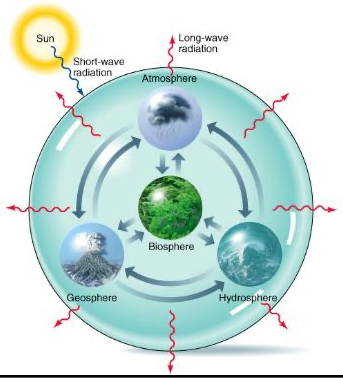
Introduction to Earth System

The components of the Earth System



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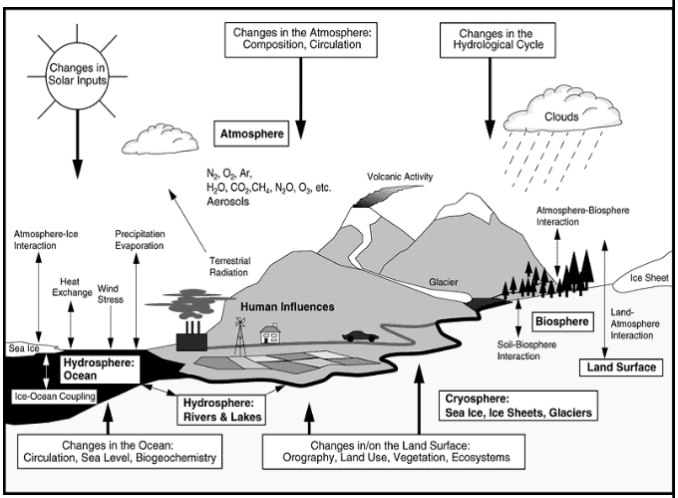
Components of the Earth System

- Geosphere
- Atmosphere
- Hydrosphere
- Biosphere



IPCC, 2001

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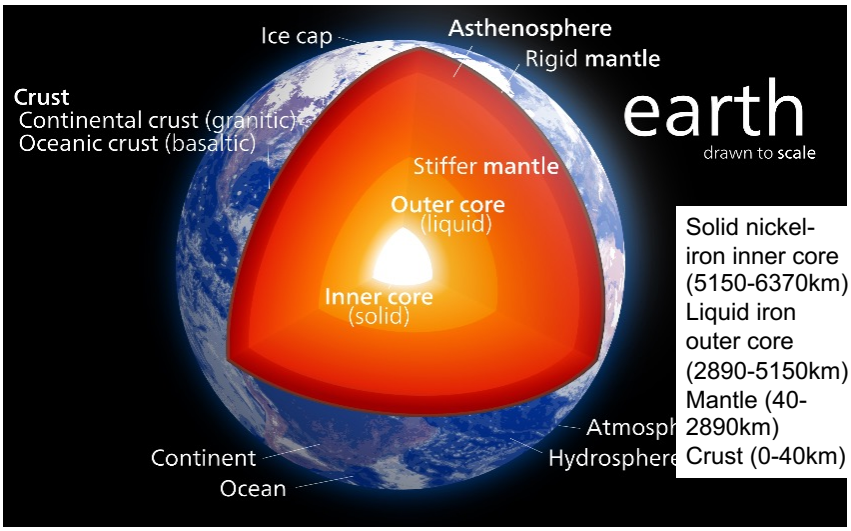
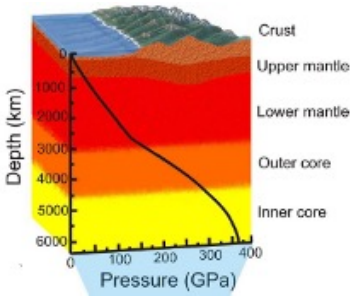
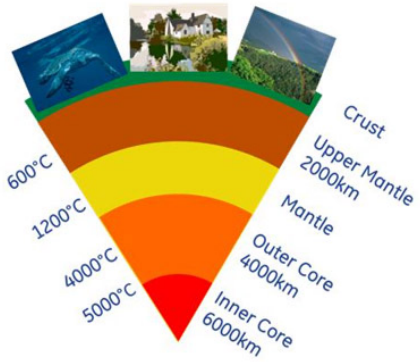
The structure of the Earth



Q. Why a layered planet?

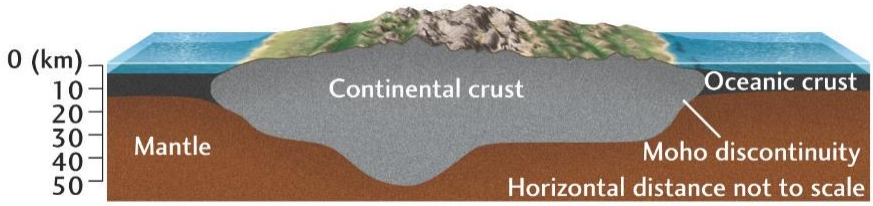
The structure of the Earth





- Temperature & pressure increase with depth
- Temperature & pressure in the inner core?

