Introduction to Oceanography

- Lecture 5: Plate Tectonics 3

Landers earthquake fault scarp, California, Photo by G. Peltzer (UCLA/JPL/NASA), courtesy JPL, http://www-radar.jpl.nasa.gov/sect323/InSar4crust/Landers_Co_fig1.jpg

Introduction to Oceanography

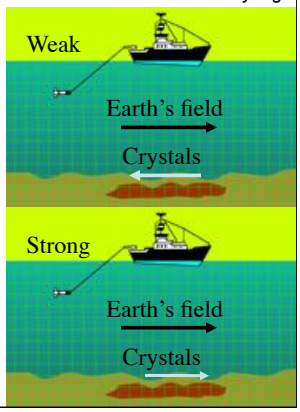
- Extra Credit update
- First midterm on Thursday of next week.

Satellite image of a divergent plate boundary on land – Afar, Ethiopia, NASA, Public Domain, http://visibleearth.nasa.gov/view_rec.php?id=17296

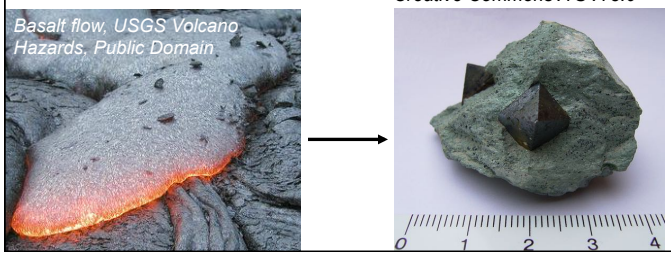
Dating rocks with magnetism

- 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.

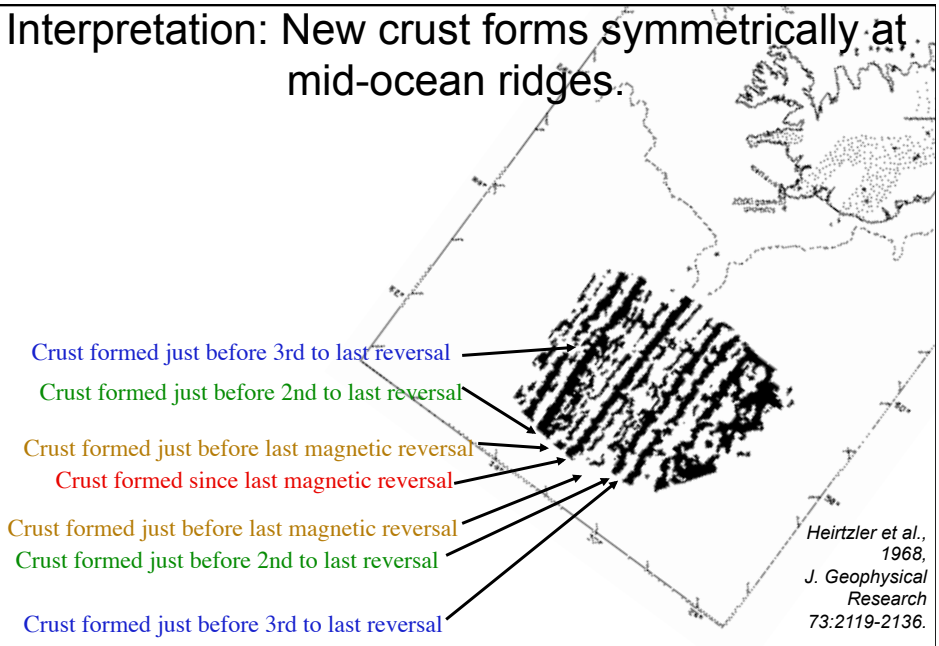
Modified by E. Schauble, from image at www.hunley.org.



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

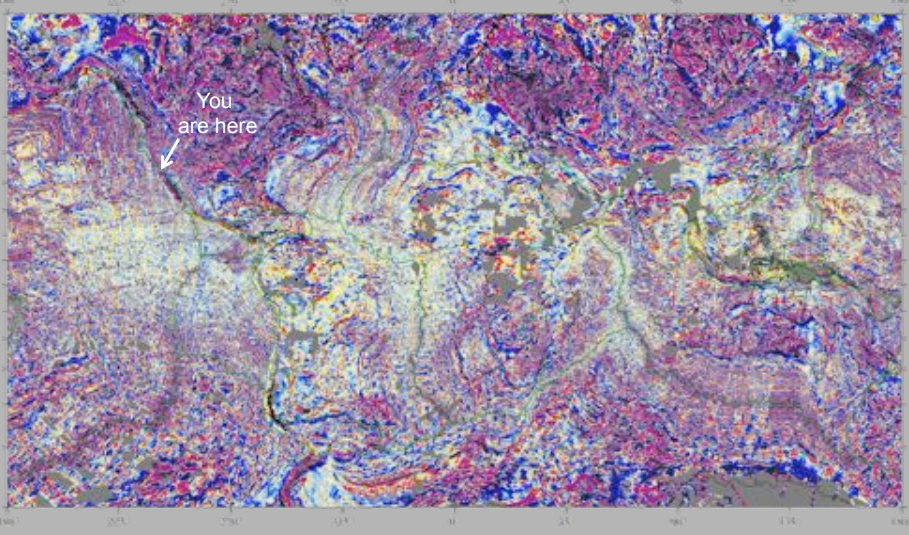


Interpretation: New crust forms symmetrically at mid-ocean ridges.



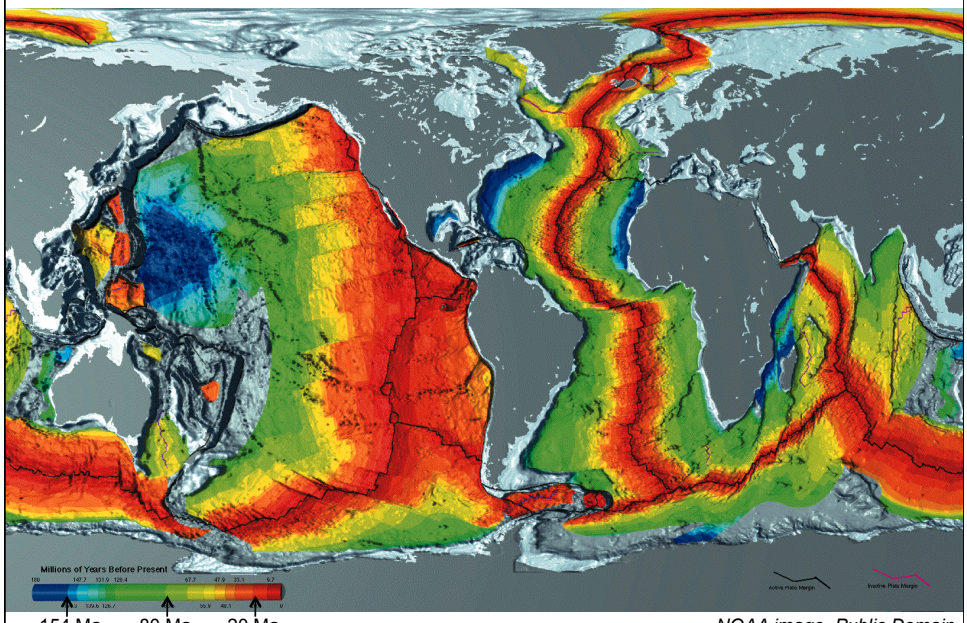
Heirtzler et al., 1968, J. Geophysical Research 73:2119-2136.

