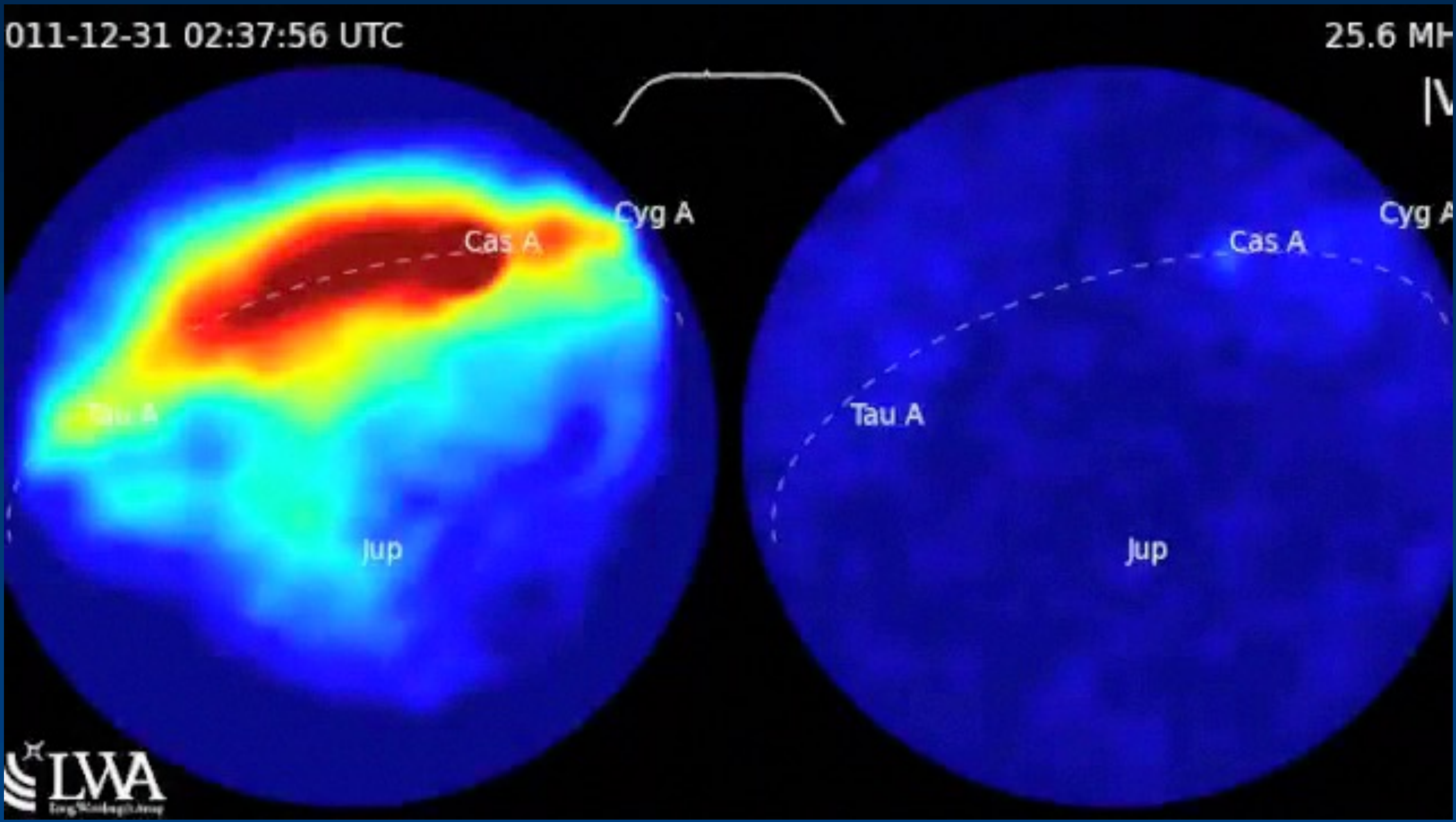
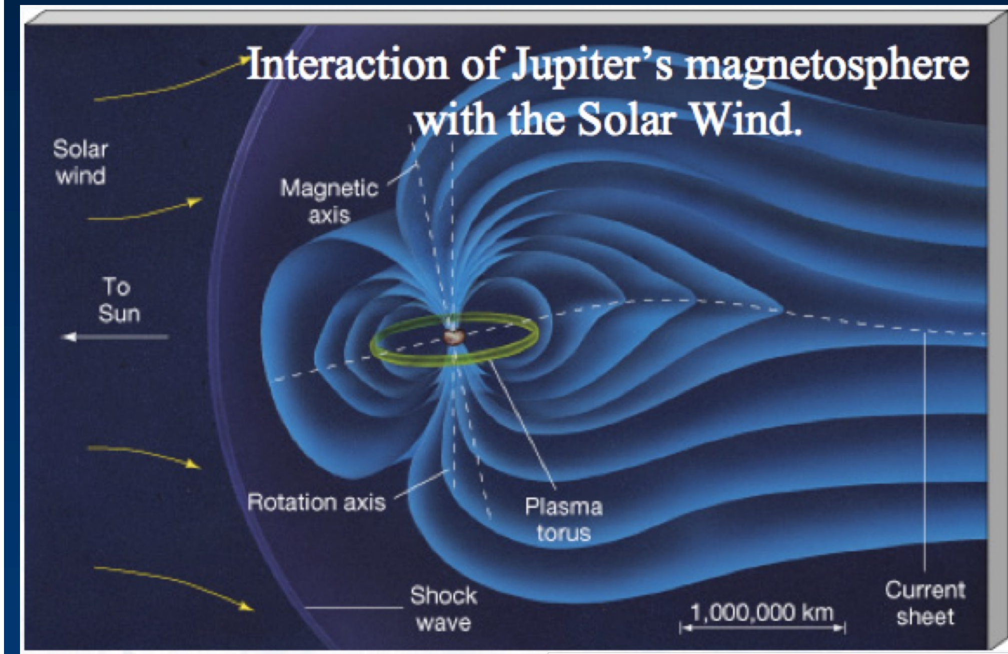
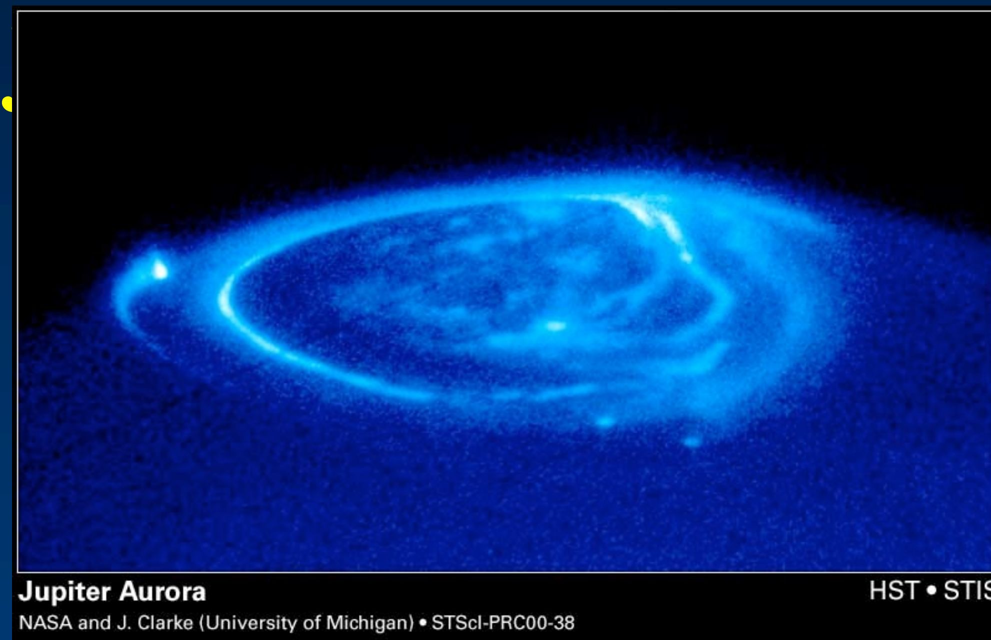
Detecting Radio Bursts from Exoplanets

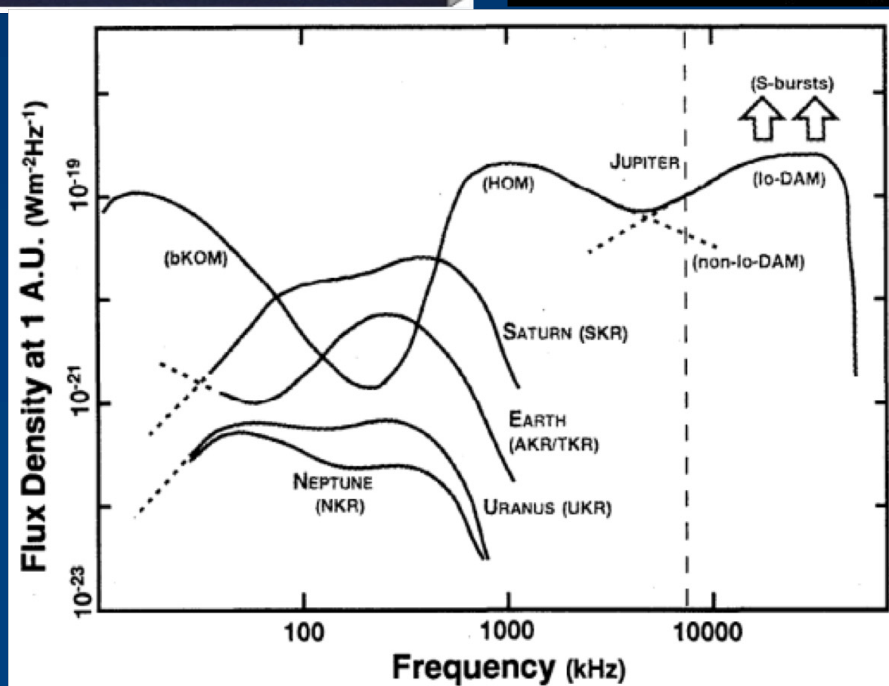
- Suitability of the LWA1
- Observations to date
- Near future: Owens Valley
- Farther future: the LWA swarm

