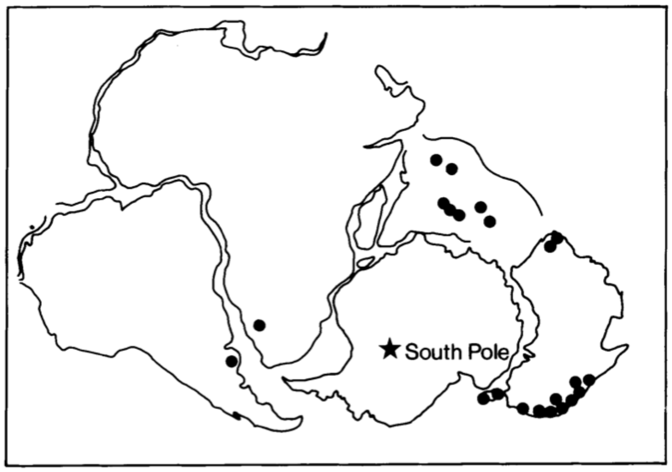


Fig. 2. Known distribution of *Eurydesma* in Gondwanaland; sites shown by solid circles.

Figure from Runnegar (1979) Alcheringa 3, 11:30:261-285

The Scientific Method

- 3) **Experiments** test if hypothesis is valid
  - Can the hypothesis predict the results for related phenomena?
    - Wegener's hypothesis is incomplete:

If continents drift and oceans close, what happens to the rocks in the ocean crust?

- In 1910's little was known about the ocean floor and Earth's interior. Few instruments to make measurements.
- BUT - from 1930's through 1950's much was learned about Earth structure, the age of rocks, and the seafloor.

USS Sea Owl, Navy image, Public Domain

- WWII and Cold war ocean surveys, global satellite gravity surveys & global seismometer stations provide the necessary clues

Probing the Earth with Seismology

- Cold, brittle crust
- Energy radiates out as seismic waves
- Like a flash bulb inside the Earth

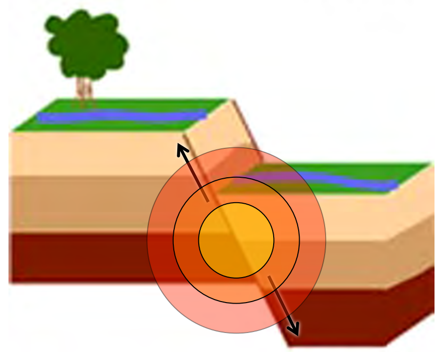
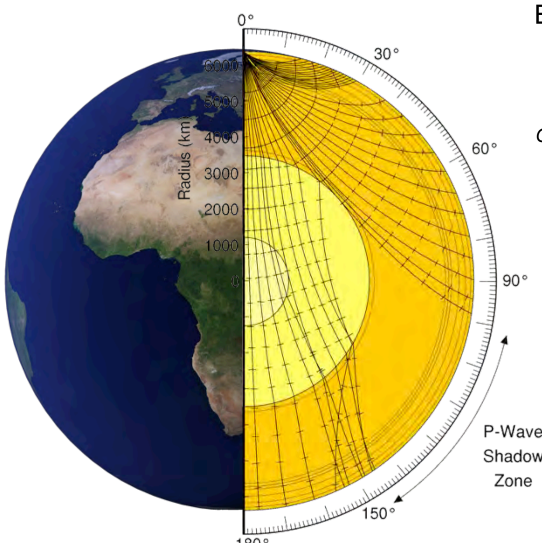


Figure by E. Schauble, modified from a USGS image, Public Domain.

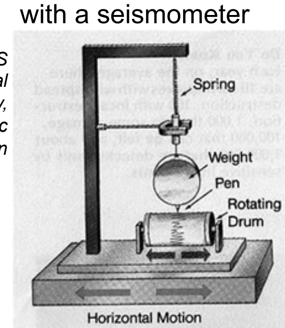
Probing the Earth with Seismology



Modified from NASA, Wikimedia Creative Commons images

Earthquake waves are detected with a seismometer

USGS Visual Glossary, Public Domain



Modern low-frequency seismometer, viewed from above. Photo by Hannes Grobe, Creative Commons A S-A 2.5