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



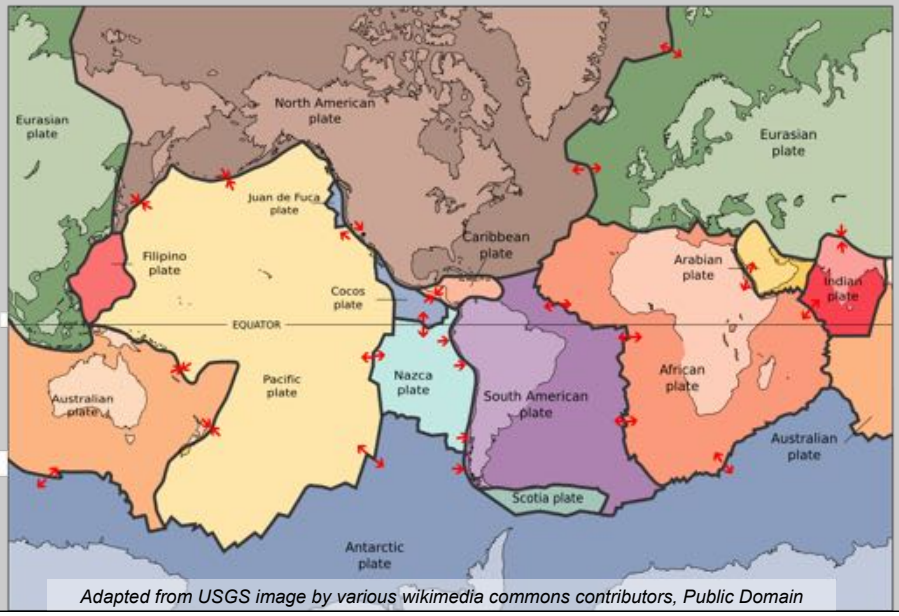
Global magnetic anomaly map, EMAG2.
NOAA/CIRES image, Public Domain
http://www.geomag.org/models/emag2.html

Age of the Ocean Floor



NOAA image, Public Domain

Schematic of 15 Largest Plates



Adapted from USGS image by various wikimedia commons contributors, Public Domain

Lithospheric Recycling

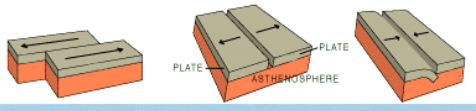
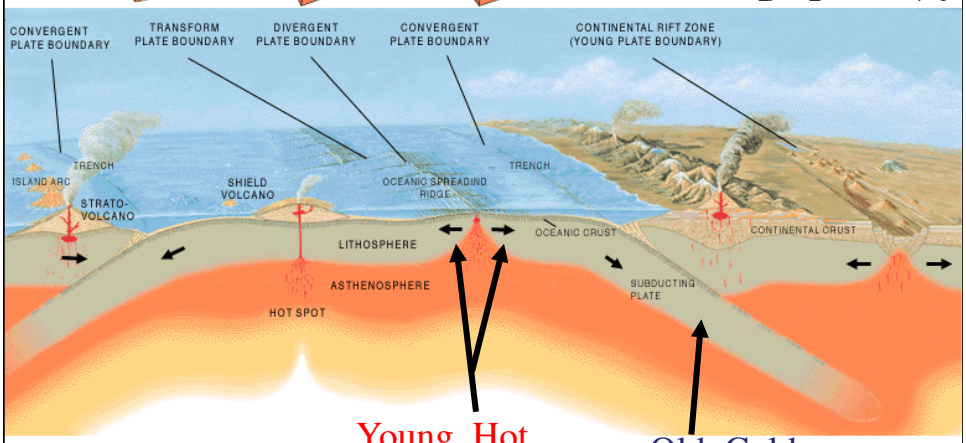


Figure: USGS, Public Domain, http://upload.wikimedia.org/wikipedia/commons/4/40/Tectonic_plate_boundaries.png



Young, Hot, Buoyant Lithosphere

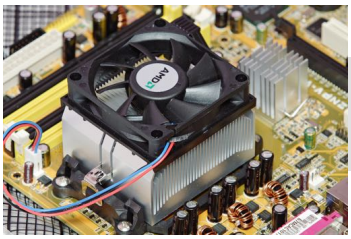
Old, Cold, Dense Lithosphere

What is Convection?

- Modes of heat transfer

Kilauea lava, photo by Greg Smith, Creative Commons A 2.0 Generic.

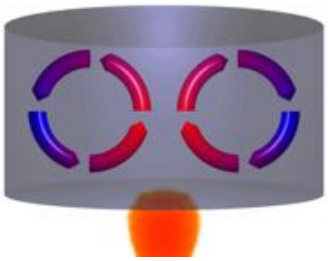
Radiative
Fireplace, the Sun, glowing lava



Desktop CPU heat sink. Fir0002/Flagstaffotos, GNU_Free_Documentation_License http://en.wikipedia.org/wiki/File:AMD_heatsink_and_fan.jpg

Conductive
Direct transfer: touching a hot stove, cool metal against a hot CPU

Convective
Heat transfer by moving "fluid".
Water on the stove



Movie by Oni Lukos, GDFL, Creative Commons-BY-SA-2.5. http://commons.wikimedia.org/wiki/File:Convection.gif

Wien's law: $\lambda_{peak} \approx 2898\ K \cdot \mu m / T \approx 2\ \mu m$
(visible light is 0.4-0.8μm)

Stefan-Boltzmann law: $j \approx (5.67 \times 10^{-8}) T^4 \approx 27$ Watts/cm^2
(full tropical sunlight is 0.11 Watts/cm^2)

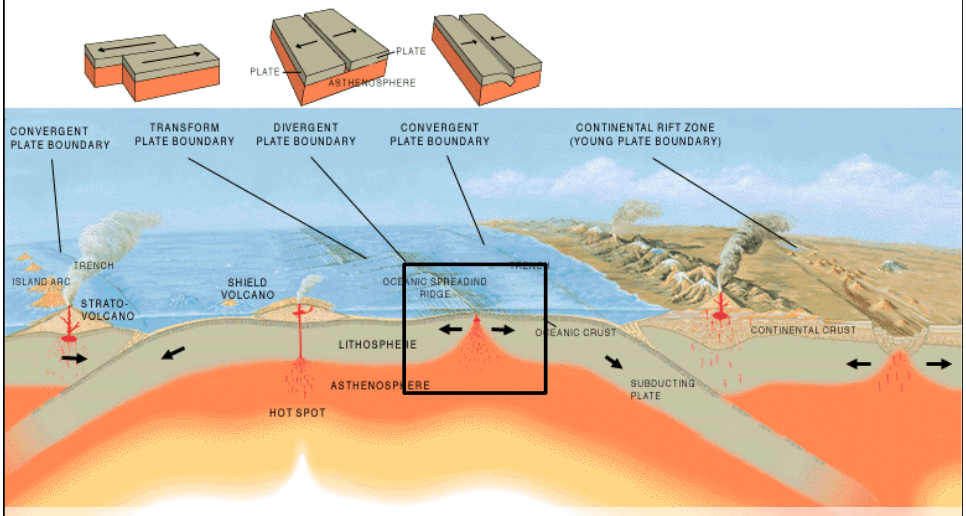
Most of the radiation is invisible!

QUESTIONS?

Movie by Jenny Wysocki, Robert Wysocki, Syracuse University Lava Project (C) 2014

Divergent plate boundaries

- Mid-Ocean Ridges: Spreading Centers
  - Local pressure-release melting → magma → new crust



USGS, Public Domain, http://upload.wikimedia.org/wikipedia/commons/4/40/Tectonic_plate_boundaries.png

Divergent Boundaries

- Map View of divergent margin

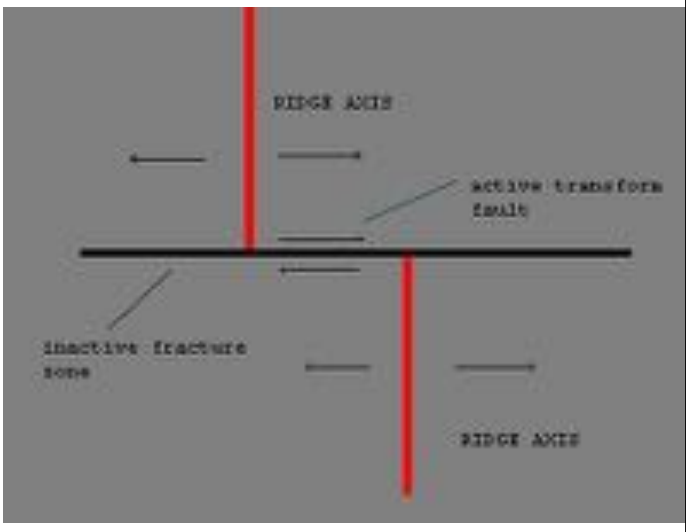


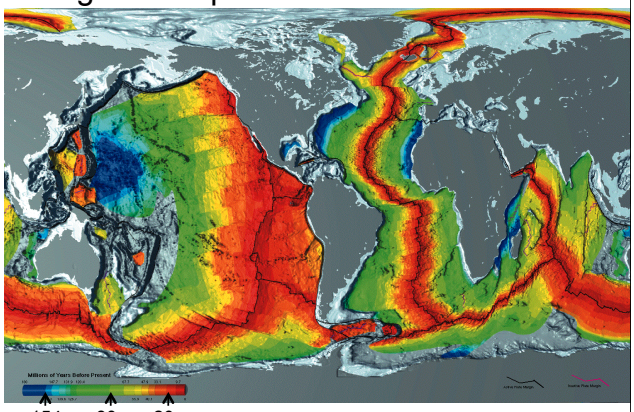
Figure by Erimus, Wikimedia Commons, Public Domain, http://en.wikipedia.org/wiki/File:Fracturezone.jpg