Emission from Jupiter



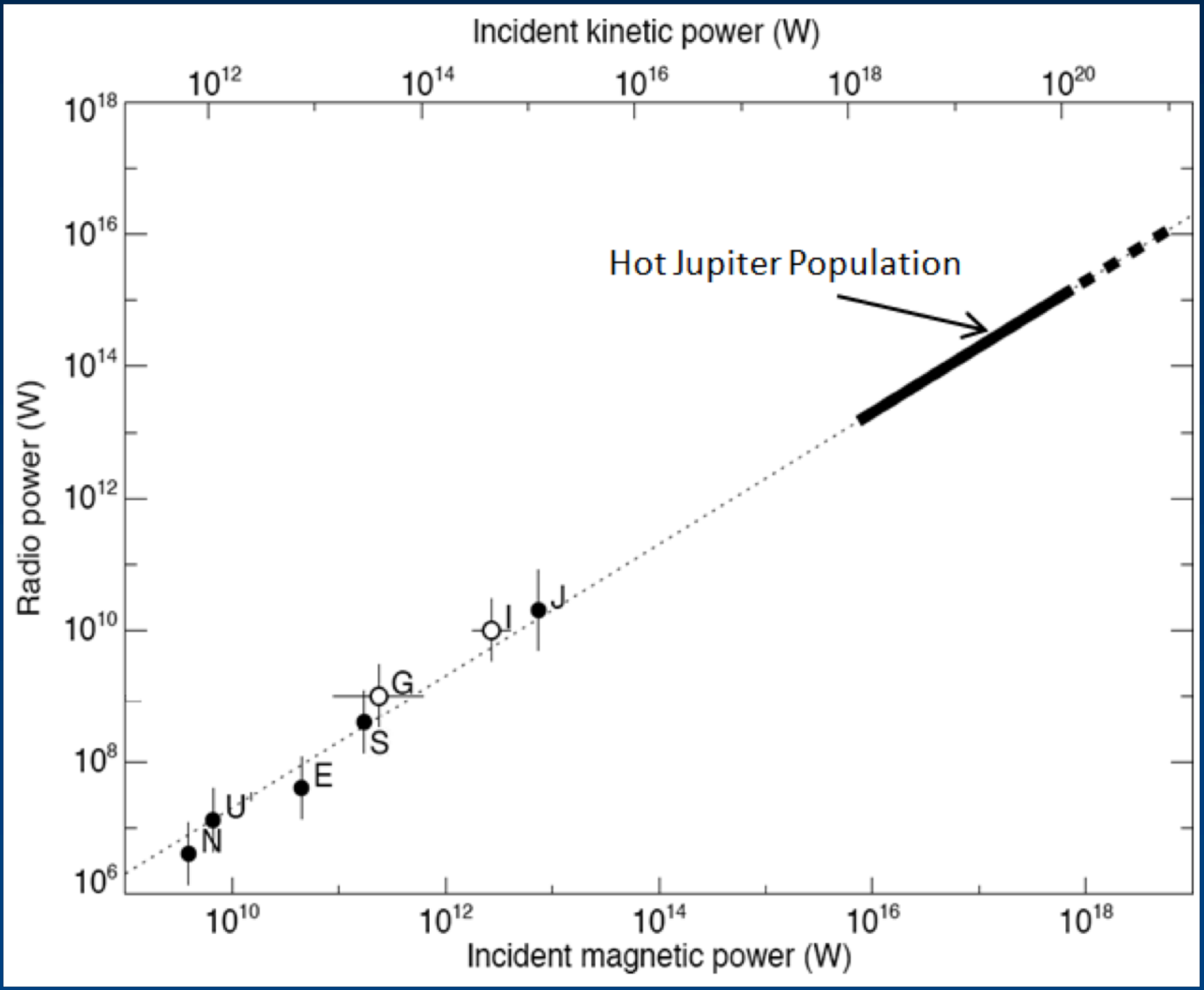

Interaction of Jupiter's magnetosphere with the Solar Wind.
Solar wind
To Sun
Magnetic axis
Rotation axis
Plasma torus
Shock wave
1,000,000 km
Current sheet


Jupiter Aurora
HST • STIS
NASA and J. Clarke (University of Michigan) • STScI-PRC00-38


Flux Density at 1 A.U. (Wm^{-2}Hz^{-1})
10^{-19}
10^{-21}
10^{-23}
100
1000
10000
Frequency (kHz)
(S-bursts)
JUPITER
(HOM)
(Io-DAM)
(non-Io-DAM)
(bKOM)
SATURN (SKR)
EARTH (AKR/TKR)
NEPTUNE (NKR)
URANUS (UKR)

Zarka (1998)