The structure of the Earth



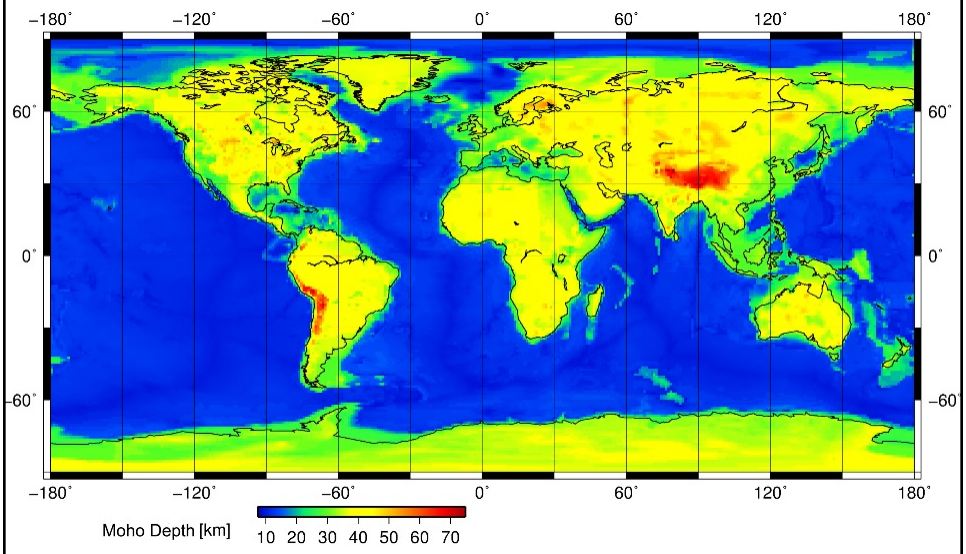
- The crust → the most familiar to us
- Rocks' age over oceanic crust and over continents?
  - <200 mil. yrs & can be > 3.5 bil. yrs, respectively

✓ Q: Oceanic crust or continental crust has a higher density?

- **Oceanic crust** ← more iron and magnesium-rich minerals
- The lower-density continental crust is thicker and stands higher

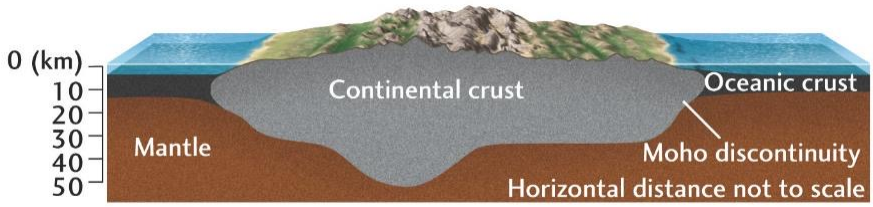
- Boundary between Earth's crust & mantle: rapid change in density → **Mohoroviçic Discontinuity or Moho**

The structure of the Earth



The depth of the Moho

The structure of the Earth



- **Q:** what is the most abundant chemical element in the earth's crust?

Answer: Oxygen
(46.6% Oxygen; 27.7% Silica; 8.1% Aluminum; 5.0% Iron; 3.6% Calcium; 2.8% Sodium; 2.6% Potassium; 2.1% Magnesium; plus trace elements)

Plate Tectonics

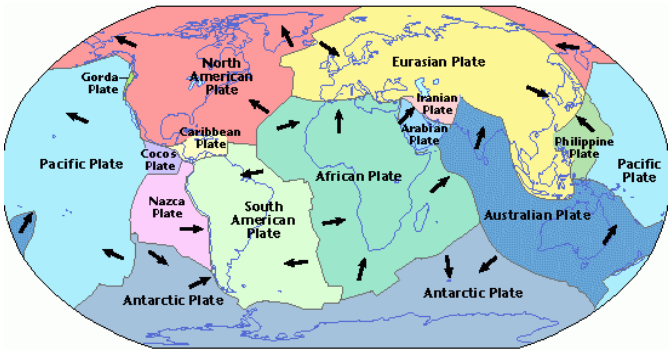
Q:

- Why are mountain ranges commonly near coastlines?
- What causes giant tsunami waves?
- Why are most devastating earthquakes near certain coastlines?

→ The dynamic of Geosphere

Plate Tectonics

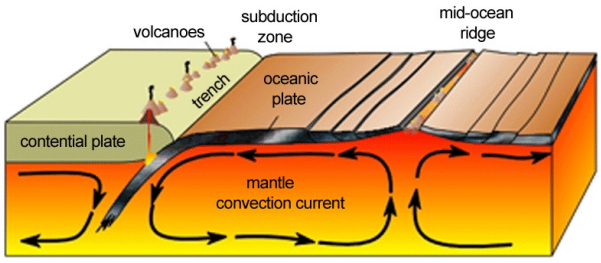
- The Earth's crust → **major plates** moving in various directions → plate interaction
- "**Tectonic**" refers to the deformation of the crust as a consequence of plate interaction.