Age of the Ocean Floor

- Crust increases in age and thickness with distance from ridge axis
- Oldest <u>oceanic</u> crust ~200 m.y. old
  - MUCH younger than age of the planet 4.6 billion years old
  - And oldest <u>continental</u> rocks
- Spreading rates agree with magnetic stripe estimates:

  Atlantic:
  2-3cm/yr

  Pacific:
  10-15 cm/yr



NOAA image, Public Domain

Types of Convergent Boundaries

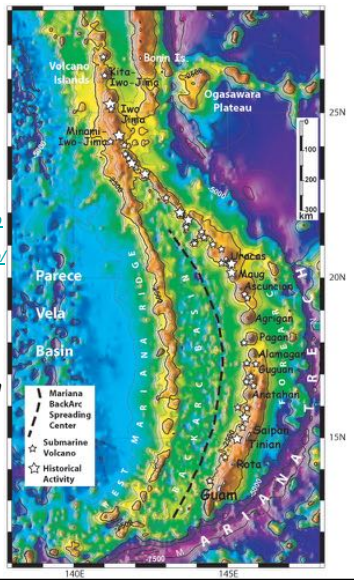
<u>Ocean-Ocean</u>: <u>volcanic island arcs</u>

Oceanic lithosphere subducts under ocean

i.e.,
Aleutians
Marianas

Marianas bathymetry from Sandwell and Smith (1997), courtesy NOAA, http://oceanexplorer.noaa.gov/explorations/03fire/background/plan/media/marianas.html, Public Domain

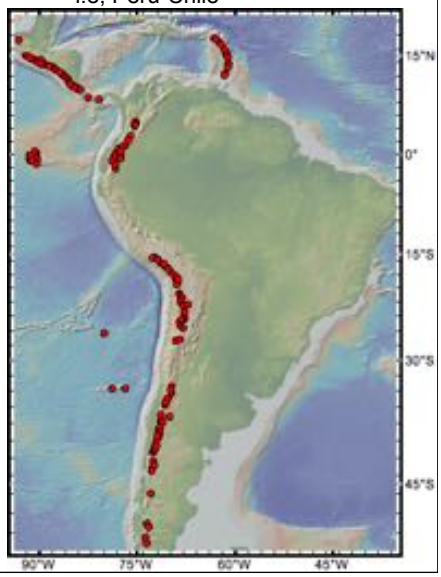
Right fig., South America bathymetry & volcanoes, created with GeoMapApp, Creative Commons A S-A 3.0, http://www.geomapapp.org/



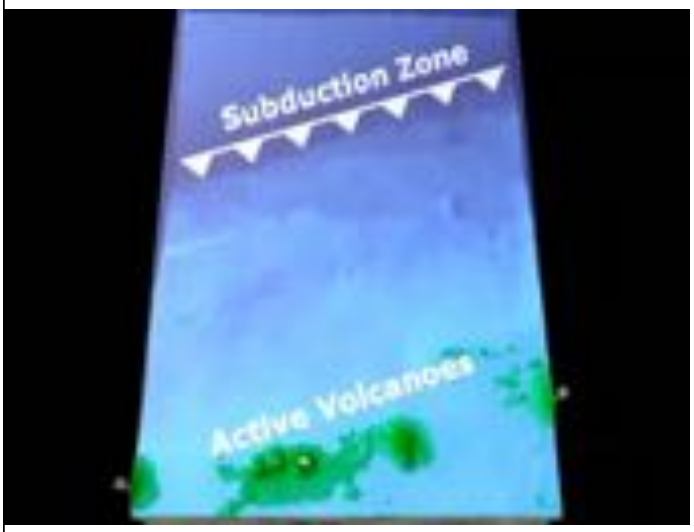
<u>Ocean-Continent</u>: Mountain + arc

Ocean subducts under continent

i.e, Peru-Chile



Volcanism at convergent boundaries

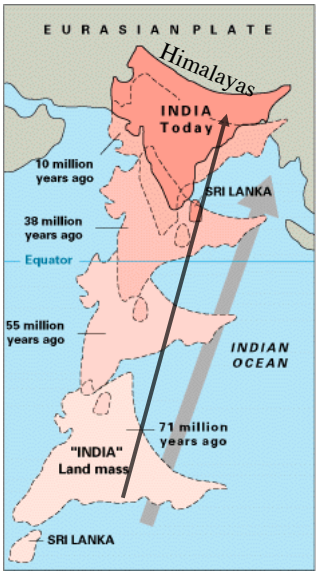


Water-rich fluid released by descending slab fluxes
(i.e., lowers melting temperature of) the overlying mantle

Movie from NOAA, Public Domain,
http://oceanexplorer.noaa.gov/explorations/03fire/logs/subduction_320.mov

Continent-Continent Convergence

- India-Asia collision
- Himalayas
- Continental crust is too buoyant to subduct, crumples and thickens at the surface.
- Extra-thick continental crust ---> BIG mountains.



USGS image, Public Domain,
http://commons.wikimedia.org/wiki/File:Himalaya-formation.gif

Continent-Continent Convergence

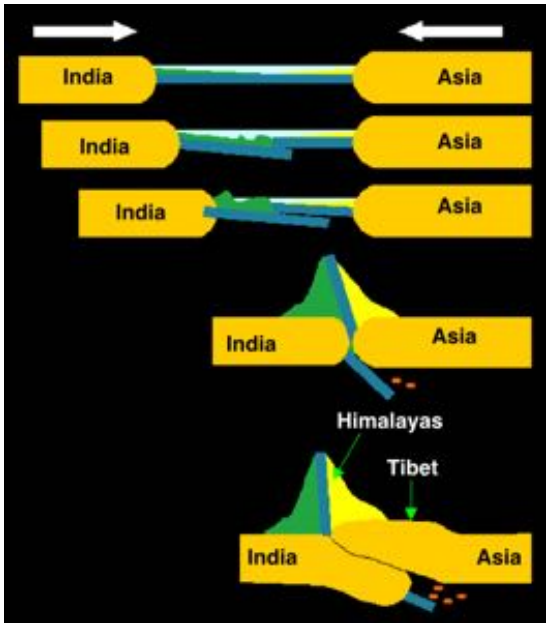
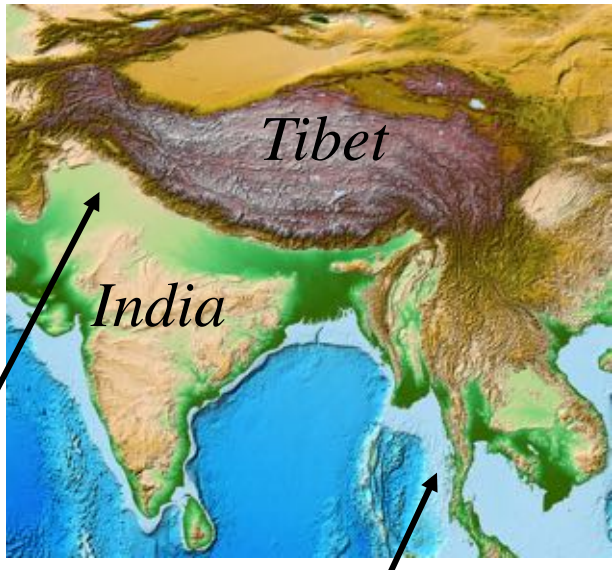