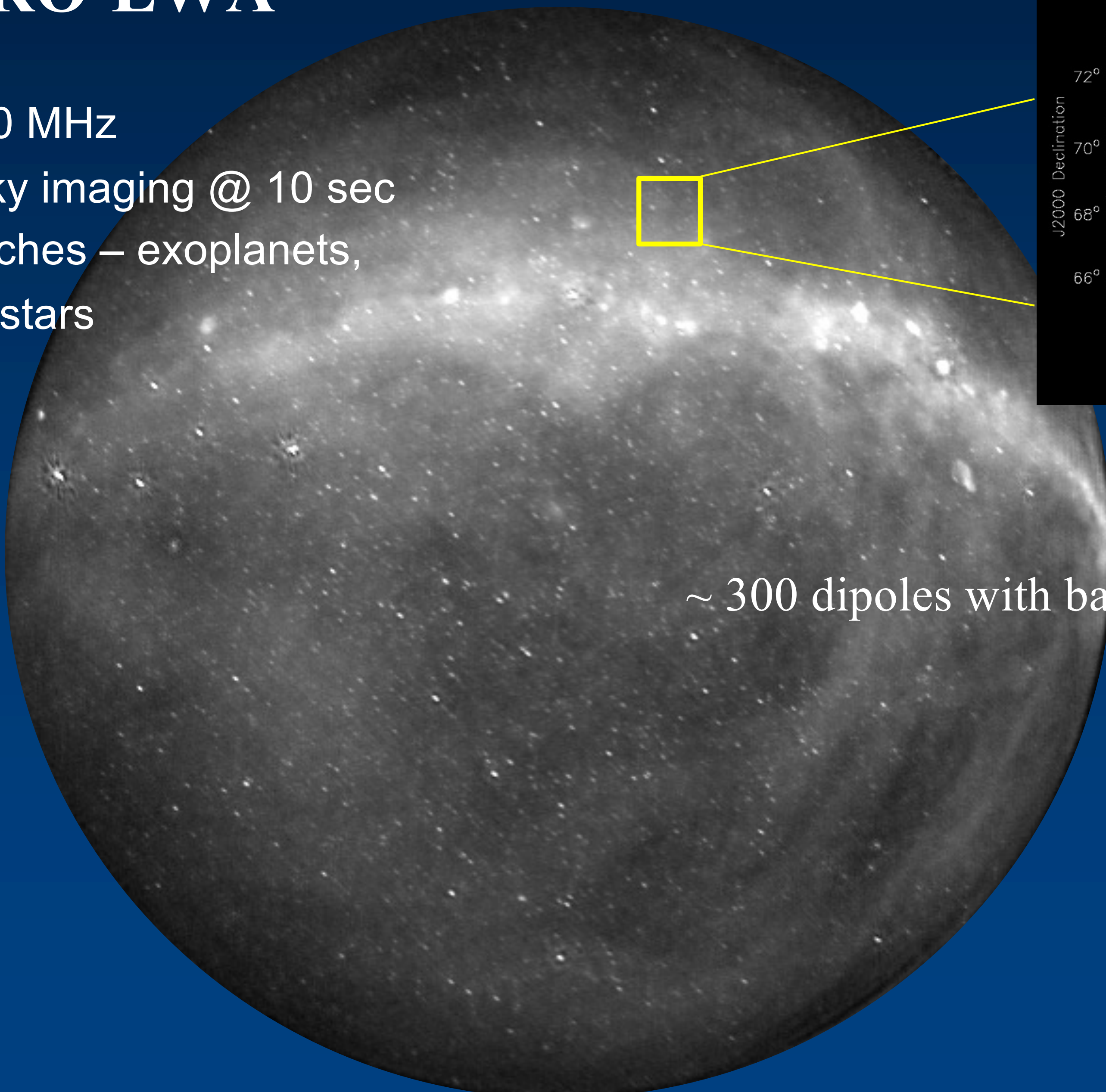
Extrapolating to Hot Jupiters

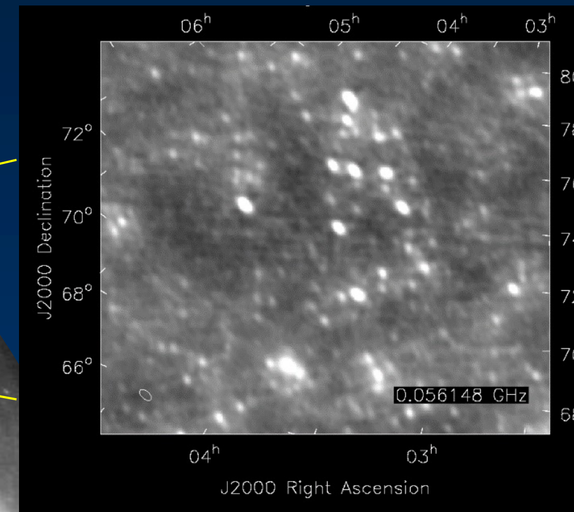


LWA Tools

OVRO-LWA

- 30-80 MHz
- All sky imaging @ 10 sec
- Searches – exoplanets, flare stars





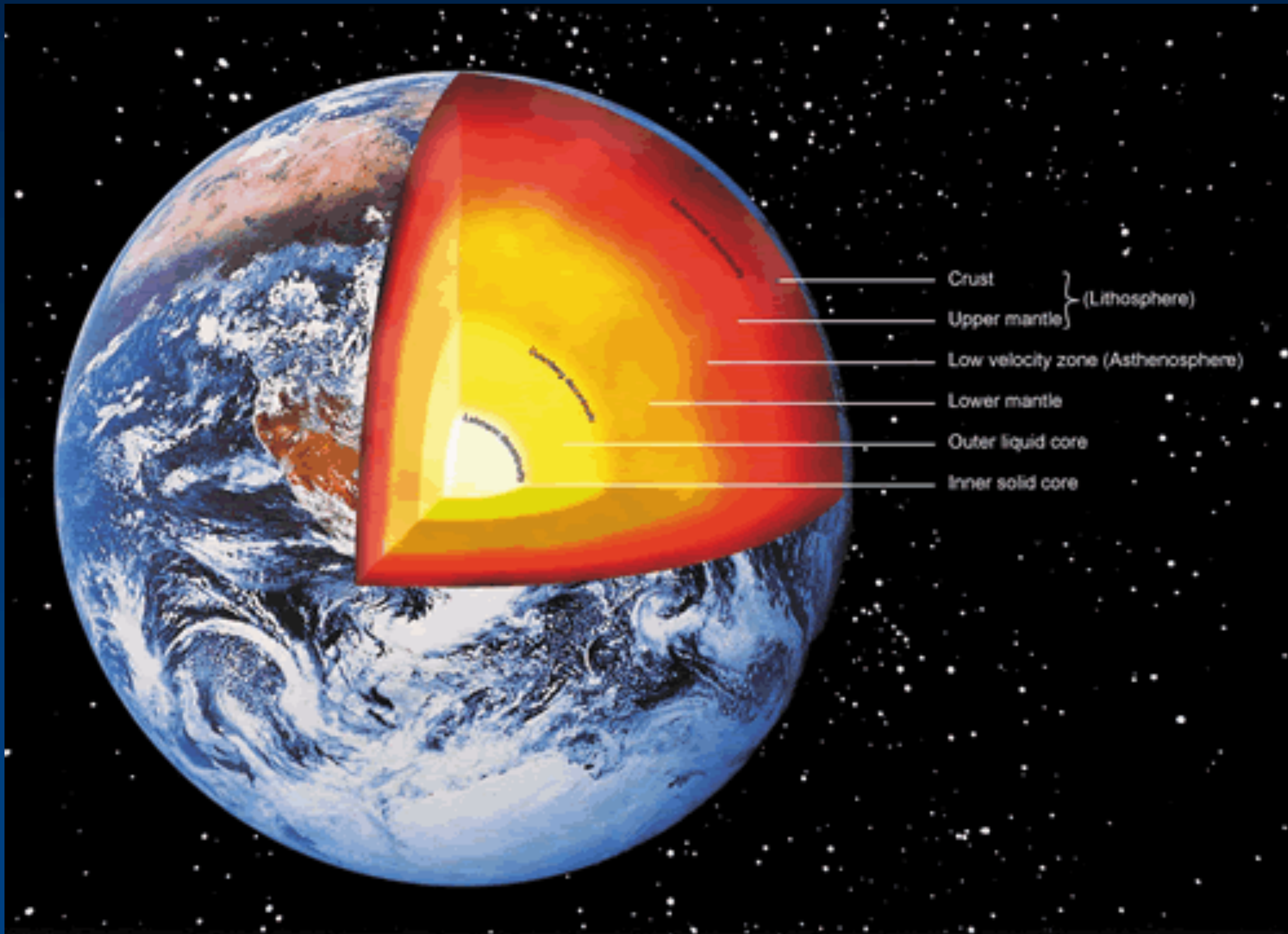
~ 300 dipoles with baselines to 2 km

Announcements

- Final Project – see handout for instructions or retrieve from class web pages
- Pick up your proto-planet if you haven't already
- HW6 is due on Thursday
- Physics Day is April 13, student talks, free lunch

Register before April 8:
https://physics.unm.edu/pandaweb/undergraduate/day2024/index.php

Earth's Interior



The Earth - Surface and Interior

Basic Data

Diameter	12,756 km (equator)
Mass	6×10^{24} kg
Density	5.5 g/cm^3
	5500 kg/m^3
Escape velocity	11.2 km/s
Temp	-130 ° F to 140 ° F
	183K to 333K
Albedo	0.31

= fraction of incoming sunlight that a planet reflects

Densities of typical surface rocks:

$\approx 3\ g/cm^3$

Average density of Earth as a whole (its mass/volume):

$\approx 5.5\ g/cm^3$

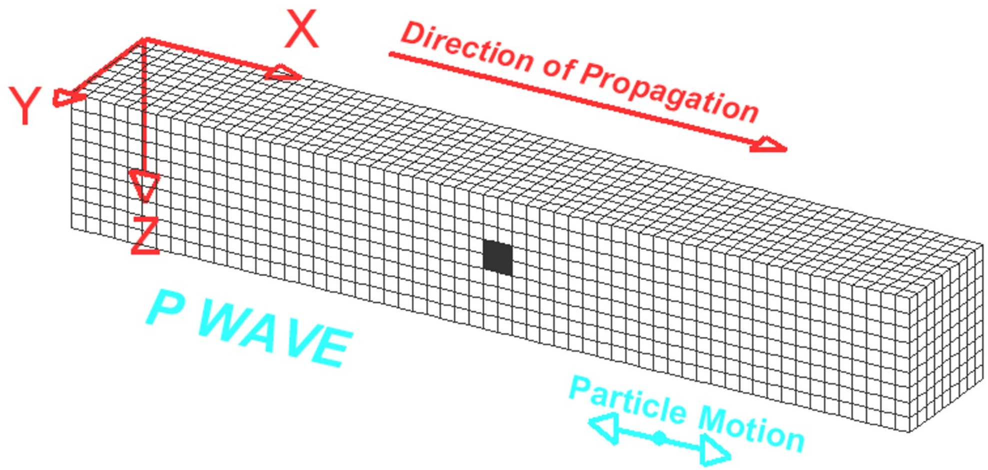
$\Rightarrow$ Interior must be much denser than the crust!

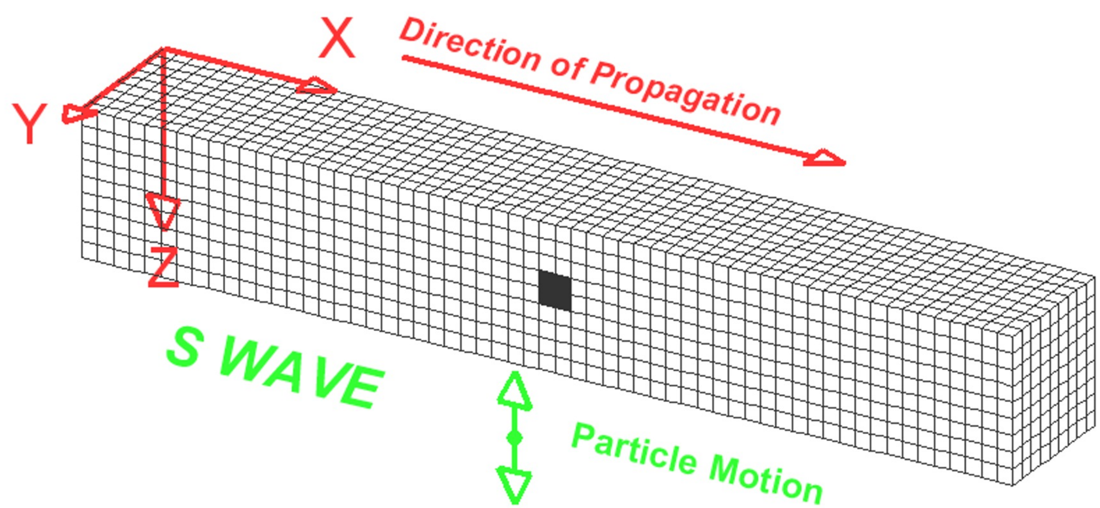
How can we probe the interior?