World plates (12 plates)

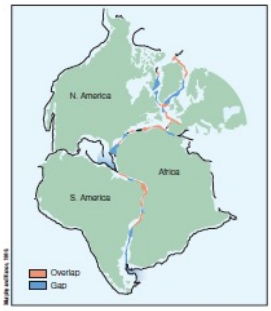
Plate tectonics

- Plates ← rigid lithosphere (made up of the crust and the extreme upper part of the mantle)



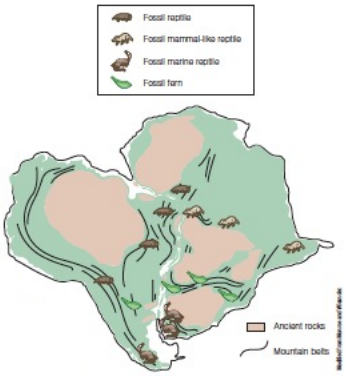
Mantle convection → transfer of thermal energy → causing the plates to MOVE

History

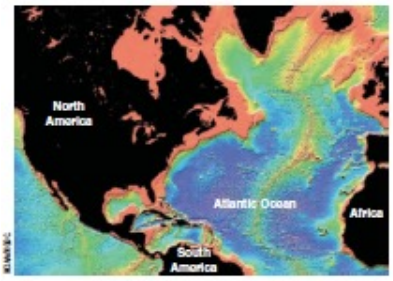


a few hundred million years ago → a supercontinent called **Pangaea**

- **1596**: Abraham Ortelius, a Dutch map maker suggested that Africa & South America were once connected
- **1912**: Alfred Wegener detailed the evidences → suggested that the continents drifted through the oceanic crust: however, many scientists rejected this hypothesis
- **1960**: the seafloor spreading process was confirmed

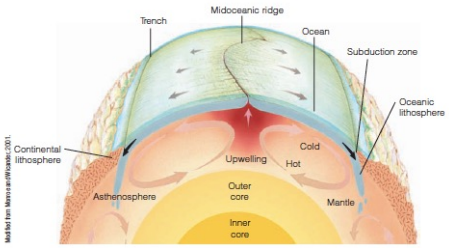


Seafloor spreading



90E 5E

- Late 1940s → found the mid-oceanic ridge
- found that most earthquakes in the Atlantic Ocean were concentrated there
- 1960 → Harry Hess (Princeton Geologists) proposed the **seafloor spreading** process
- The estimated spreading rate is **~ 2.5 cm/year**.



Q: How many years did it take for the entire Atlantic Ocean floor to form?

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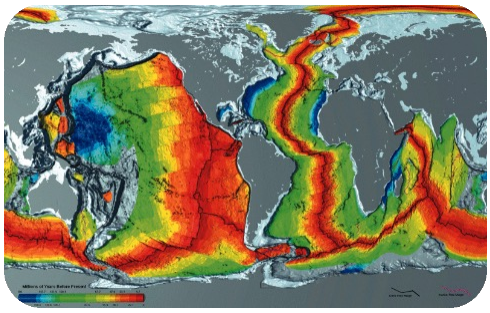
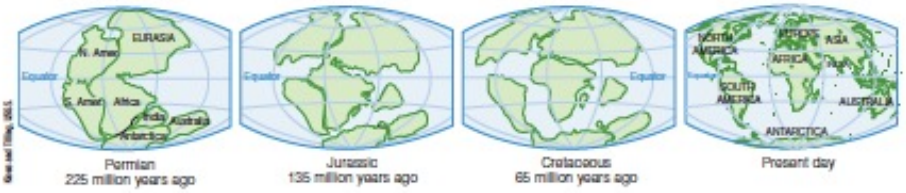
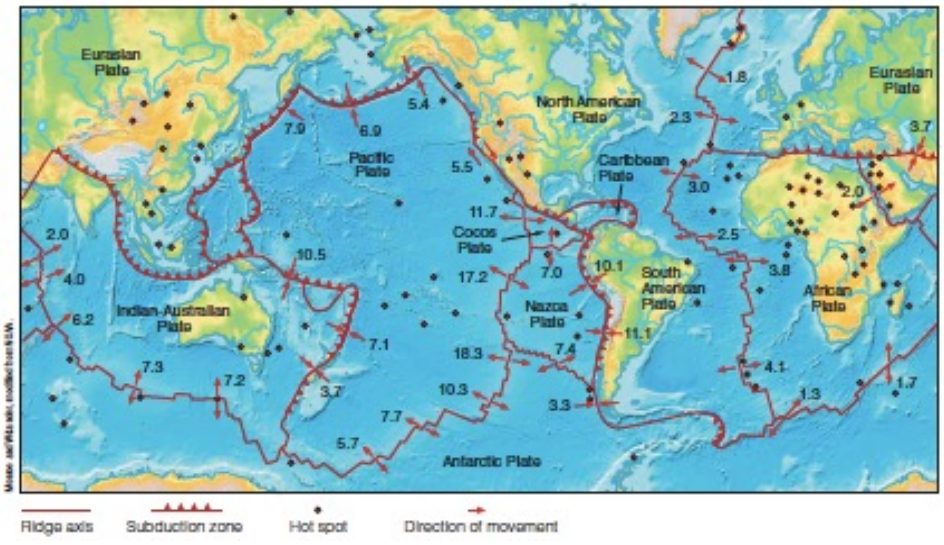
Seafloor spreading



- Prevailing notion: ocean floor was extremely old → not correct
- **At ridge axis**: youngest rock, thinnest crust, hottest flow

Evidences **support the modern theory of plate tectonics**

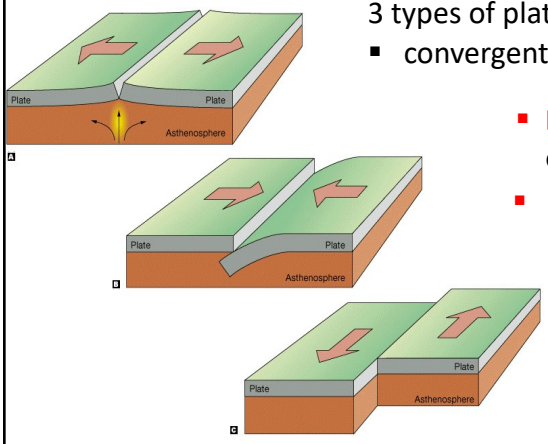




Most large lithospheric plates & general direction & velocities of plate movement (cm/yr)

- Q: Highest velocity? Dominant direction?