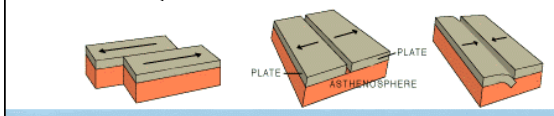
Figure by H'arnet, Wikimedia Commons, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Collision.PNG

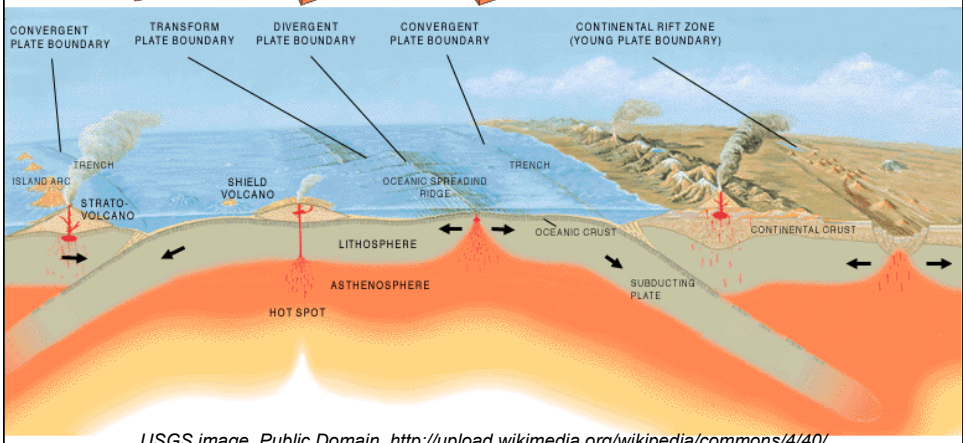
Continent-Continent Convergence



Crop of NOAA global relief map, Public Domain

QUESTIONS?





USGS image, Public Domain, http://upload.wikimedia.org/wikipedia/commons/4/40/Tectonic_plate_boundaries.png

Transform Boundaries

- Two plates sliding past each other horizontally
  - Example: San Andreas Fault
  - Transform portion: Seismically active part of Fracture Zone
  - Usually between offset ridge segments
  - Plates move <u>parallel</u> to plate margin

San Andreas Fault, Carrizo Plain, CA. Wikimedia Commons, Photo by Ian Kluft Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Kluft-photo-Carrizo-Plain-Nov-2007-Img_0327.jpg

Transform Boundaries

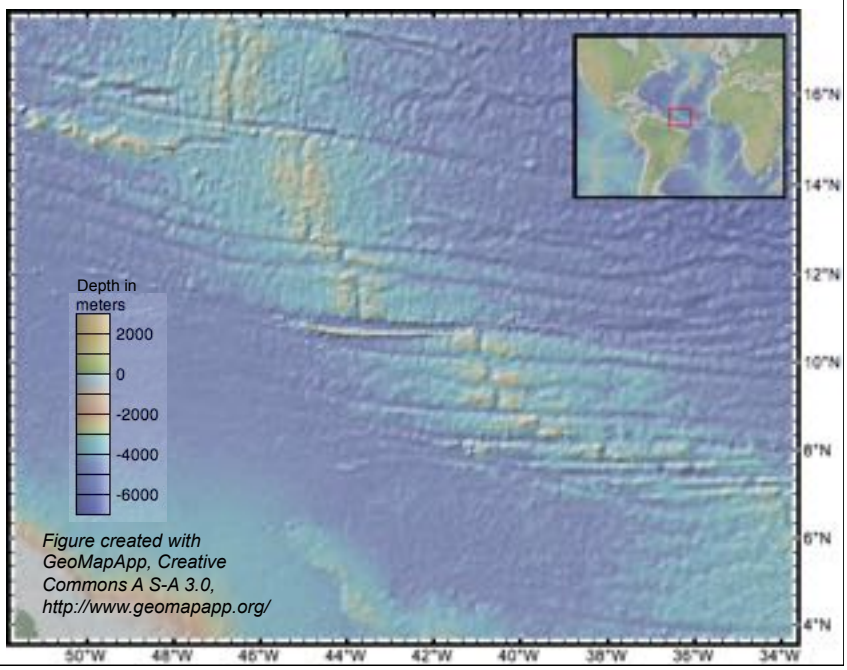
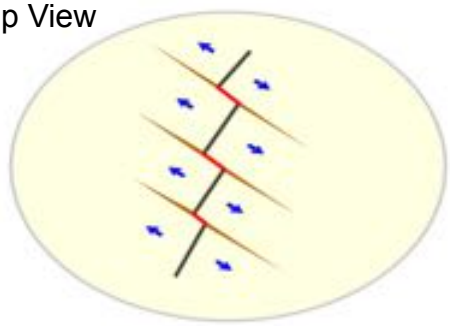


Figure created with GeoMapApp, Creative Commons A S-A 3.0, http://www.geomapapp.org/

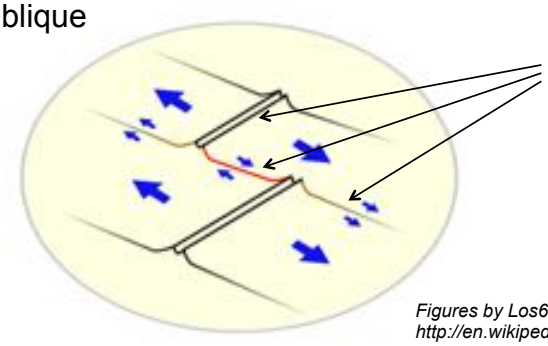
Map View



Transform Boundaries

Most common as more-or-less right-angle offsets of spreading segments along the mid-ocean ridge.

Oblique



Where do you expect to see earthquakes?

Figures by Los688, Wikimedia Commons, Public Domain, http://en.wikipedia.org/wiki/File:Transform_fault-1.svg

Transforms and seismicity (Mw > 5.0, 1973-2009)

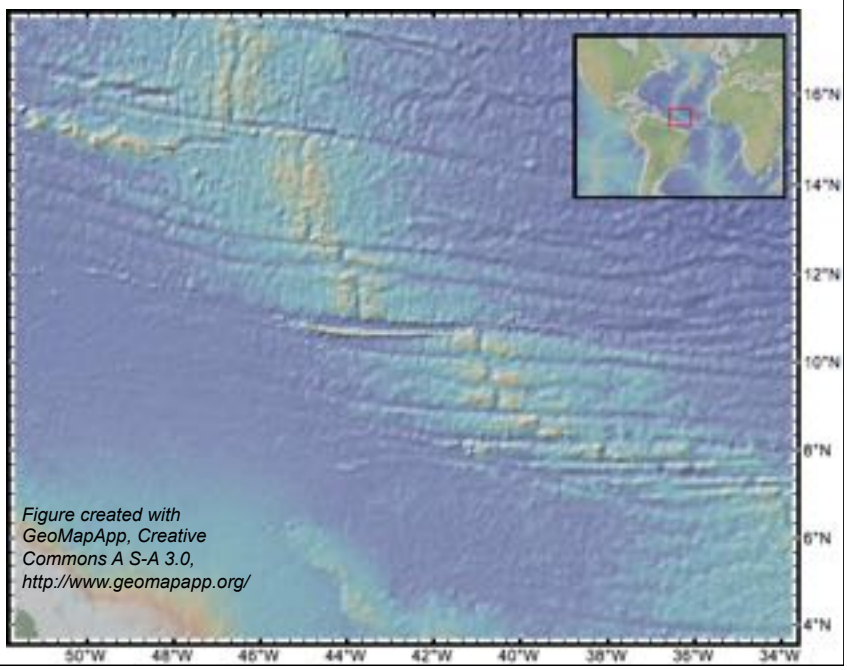
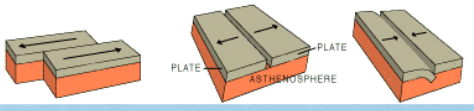
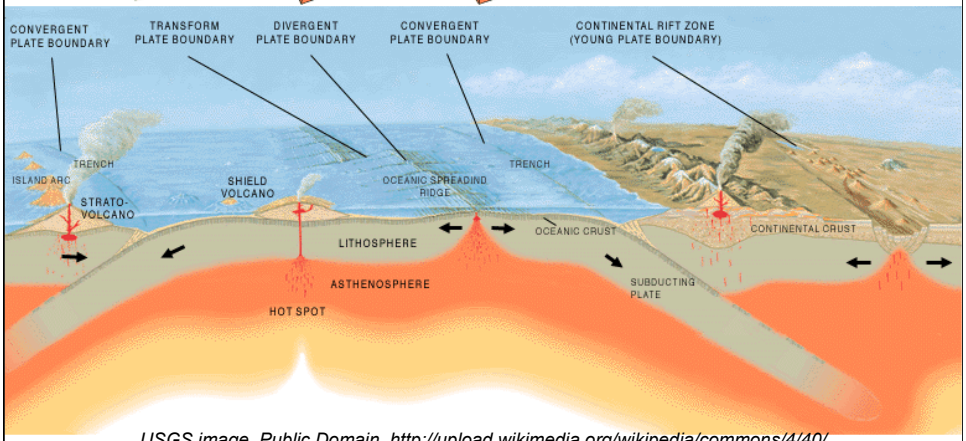


Figure created with GeoMapApp, Creative Commons A S-A 3.0, http://www.geomapapp.org/

QUESTIONS?