Seismology

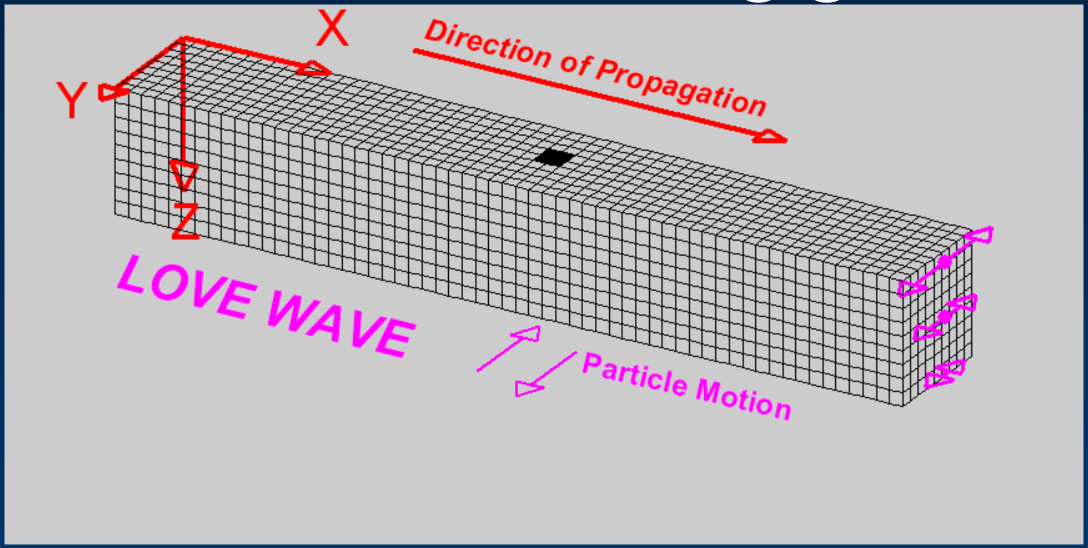
- Study of earthquakes and seismic waves that move through and around the Earth
- Primary and Secondary waves move through the Earth. Love and Rayleigh waves move around surface.

- P waves – "primary", pressure or longitudinal. Fastest waves. Can pass through liquid.
- S waves – "secondary", shear or transverse. Cannot travel far in liquid

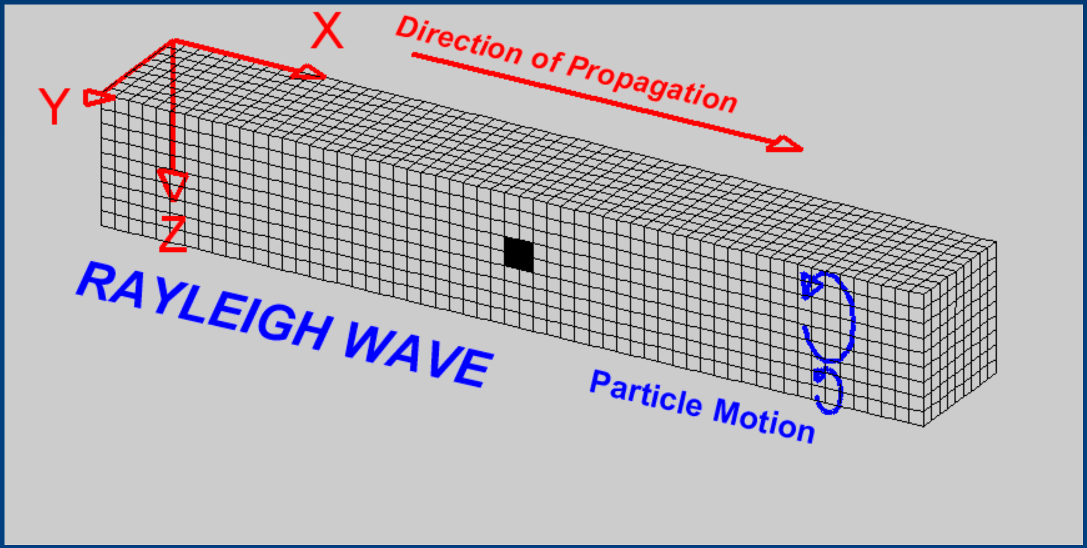




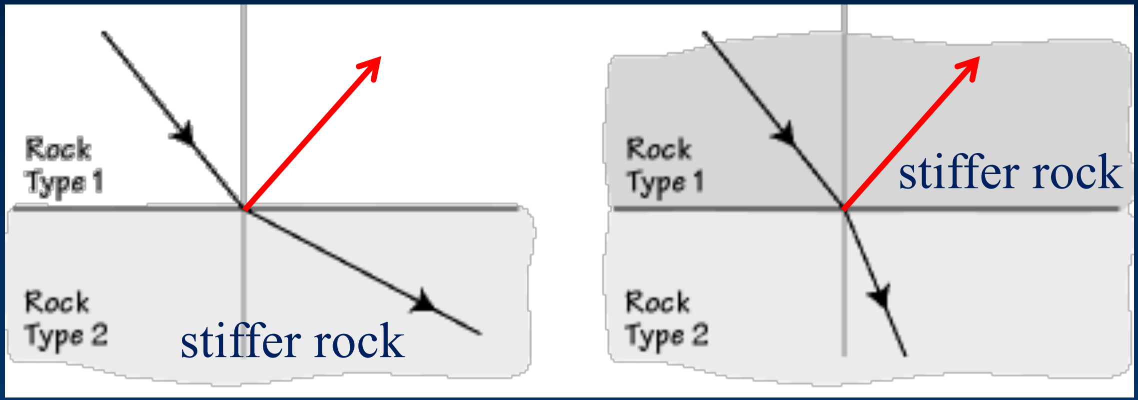
- Love waves - surface waves moving ground side-to-side



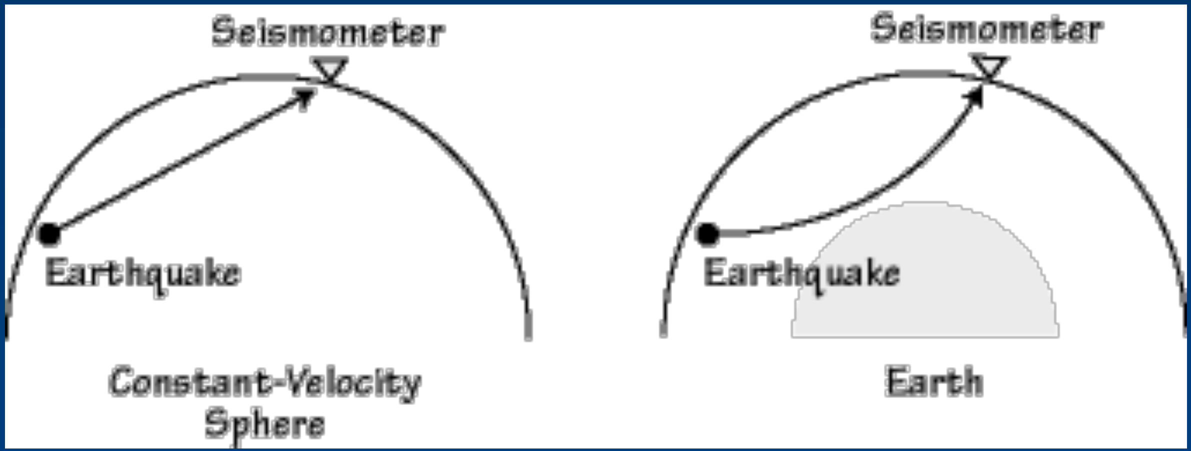
- Rayleigh waves - surface waves rolling the ground (up-down, back-forward)