Plate boundaries



3 types of plate boundaries:

- convergent, divergent, & transform

- **Divergent boundaries** (e.g. ocean ridge)
- **Convergent boundaries**
  - One or both of the plates are oceanic lithosphere → the denser plate will slide down → **subduction zone**
  - Two continental plates → neither side is dense enough to be subducted deep into the mantle → **largest mountain ranges**

- **Transform boundary?** E.g. San Andreas Fault

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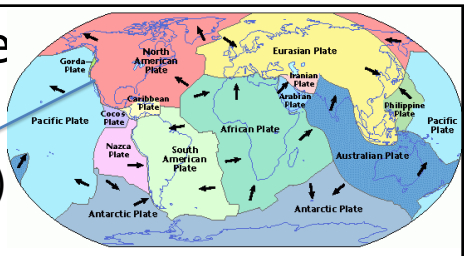
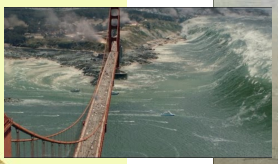
Plate boundarie

- **Transform boundary**
  (E.g. San Andreas Fault)





~1,200 kilometers

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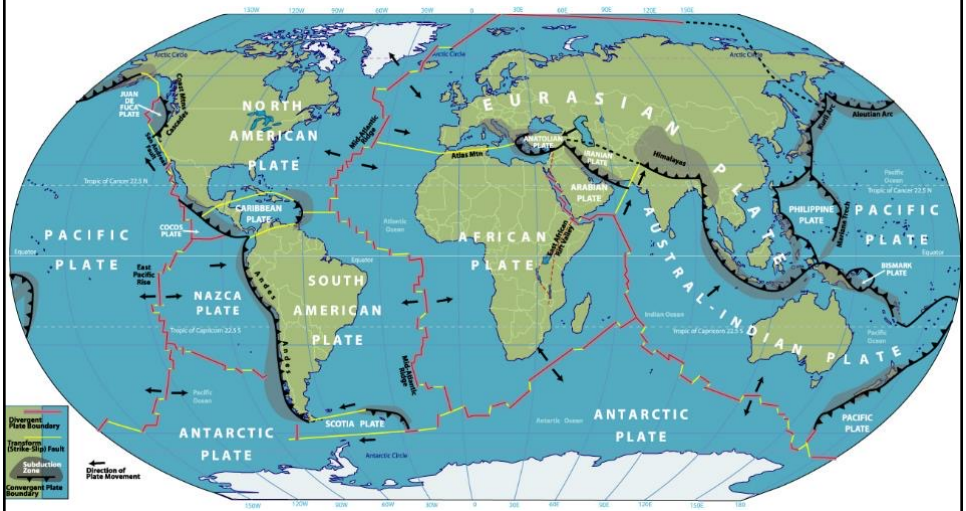
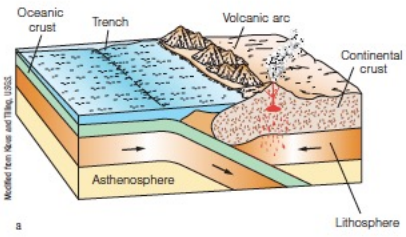
Plate boundaries



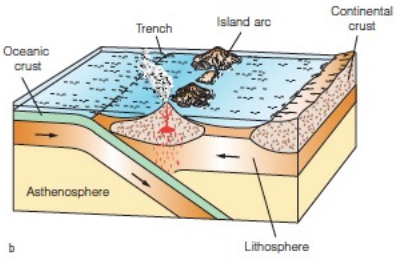
Divergent **Convergent** **Transform**

Hazards and Plate Boundaries

Convergent boundaries



Continental volcanic arc



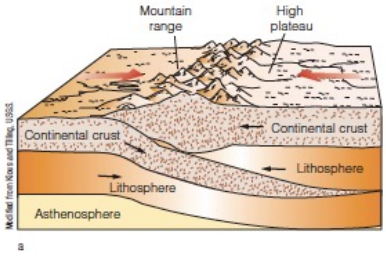
Oceanic island arc

- Sudden slippage of the continental plate over the ocean floor is generally under the water → sudden movement of a lot of water can cause a **huge tsunami wave**