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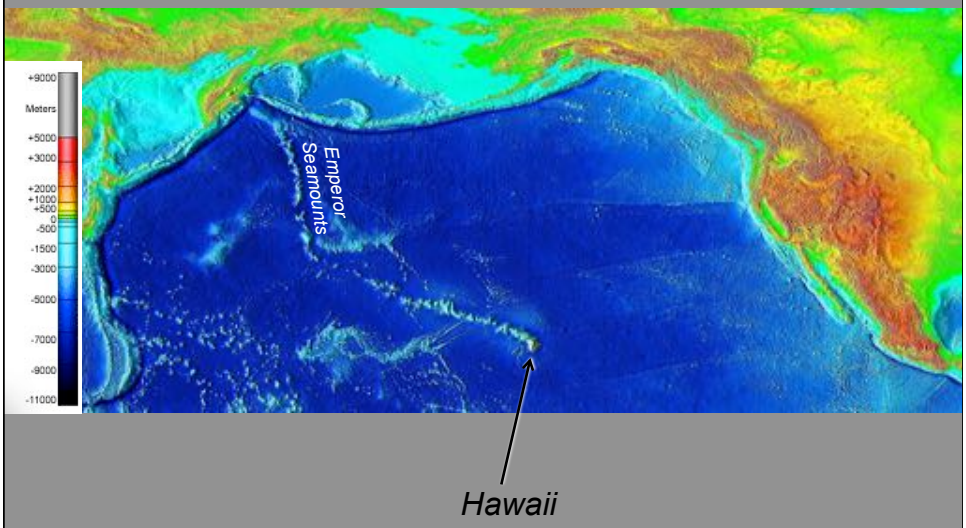
Hotspots & Mantle Plumes

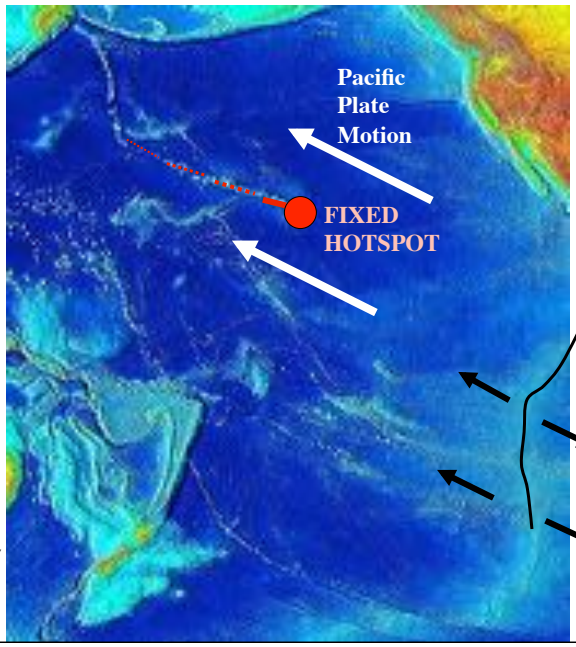
- Stationary volcanic sources in mantle
  - Persist for ≥ $1x10^7$ years
- Ocean Crust ~ 10% generated at hotspots
- Heat transfer: ~10-30% of mantle heat flux
  - May transport heat directly from the core
- Hotspot Island Chains
  - Hawaii-Emperor Chain
  - Stationary heat source tracks plate motions

Hawaii-Emperor Seamount Chain Traces Past Plate Motion



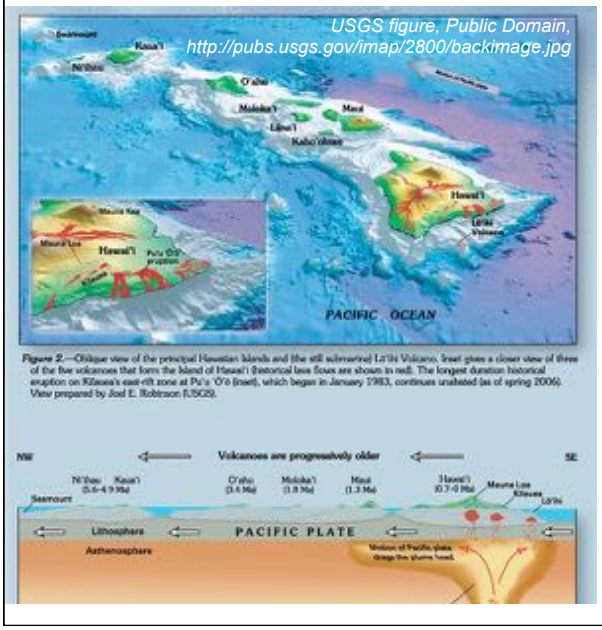
NOAA image, using ETOPO2v2 Database, Public Domain, http://www.ngdc.noaa.gov/mgg/image/2minrelief.html

Hotspots & Mantle Plumes

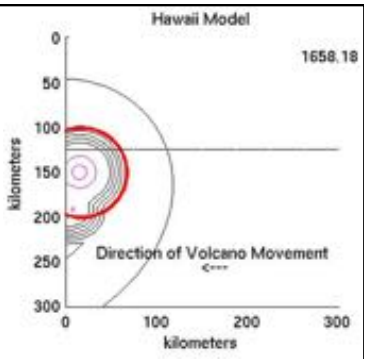


NOAA image, using ETOPO2v2 Database, Public Domain, e.g., http://www.ngdc.noaa.gov/mgg/image/2minrelief.html

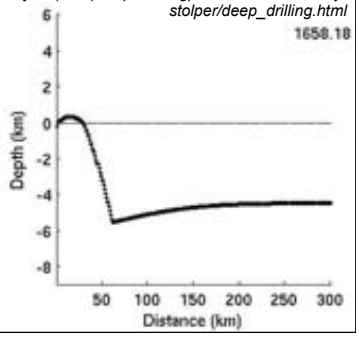
Hotspots & Mantle Plumes



USGS figure, Public Domain, http://pubs.usgs.gov/imap/2800/backimage.jpg



Movie by D. Stolper, Hawaii Scientific Drilling Project (NSF), http://web.gps.caltech.edu/faculty/stolper/deep_drilling.html



Tectonic Evolution of Ocean Basins

Oceanic life cycles (Wilson Cycle): ~200-500 million years to open and close

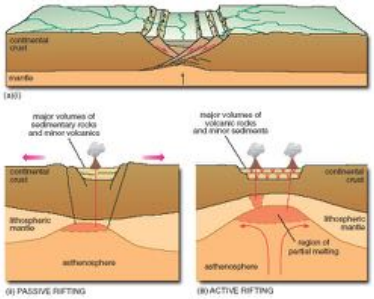
African Rift Valley: An embryonic ocean?

Ol Doinyo Lengai, photo by Clem23, Wikimedia Commons Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:NgareSero.jpg

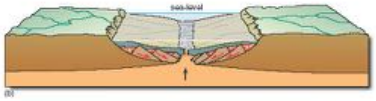
Tectonic Evolution of Ocean Basins

Oldest oceanic crust is less than 200 million years old – oceans are created and destroyed repeatedly.