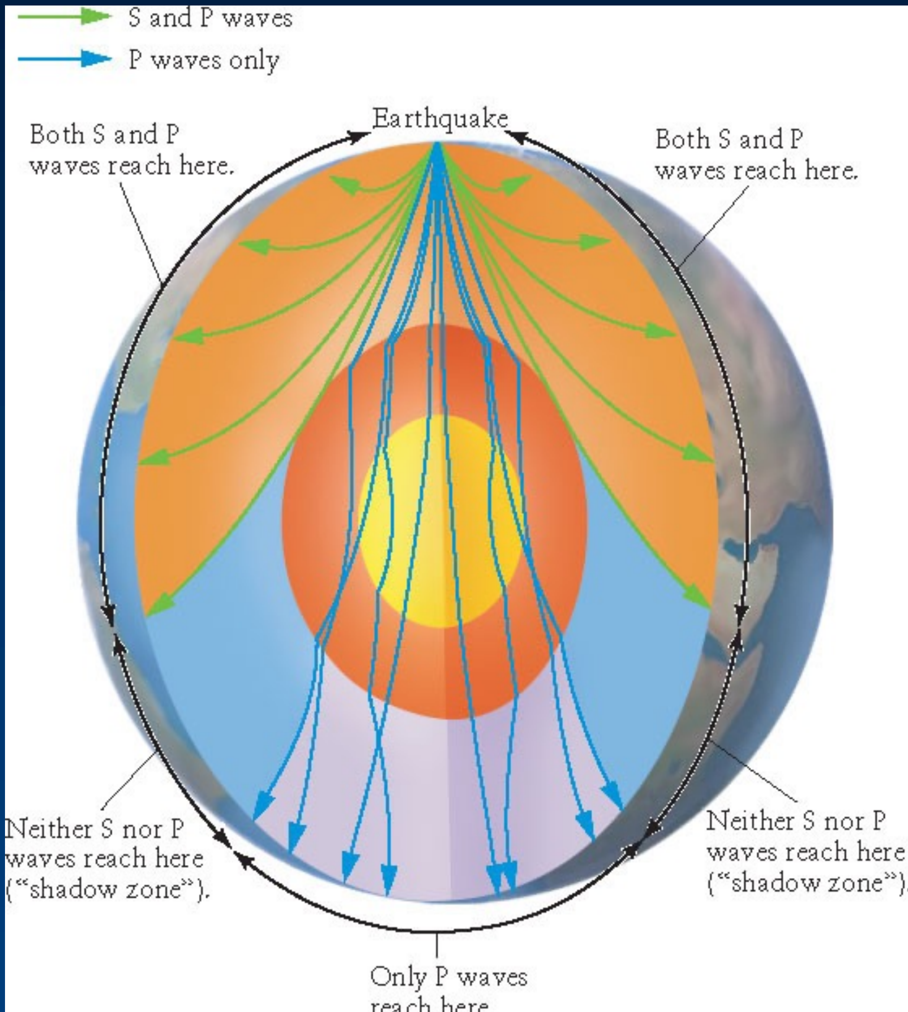


Refraction of seismic waves



Also get reflected wave component at a sharp boundary, angle of incidence = angle of reflection





This is the distribution of waves you will see, paths curve where there are changes in density and composition (refract)

⇒ The Earth must have a liquid core!

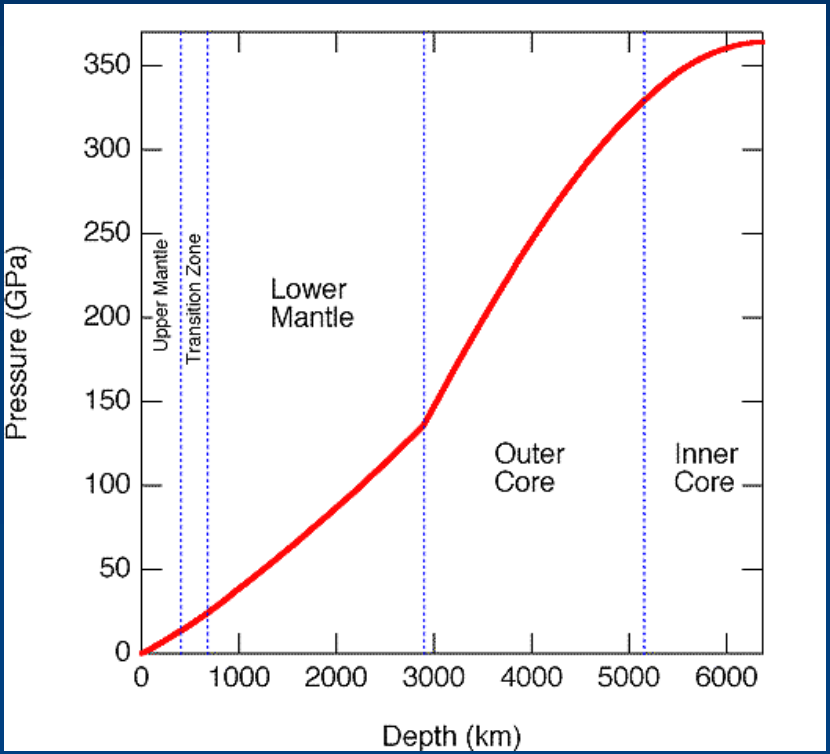
[Inner core is solid, though, due to enormous pressure.]

Table 9-3 Earth's Internal Structure

Region	Depth Below Surface (km)	Distance From Center (km)	Average Density (kg/m^3)
Crust (solid)	0–5 (under oceans) 0–35 (under continents)	6343–6378	3500
Mantle (plastic, solid)	from bottom of crust to 2900	3500–6343	3500–5500
Outer core (liquid)	2900–5100	1300–3500	10,000–12,000
Inner core (solid)	5100–6400	0–1300	13,000

Note: mantle is solid, but upper levels are "plastic", acts like a very thick, or *viscous* fluid. Can flow slowly.

Yellow curve is temperature, red curve is melting point of Earth's material at these levels, and depends on pressure. Pressure increases with increasing depth.



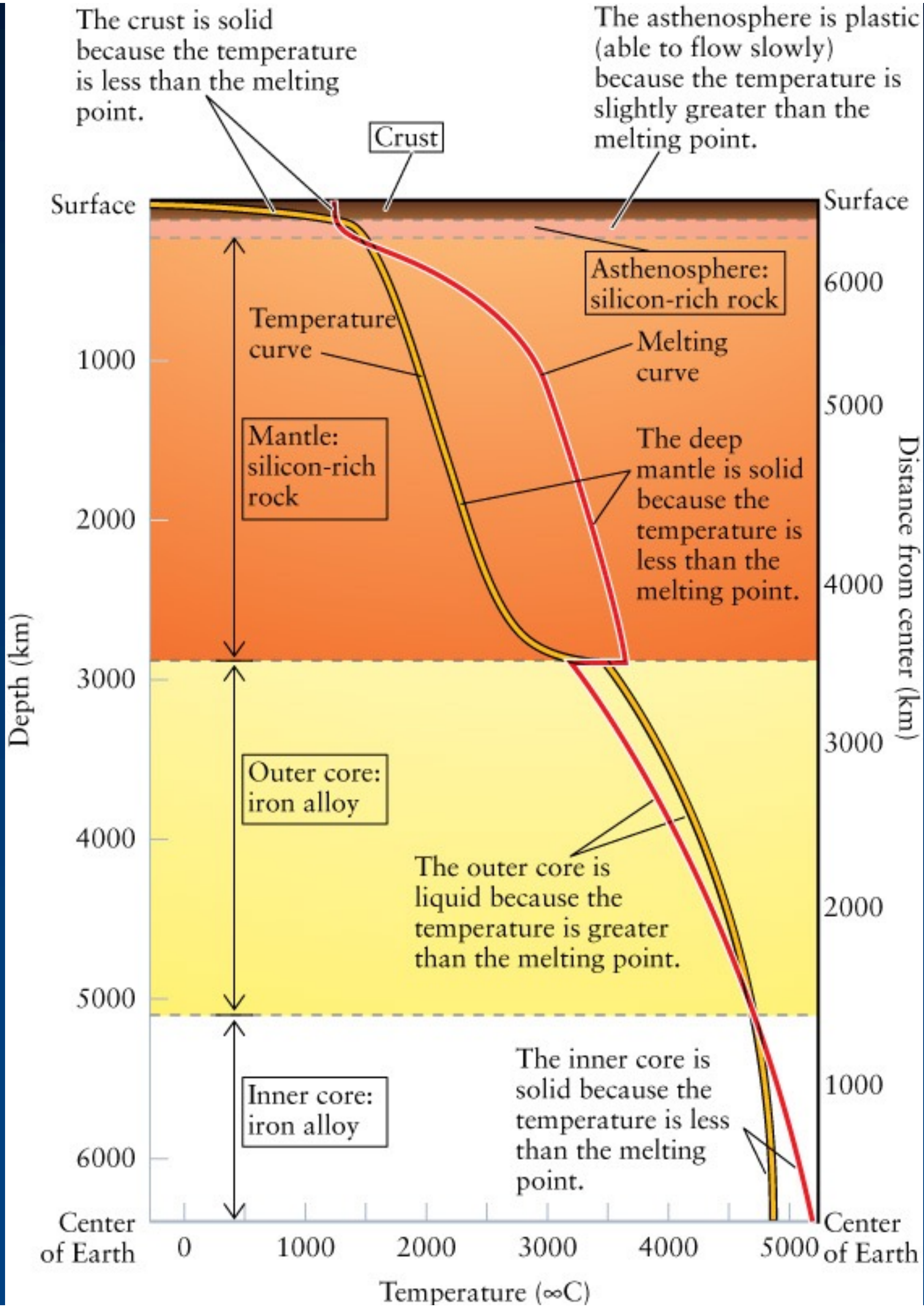
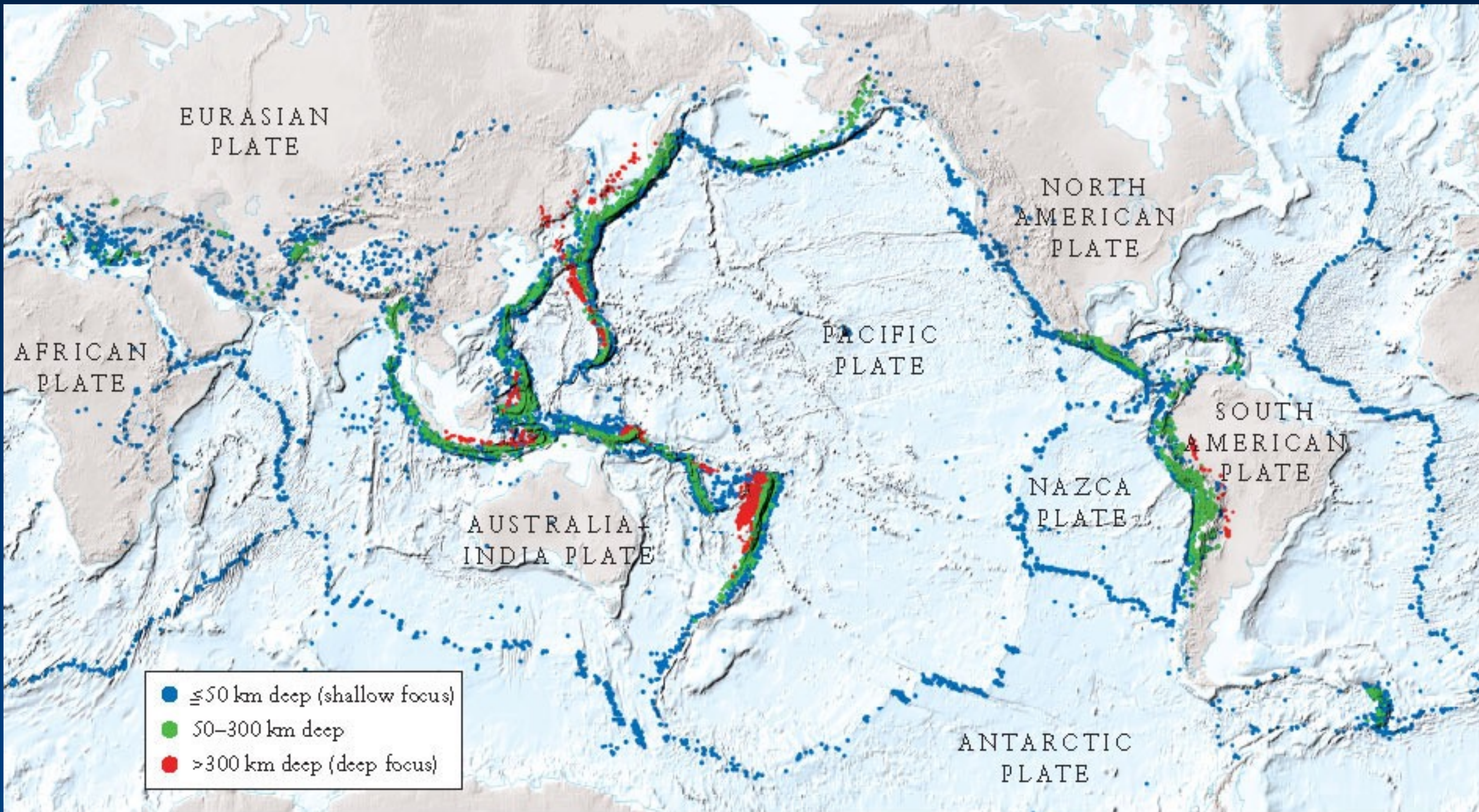