Hazards and Plate Boundaries

Collision of continents

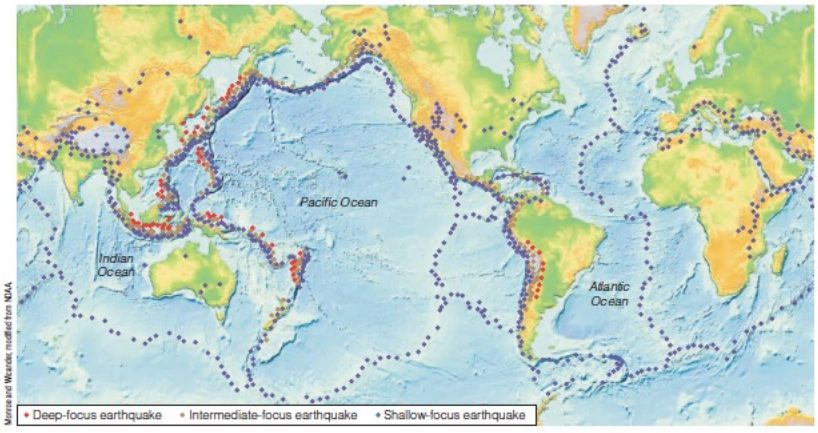
- Neither plate sinks
- Promotes thickening of the combined lithospheres and growth of high mountain ranges
- Accompanied by large earthquakes



The Himalayas → created by collision between the Indian and Eurasian Plates

Hazards and Plate Boundaries

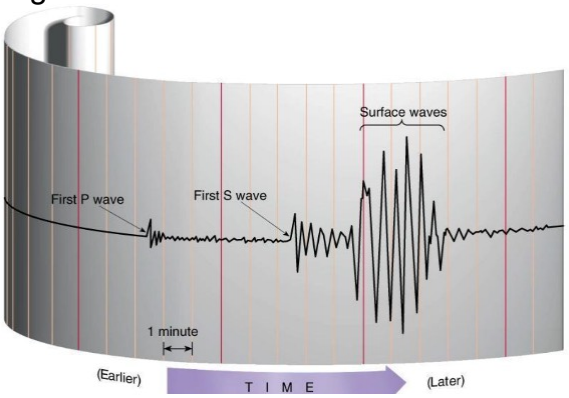
- Most of Earth's earthquake & volcanic activity occurs along or near moving plate boundaries



Earthquakes

Earthquakes

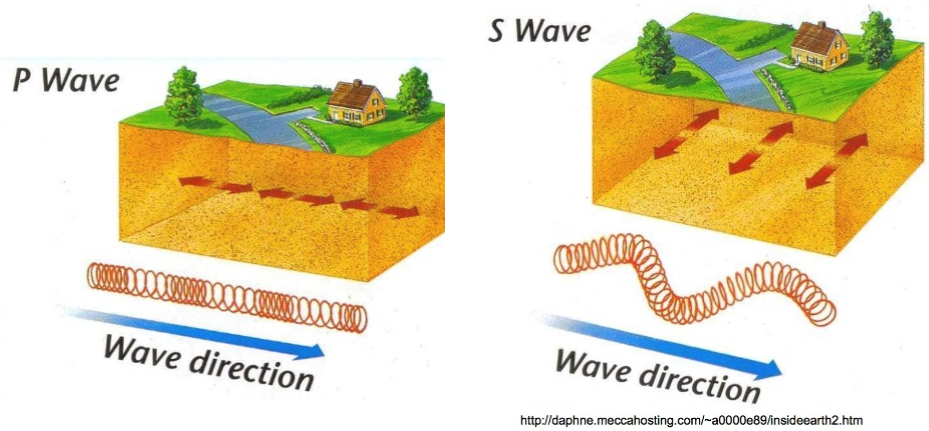
Typical Seismogram



http://isu.indstate.edu/jspeer/Earth&Sky/EarthCh11.ppt

P-wave: A type of seismic wave that compresses and expands the ground
S-wave: A type of seismic wave that moves the ground up and down or side to side