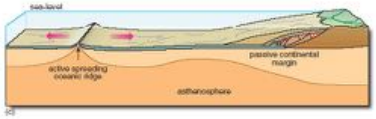
Embryonic – linear rift valleys



Juvenile – narrow seaway



Mature – broad ocean, well-developed passive margins



Declining/terminal – active margins, narrowing or irregular basin

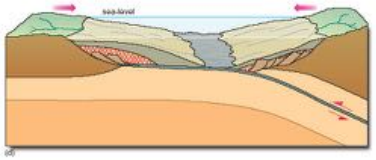
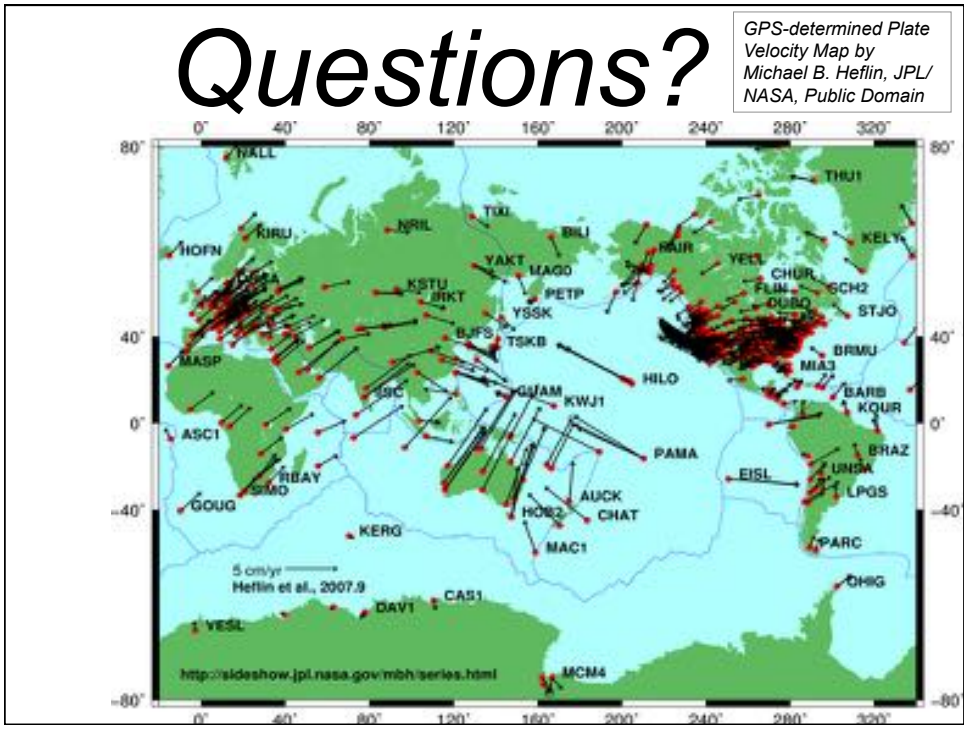


Figure from Open University Learning Space, "Geological processes in the British Isles", Creative Commons A S-A 2.0, http://dspace.jorum.ac.uk/xmlui/download/bitstream/handle/123456789/993/Items/SXR260_1_006i.jpg?sequence=33

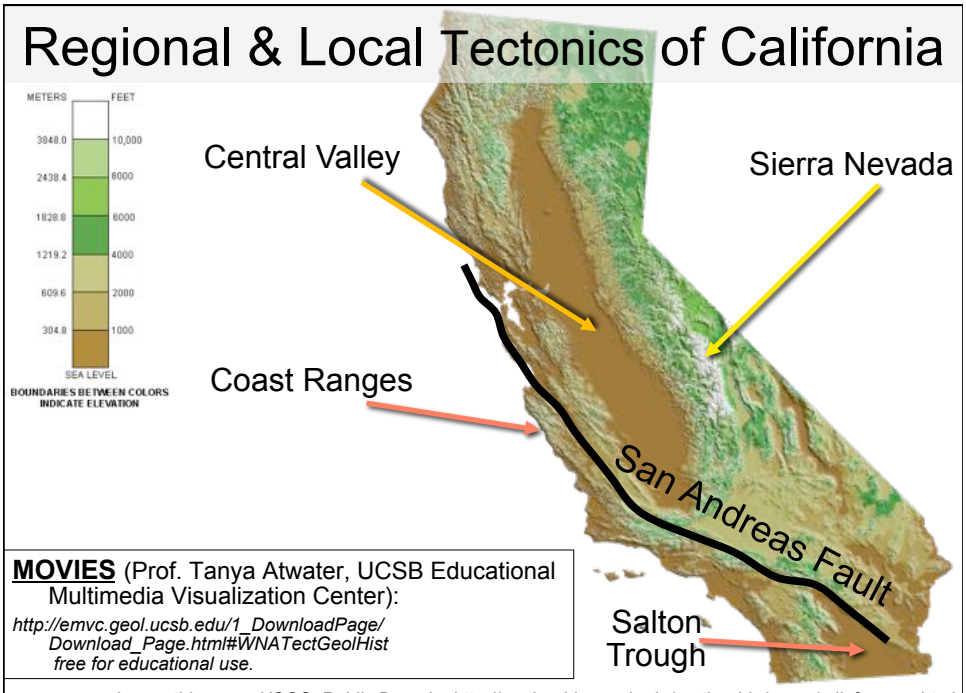
Questions?



Paleogeographic reconstruction

Paleogeographic Atlas Project, Ziegler et al., U. Chicago, http://www.geo.arizona.edu/~rees/global290-0pgeogrev.mov

Regional & Local Tectonics of California

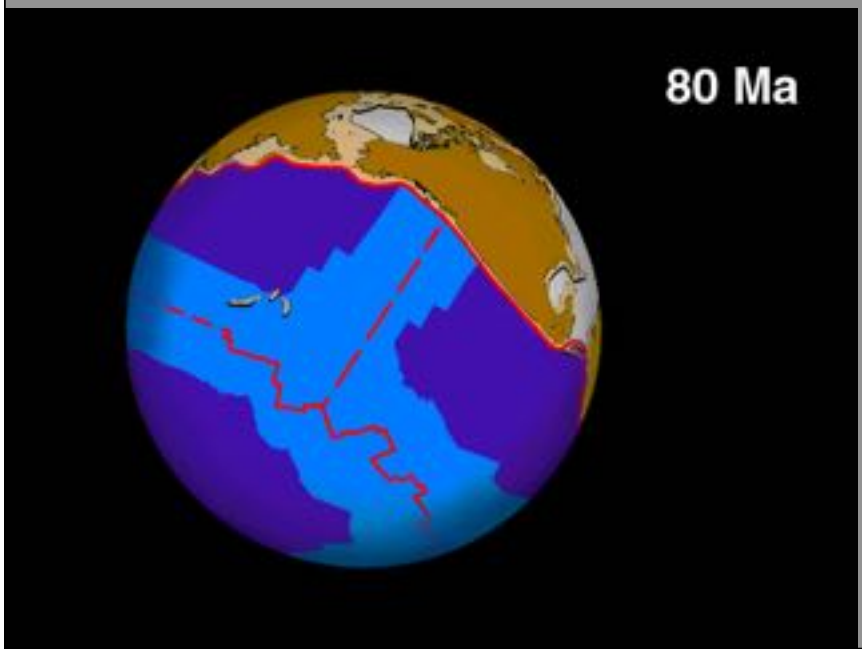


MOVIES (Prof. Tanya Atwater, UCSB Educational Multimedia Visualization Center):