Plate tectonics



Plates 10-50 km thick, extend into upper mantle

Plate motion ~ a few cm/year. Directly measurable

Plate tectonics

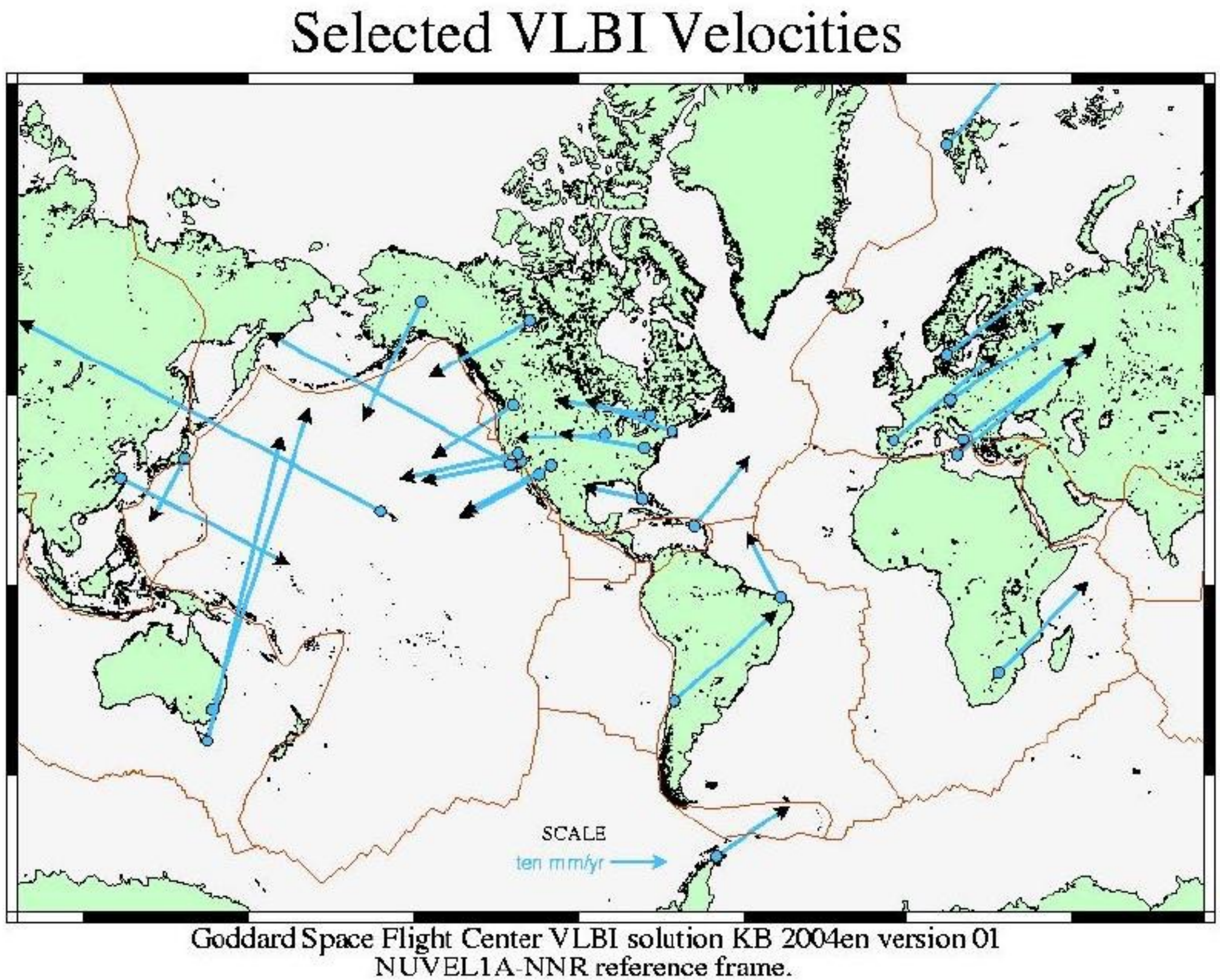


Plate motion ~ a few cm/year

Other indications of tectonic motions

- Shapes of plates seem to fit with each other
- Fossils indicate earlier joining of continents
- Volcanic, seismic and geothermal activity