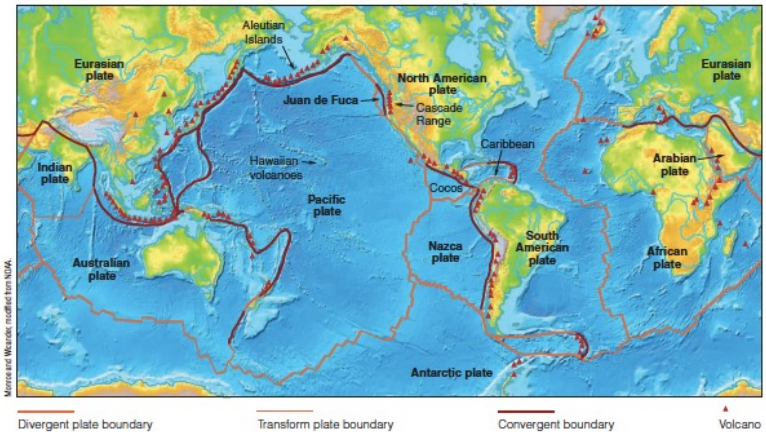
Seismic waves



http://daphne.meccahosting.com/~a0000e89/insideearth2.htm

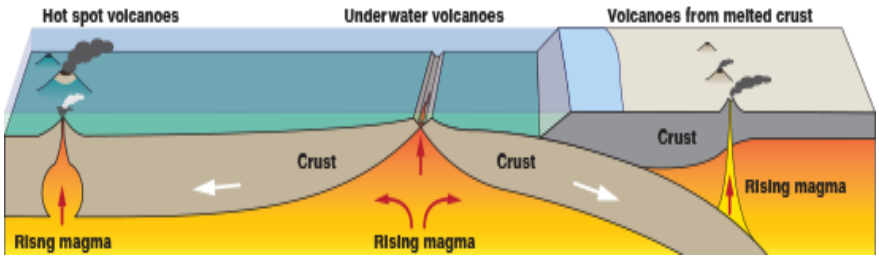
Hazards and Plate Boundaries

Volcanoes



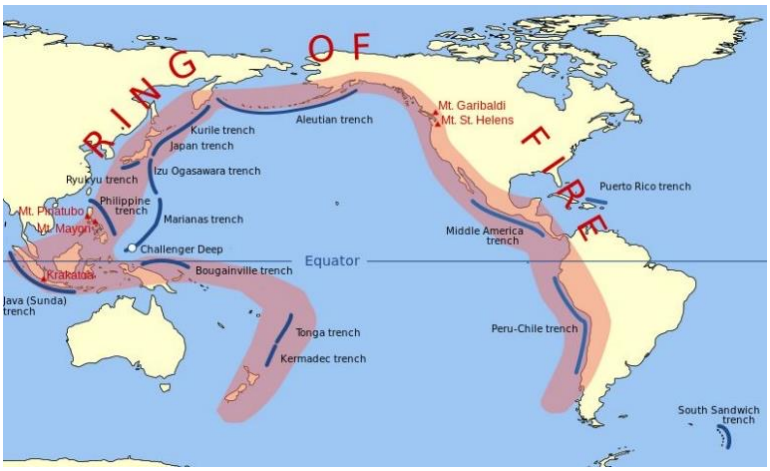
A **volcano**: an opening on the surface that allows material warmer than its surroundings to escape from its interior

Volcanoes



Volcanoes on Earth form from rising magma.

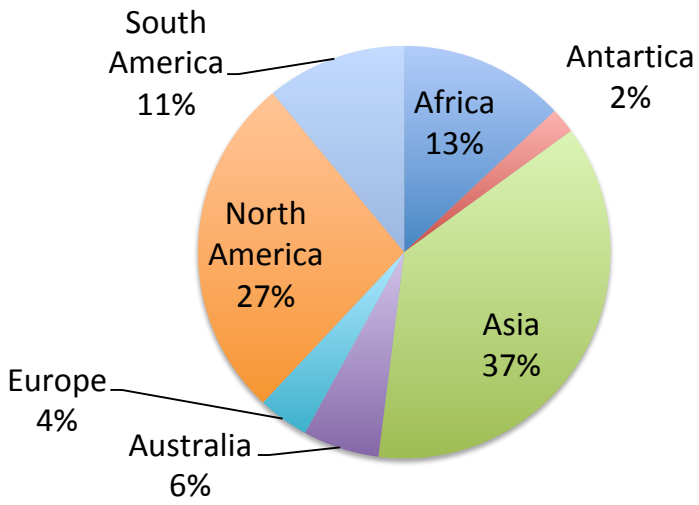
Volcanoes – Ring of fire



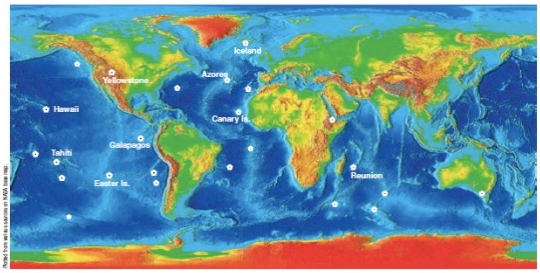
The **Ring** of **Fire**: edges of the Pacific Plate

- ✓ over 450 volcanoes
- ✓ home to ~75% of all active **volcanoes** on Earth

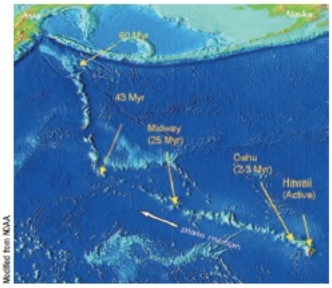
Volcanoes



Hotspot volcanoes



- Hotspots are anchored deep in the Earth → burn a track in the overlying lithospheric



The relief map of the Hawaiian-Emperor chain of volcanoes → movement of ~ 9cm/year

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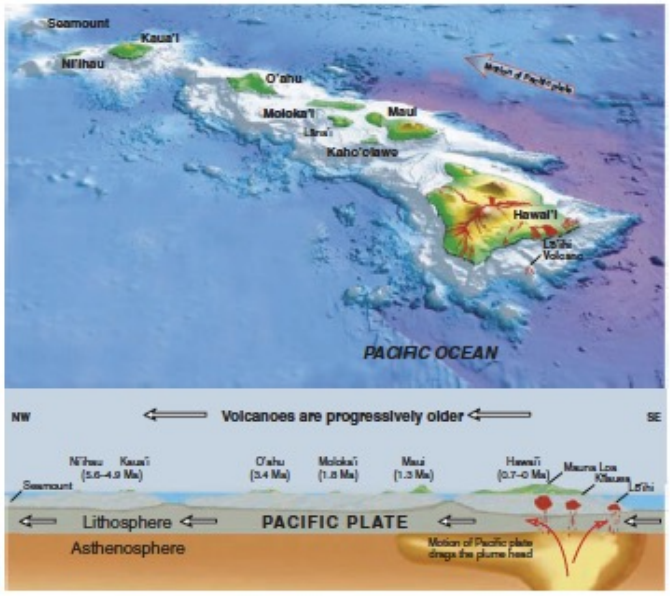
Hotspot volcanoes