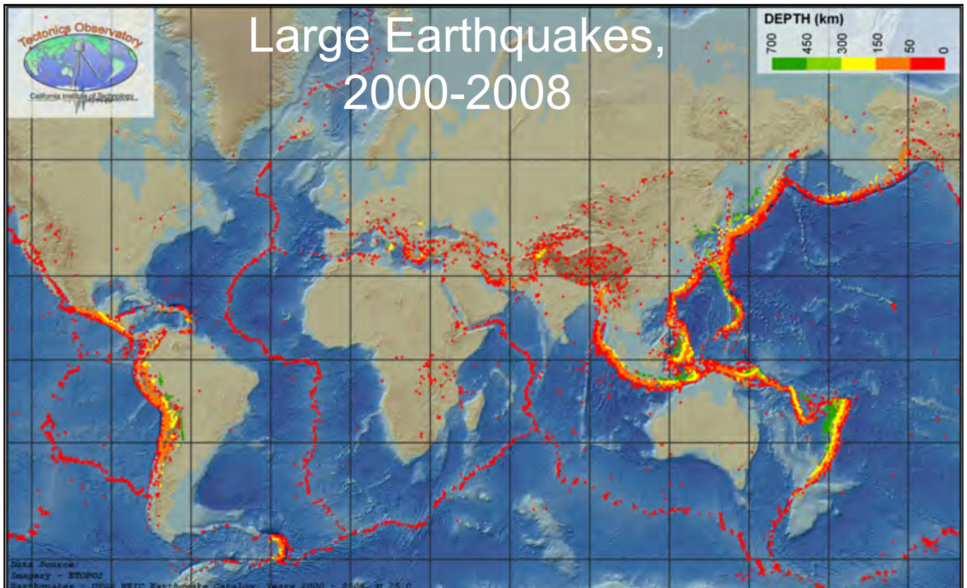
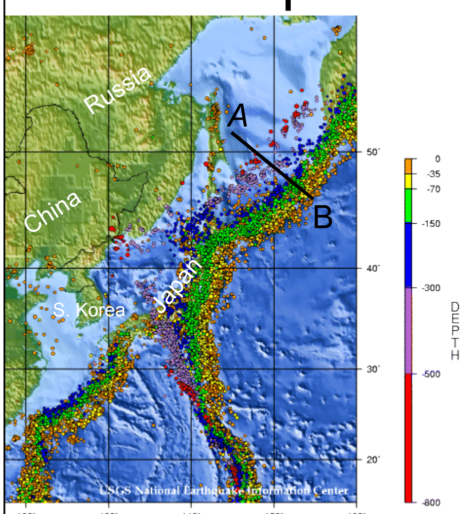


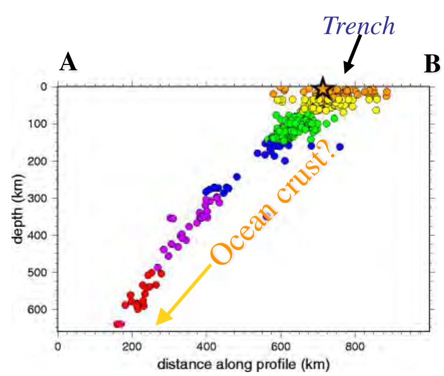
Image from NSF/Caltech, www.nsf.gov/news/mmg/media/images/global_seismicity_h.jpg, Public Domain

Observation 3: Earthquakes are concentrated in a few "strips" or lines near the Earth's surface. This suggests "cracks" or boundaries between rigid areas.

Earthquakes near Trenches



USGS Natl. Earthquake Center, Public Domain



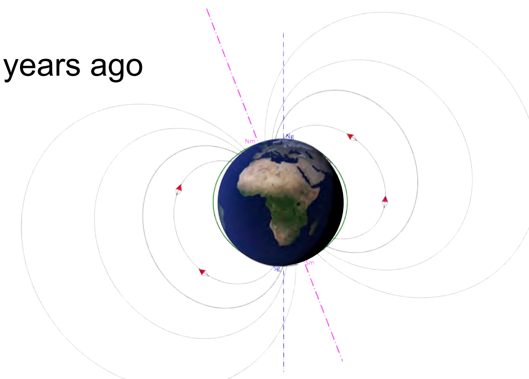
USGS Natl. Earthquake Center, Public Domain

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.

Records of Earth's magnetic field

- Convection in outer core generates the Earth's magnetic field
  - Dominantly dipolar magnetic field
    - like a bar magnet aligned near the rotation axis
  - Magnetic poles reverse locations ~1/250,000 years
  - Last reversal ~780,000 years ago

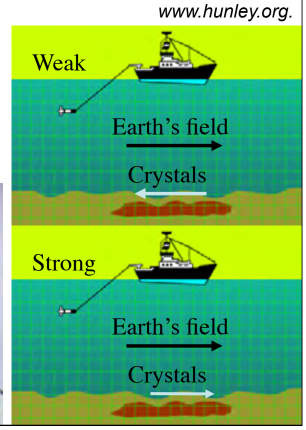


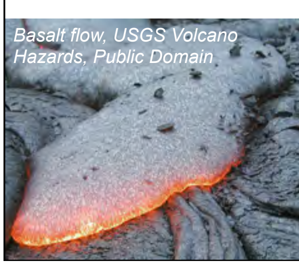
E. Schauble, modified from images by NASA and JrPol (Public Domain & Creative Commons Share Alike

Dating rocks with magnetism

- At volcanoes, molten rock erupts and cools. As it cools crystals form (it solidifies).
- Some crystals with iron in them are magnetic. They tend to line up with the Earth's magnetic field when they cool down.
- If the Earth's magnetic field reverses, the crystal magnets stay put -- they are frozen in place.
- A magnetometer towed behind a boat will pick up a weak field if the crystal magnets point the opposite direction from the Earth's field. (They partly cancel each other out).
- A magnetometer will pick up a strong field if the crystals point the same direction and the Earth's magnetic field.