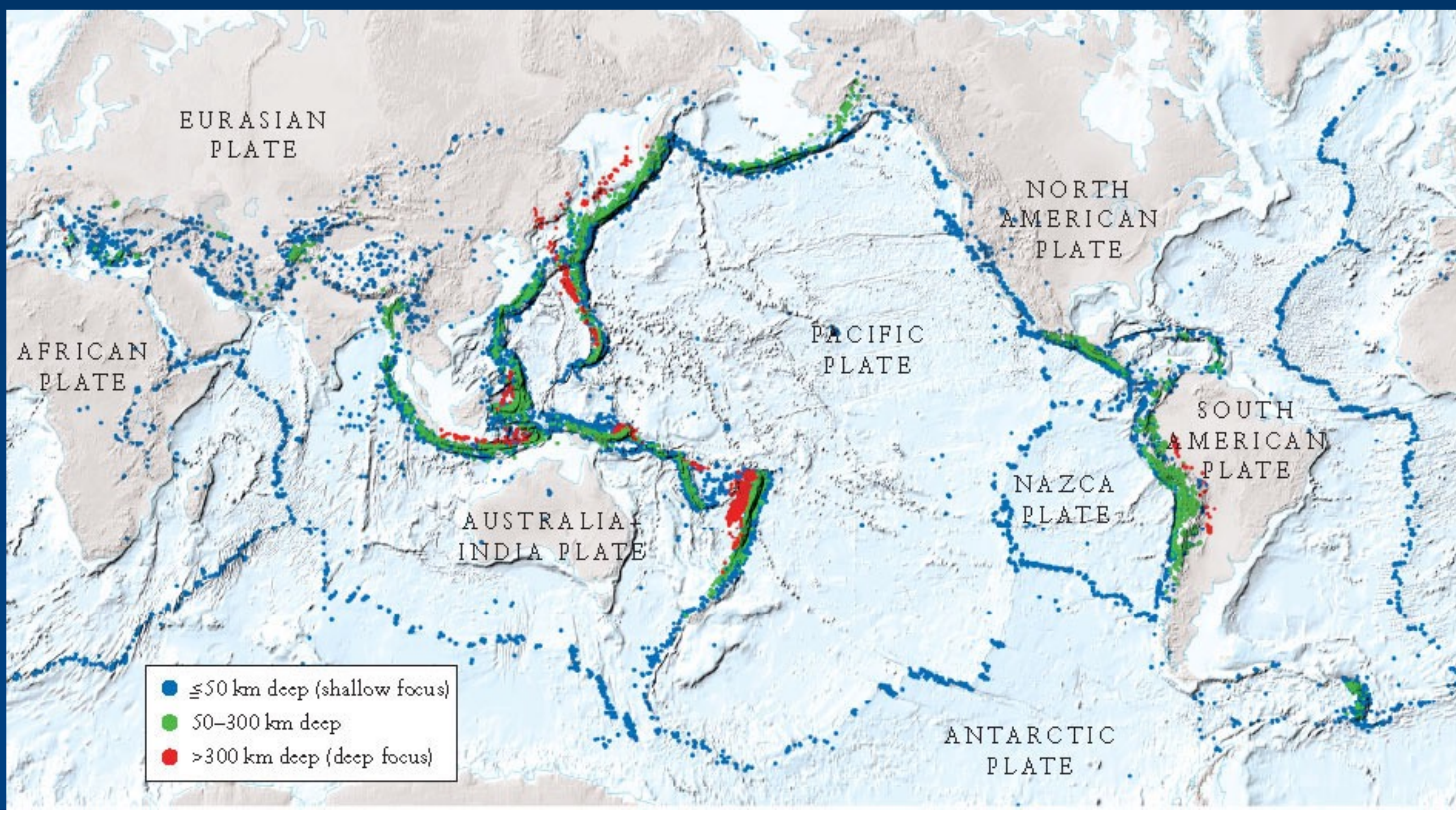
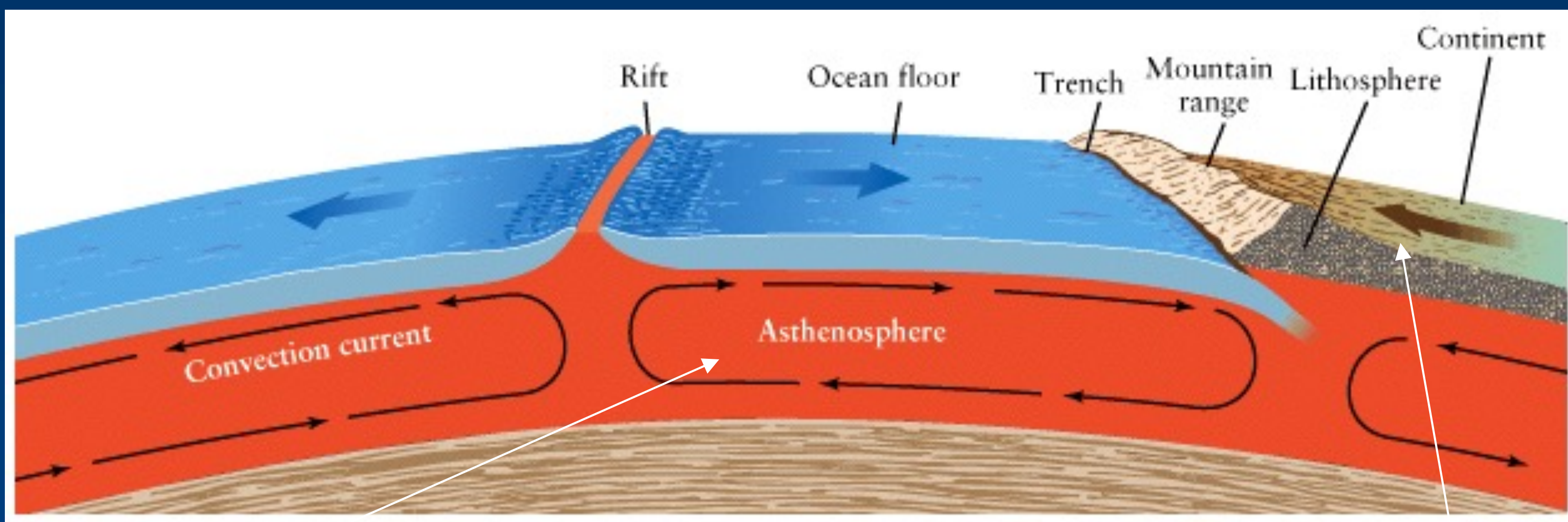


Plate tectonics

- Solid plates float on plastic upper mantle
- Driven by convection currents. Interior is still hot!



Asthenosphere **is flowing, soft upper layer of the mantle**

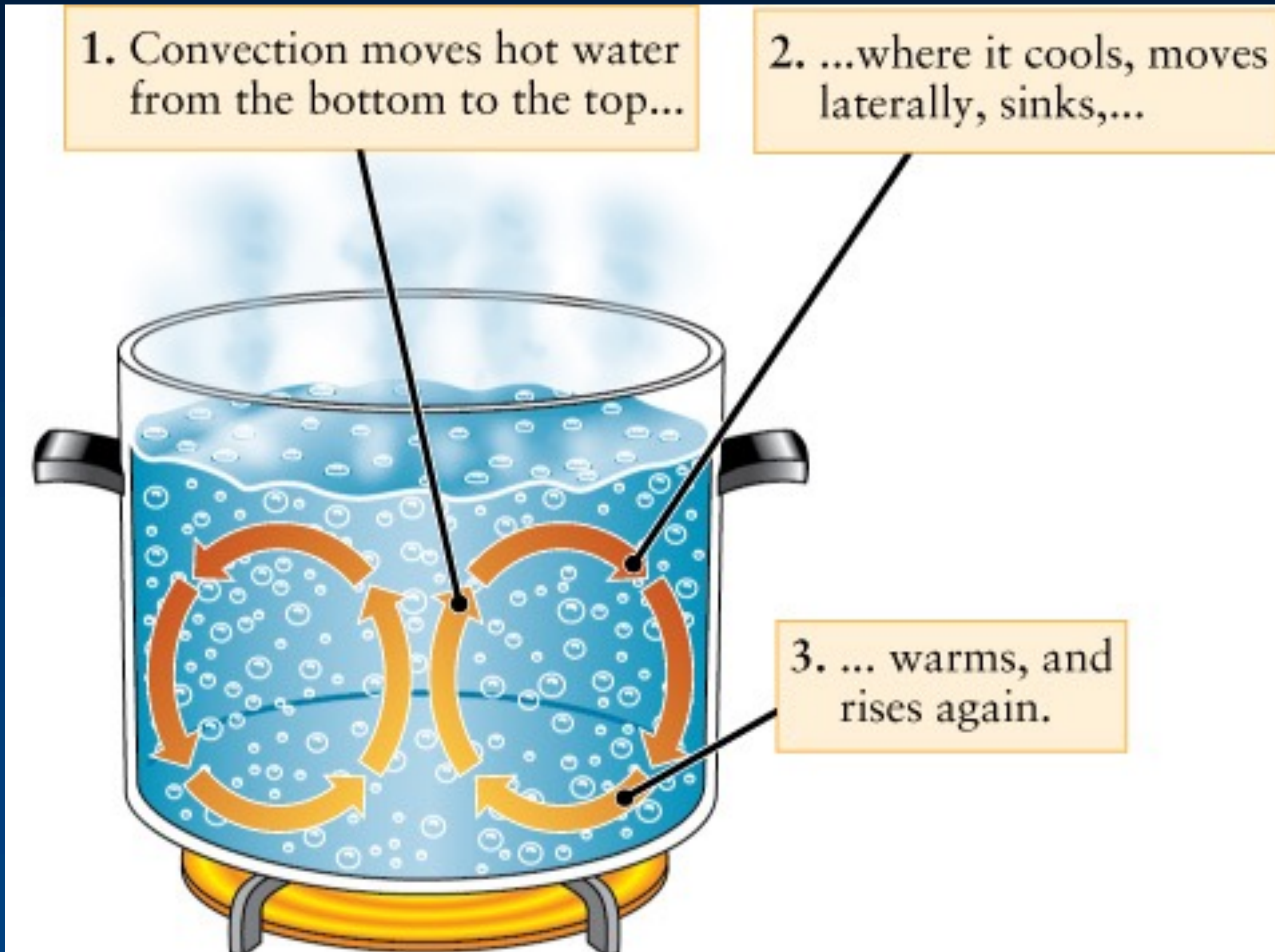
Lithosphere **is rigid layer of crust and top of mantle**

Why is Earth so hot?