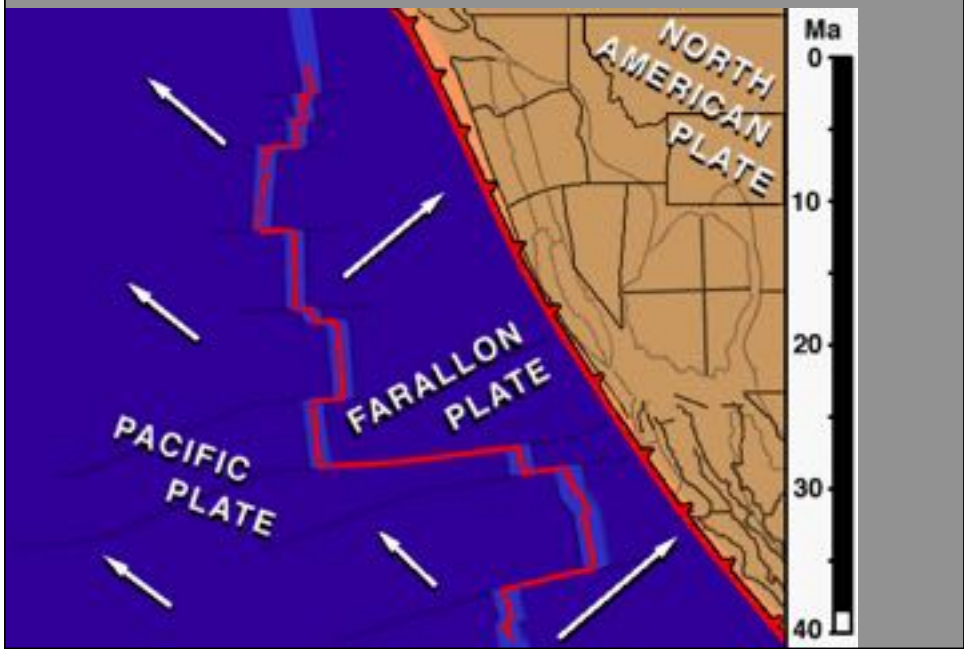
http://emvc.geol.ucsb.edu/1_DownloadPage/Download_Page.html#WNATectGeolHist
free for educational use.

Image this page: USGS, Public Domain, http://earthguide.ucsd.edu/earthguide/maps/reliefmapca.html

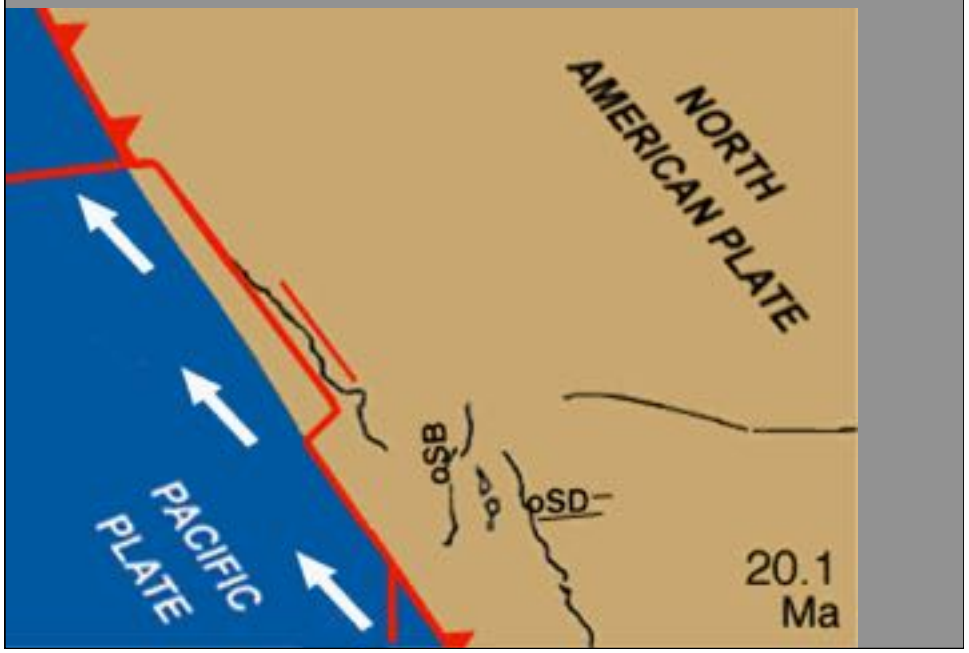
Pacific Plate Evolution



Easternmost Pacific Plate Evolution

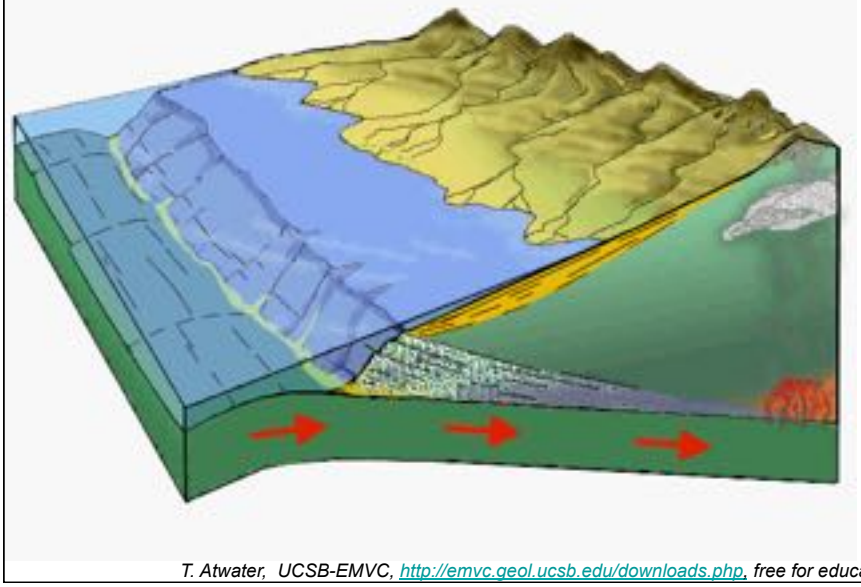


Southern CA Evolution



Coast Ranges & Central Valley

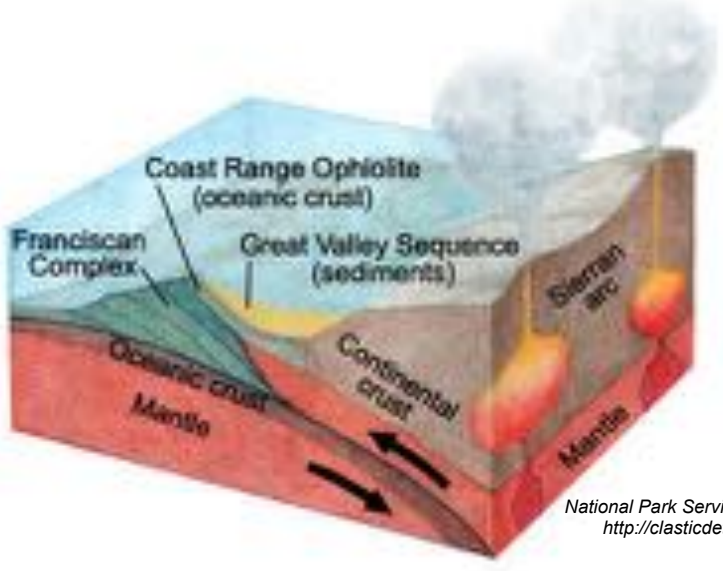
- Between subduction zone and the Sierras



T. Atwater, UCSB-EMVC, http://emvc.geol.ucsb.edu/downloads.php, free for educational use.

Coast Ranges & Central Valley

- Between subduction zone and the Sierras



National Park Service Figure, Public Domain, http://clasticdetritus.files.wordpress.com/2008/02/subduct-nps.jpg