Modified by E. Schauble, from image at www.hunley.org.

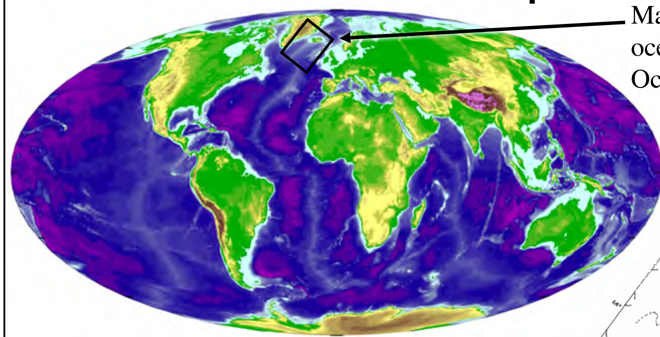




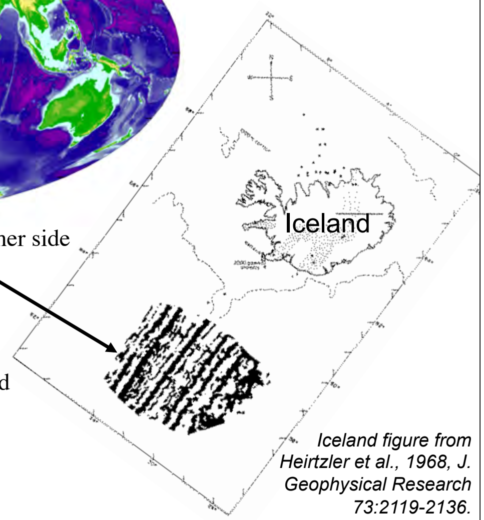
Basalt flow, USGS Volcano Hazards, Public Domain

Magnetite, photo by Density, Creative Commons A S-A 3.0

The oceanic "tape recorder"



Magnetic survey of a mid-ocean ridge in the Atlantic Ocean near Iceland.



Areas of strong and weak magnetism on either side of the mid-ocean ridge are mirror-images

The crest of the ridge has strong magnetism (I.e. crystals and Earth aligned.)

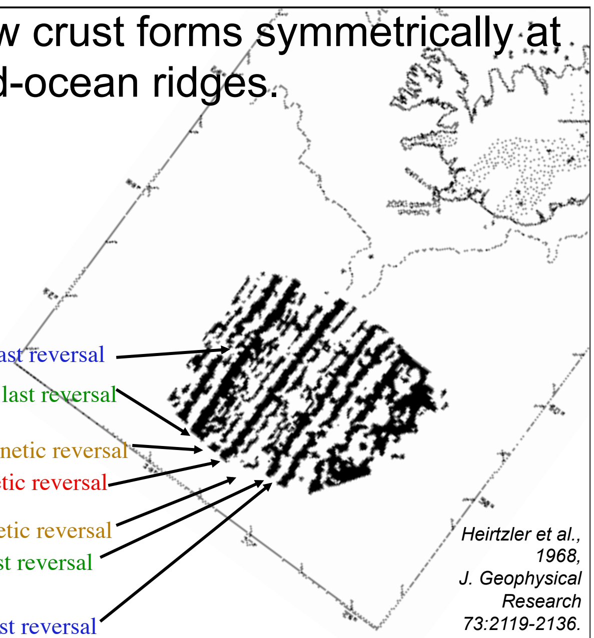
Farther away weaker magnetism (Crystals formed when the Earth's field was reversed),

Many oscillations from strong to weak.

Globe image by Plumbago, Wikimedia Commons, Creative Commons A S-A 3.0

Iceland figure from Heirtzler et al., 1968, J. Geophysical Research 73:2119-2136.

Interpretation: New crust forms symmetrically at mid-ocean ridges.



Crust formed just before 3rd to last reversal

Crust formed just before 2nd to last reversal

Crust formed just before last magnetic reversal

Crust formed since last magnetic reversal

Crust formed just before last magnetic reversal

Crust formed just before 2nd to last reversal

Crust formed just before 3rd to last reversal

Heirtzler et al., 1968, J. Geophysical Research 73:2119-2136.

This interpretation is confirmed by the age of sediments and volcanic rocks on the seafloor (youngest at the top of the ridge).