- The rising column or plume of hot rock appears to **remain fixed** in its place as one of Earth's plates moves over it
- a clear record of the **direction and rate of movement** of the lithospheric plates

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B2-SA-NDT-Earth System

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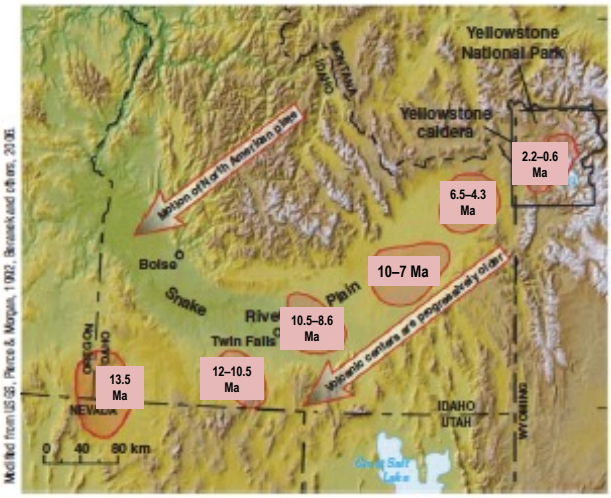
Hotspot volcanoes

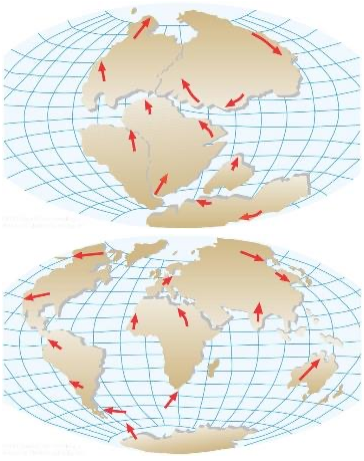


Snake River Plain of southern Idaho
(a series of extinct calderas)

Assuming that the hotspots remain fixed:

- Q: Estimate the rate of the movement of North American plate?
- Q: If the rate is changing?

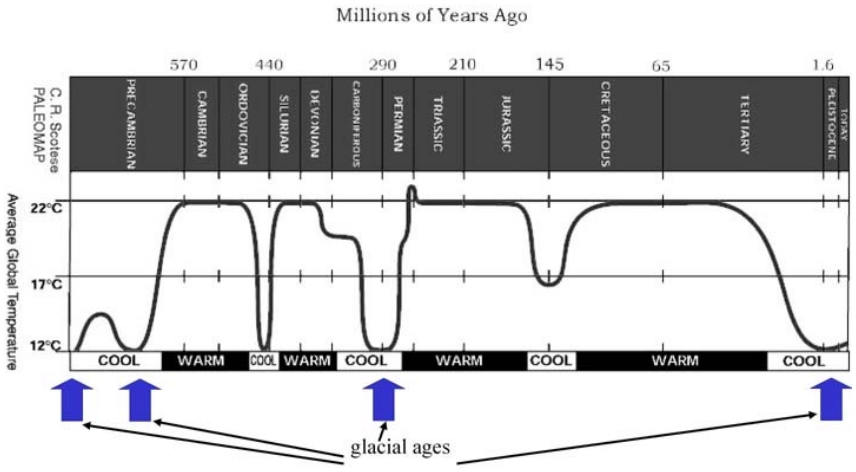
How does tectonics influence Earth's climate?

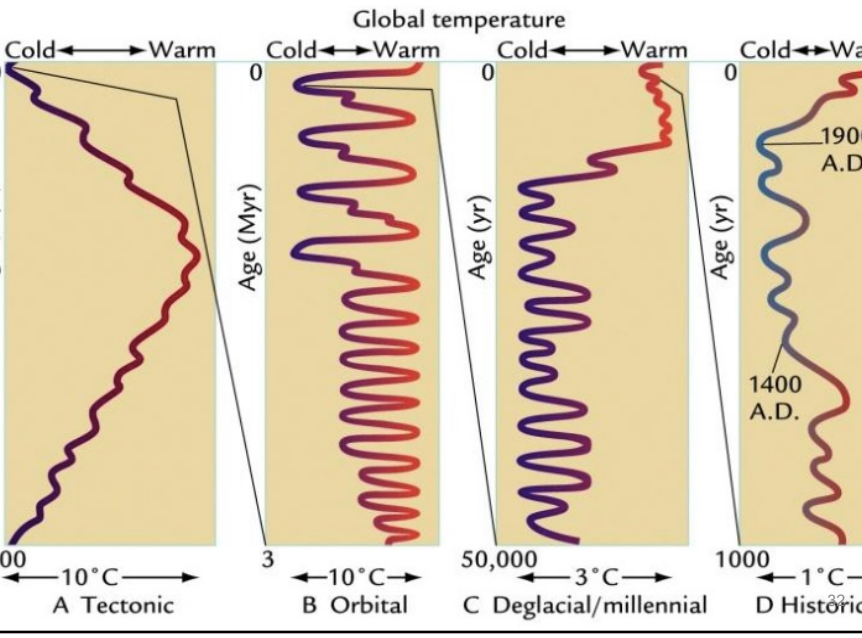


Lyell, 1830

- Concentration of polar land area → cool the Earth
  Q: why?
- Tectonic processes can have local to global-scale climatic impacts
- Direct & indirect impacts

How do tectonics affect the climate?