The Sierra Nevada

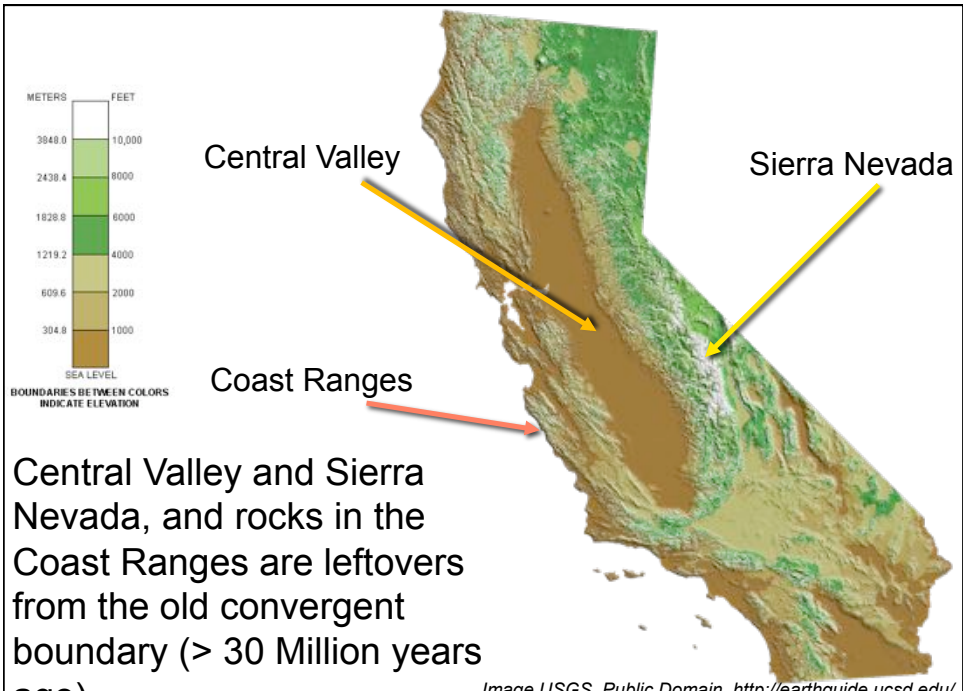
Zeimusu, Wikimedia Commons CC A S-A 1.0, http://commons.wikimedia.org/wiki/File:Mount_Whitney_2003-03-25.jpg

The Sierra Nevada are the roots of ancient volcanoes

Ocean-Continent ConvergentBoundary

Coast Ranges (scraped off the Farallon Plate)

Glen Canyon Park, San Francisco. Eric A Schiff, Wikimedia Commons CC A S-A 2.5, http://en.wikipedia.org/wiki/File:Glen_Canyon_Park_Chert_Outcrop.jpg



Central Valley and Sierra Nevada, and rocks in the Coast Ranges are leftovers from the old convergent boundary (> 30 Million years ago)

Image USGS, Public Domain, http://earthguide.ucsd.edu/earthguide/maps/reliefmapca.html

Young features (< 30 Million years) San Andreas, Salton Sea, Gulf of California, Santa Monica Mtns.

San Andreas: A transform boundary

San Andreas forms a complex web of faults, including many in LA region

Produces regions of tension and compression between active fault segments

Leads to

- **Transpressional** ranges (Santa Monica Mtns.)
- **Pull-apart** basins (LA Basin, Death Valley, Salton Sea)

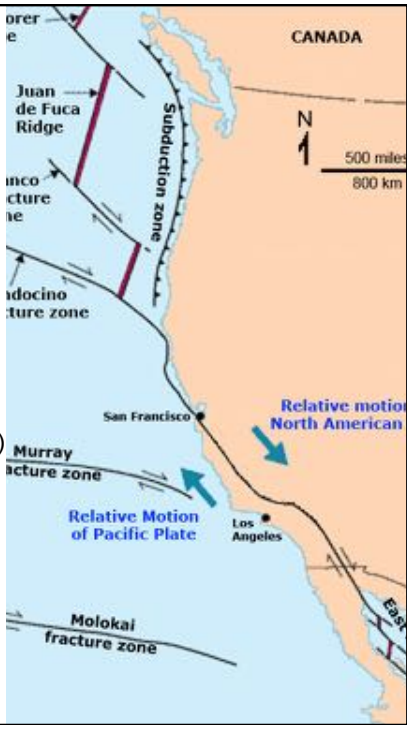


Figure by USGS, This Dynamic Earth, Public Domain, http://pubs.usgs.gov/gip/dynamic/understanding.html

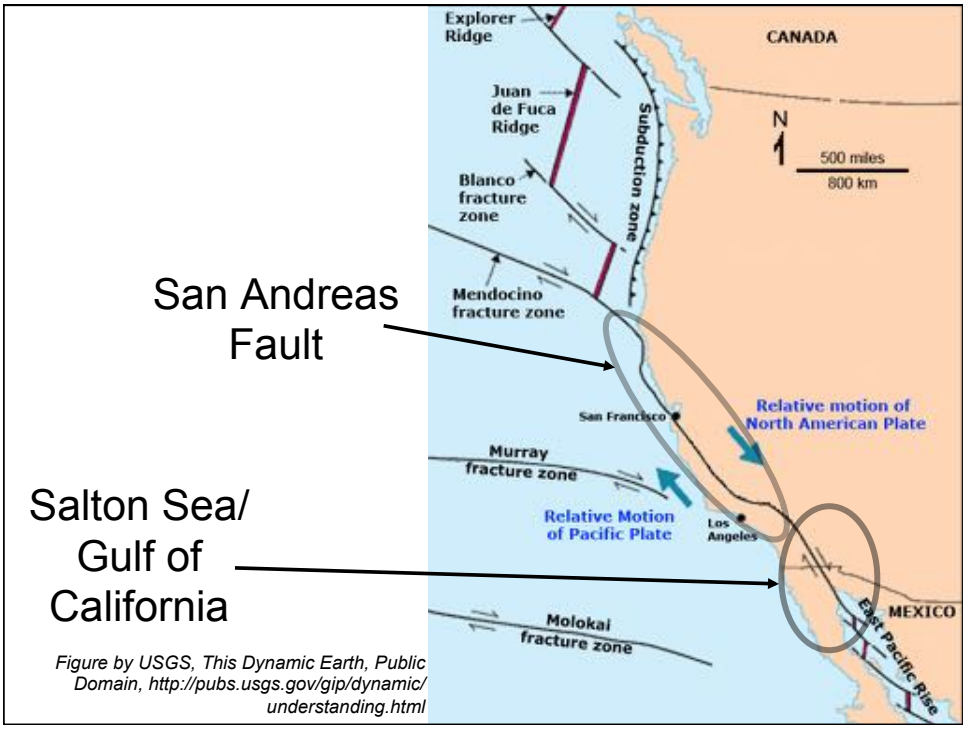
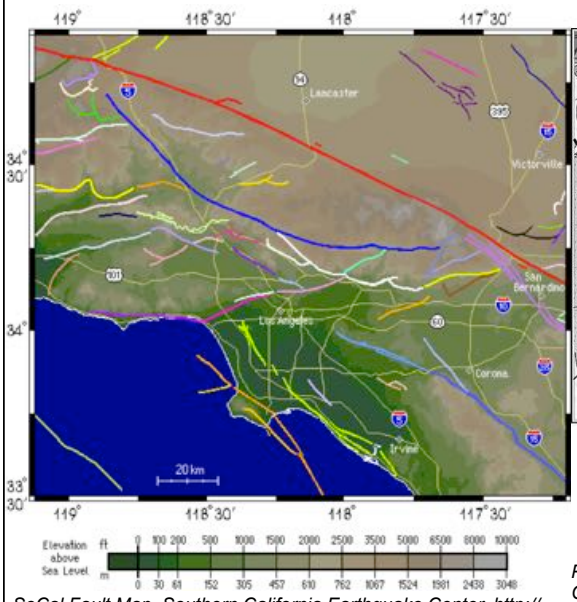
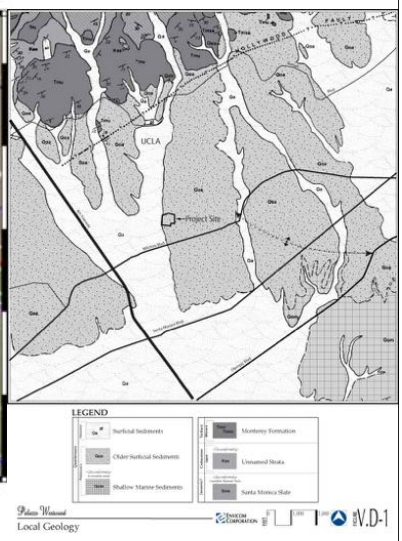


Figure by USGS, This Dynamic Earth, Public Domain, http://pubs.usgs.gov/gip/dynamic/understanding.html

The San Andreas isn't the only fault in Southern California



SoCal Fault Map, Southern California Earthquake Center, http://www.data.scec.org/faults/lafault.html



Palazzo Westwood planning documents, LA City Planning, http://cityplanning.lacity.org/eir/Palazzo/figures/VD-02.jpg

QUESTIONS?

Image USGS, Public Domain, http://earthguide.ucsd.edu/earthguide/maps/reliefmapca.html

USGS Image, Robert Wallace