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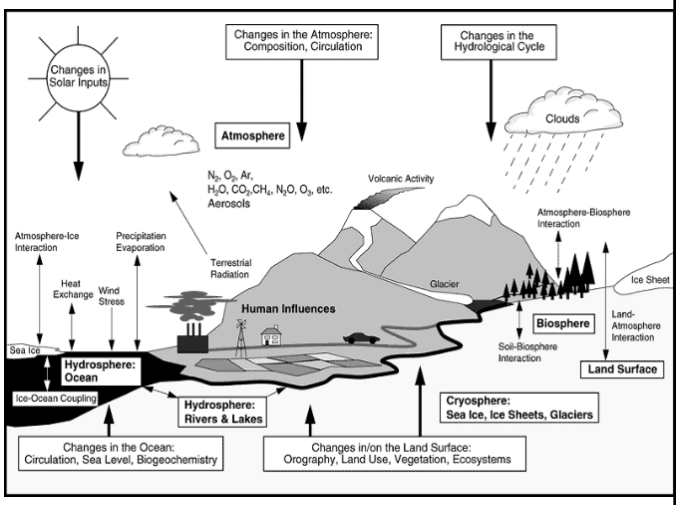
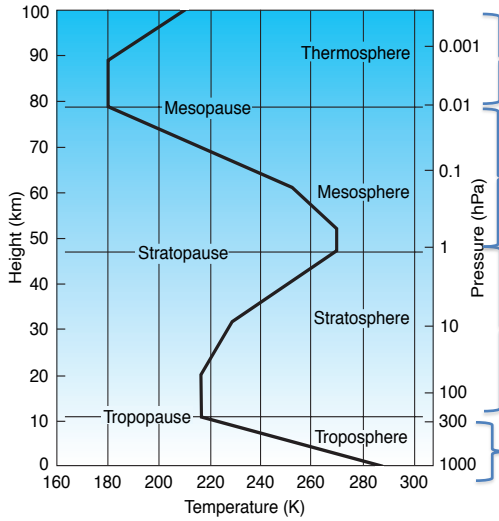


IPCC, 2001

The Atmosphere (by temperature)



A typical midlatitude vertical temperature profile, as represented by the U.S. Standard Atmosphere.

Thermosphere: T increases← absorption of solar radiation & photodissociation (N_2, O_2) & photoionization

Mesosphere: T decreases → a minimum that defines mesopause

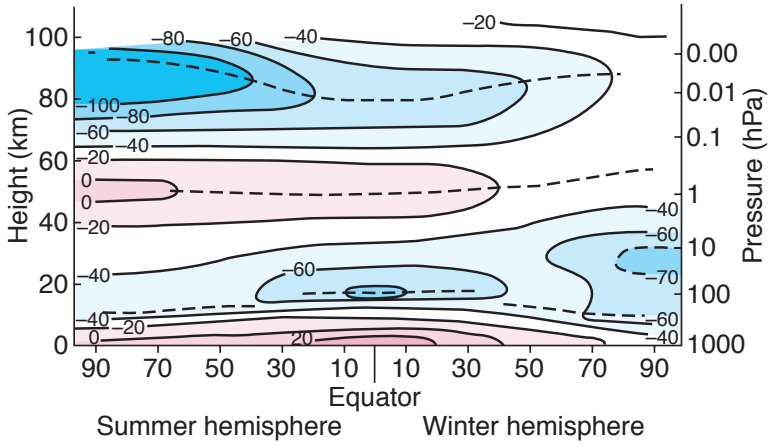
Stratosphere: T increases
- vertical mixing: strongly inhibited
- residence times: longer
- air: extremely dry and ozone rich
- stratopause: max T at 50km

Troposphere: T generally decreases; average lapse rate:

$$\Gamma \equiv \frac{\partial T}{\partial z} \sim 6.5\ ^{\circ}\mathrm{C\ km^{-1}}$$

- 80% of the mass of the atm
- Inversion layer

Temperature in the atmosphere



Q. Where in the Earth system is the coldest temperature found?

Q. Estimate the mean lapse rate in the troposphere

- at the equator?
- at 90N?

Q. Is the temperature gradient in the winter hemisphere stronger or weaker?

Practice #1 with Python

Vertical pressure profile in the atmosphere

$p(z)=p_0*\exp(-z/H)$

where H=8000(m); p_0=1000.; Z=0., 1000., …9000.; dz=1000.

1. Plot the vertical profile of pressure
2. Plot the analytical density at different atmospheric levels
3. Calculate (approximately) the density at different atmospheric levels by using forward, backward, central difference method, etc.
4. Compare the obtained simulation results with the analytical results.
5. If dz=500 (i.e. the levels are 0., 500., ..., 9000.). Compare the new simulation results with those obtained with dz=1000.

Hint

The approximation of the derivative

$$\partial_x f^+ \approx \frac{f(x+dx)-f(x)}{dx}$$ Forward differencing

$$\partial_x f^- \approx \frac{f(x)-f(x-dx)}{dx}$$ Backward differencing

$$\partial_x f \approx \frac{f(x+dx)-f(x-dx)}{2dx}$$ Centered differencing