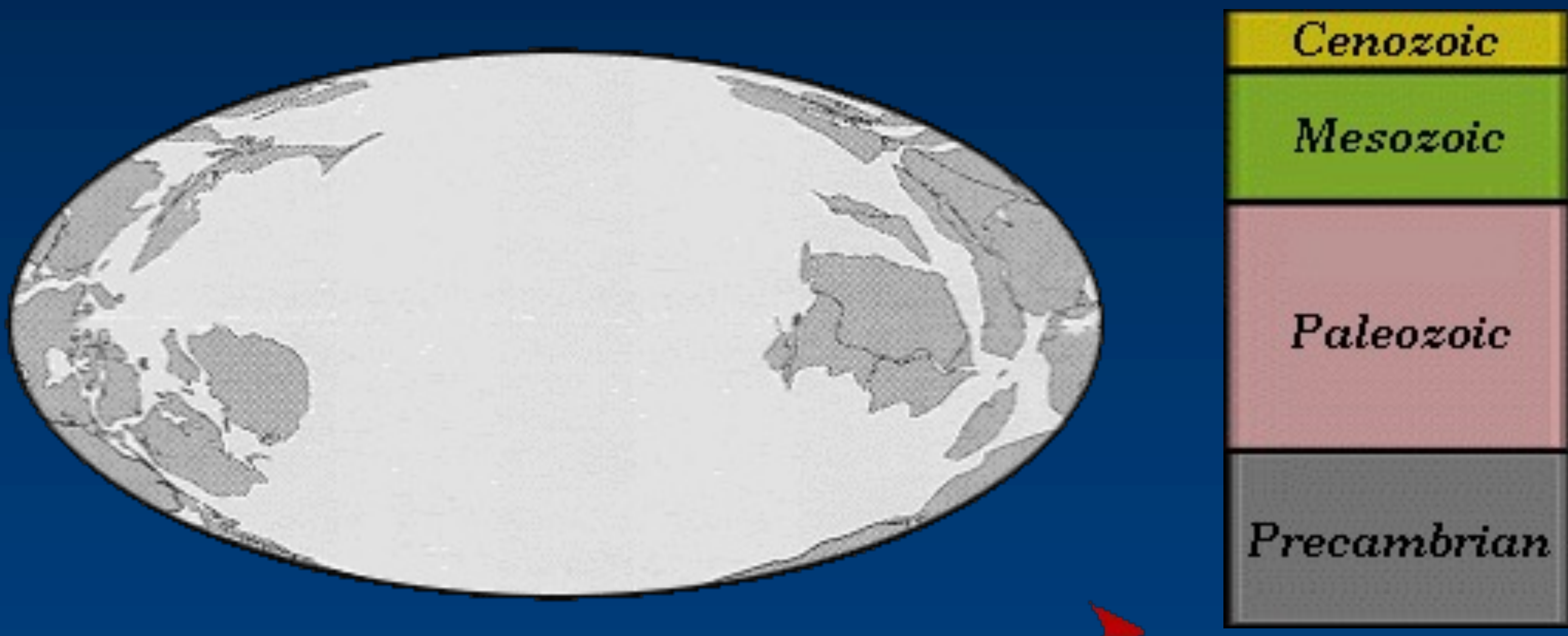
Origin of internal heat driving plate tectonics

Inner Earth is hot, and heat flows from hotter to cooler regions.

1. Original heat of colliding planetesimals which formed Earth - Earth hasn't cooled off completely.
2. Radioactive decay of elements in Earth, such as uranium, thorium and potassium.


1. Convection moves hot water from the bottom to the top...
2. ...where it cools, moves laterally, sinks,...
3. ... warms, and rises again.

Continental drift

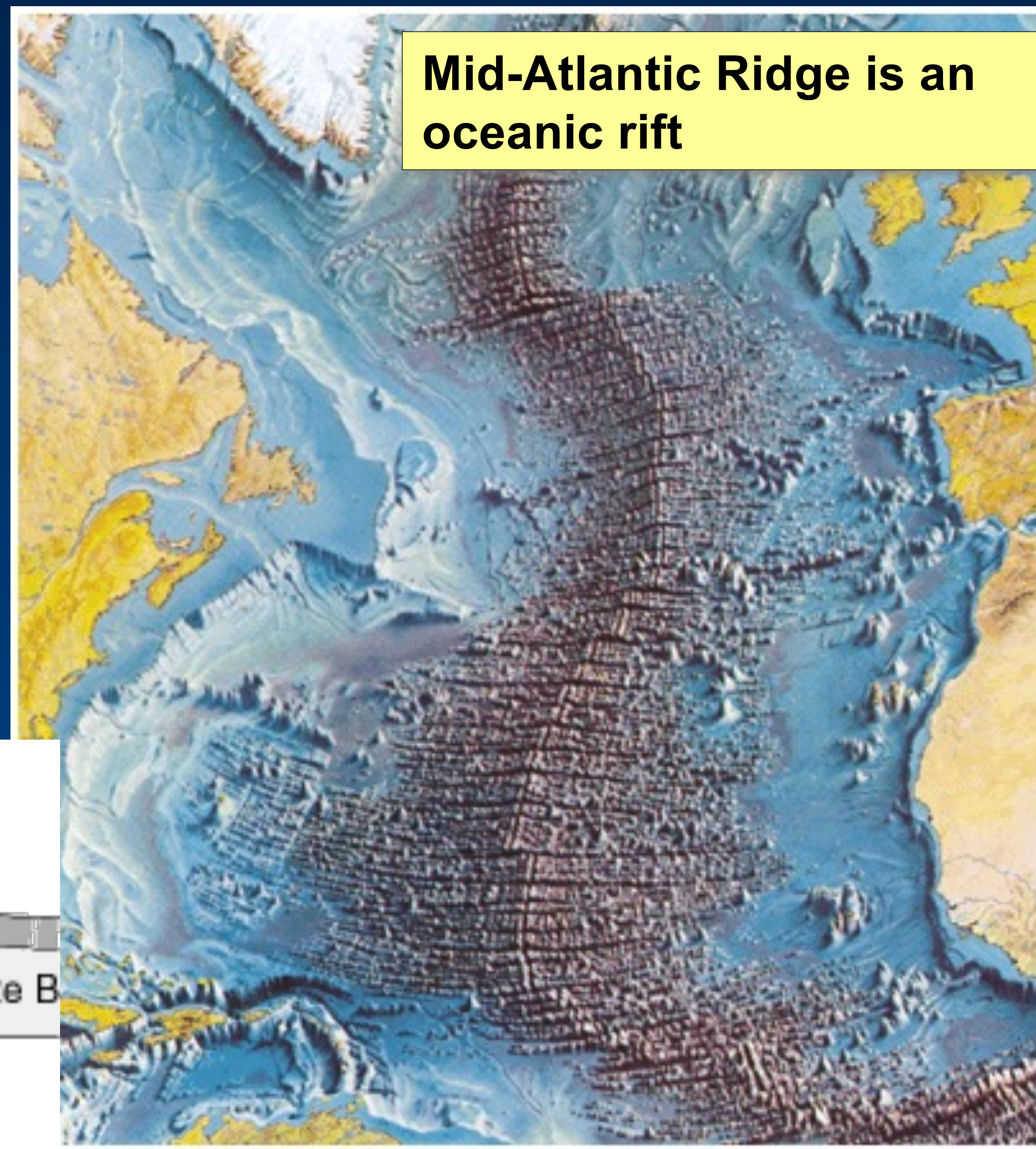


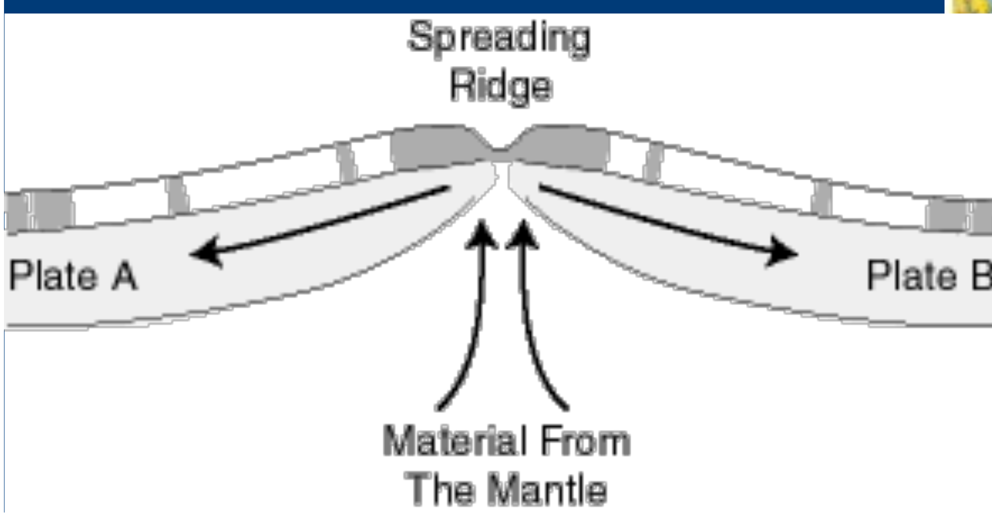
http://www.ucmp.berkeley.edu/geology/anim1.html

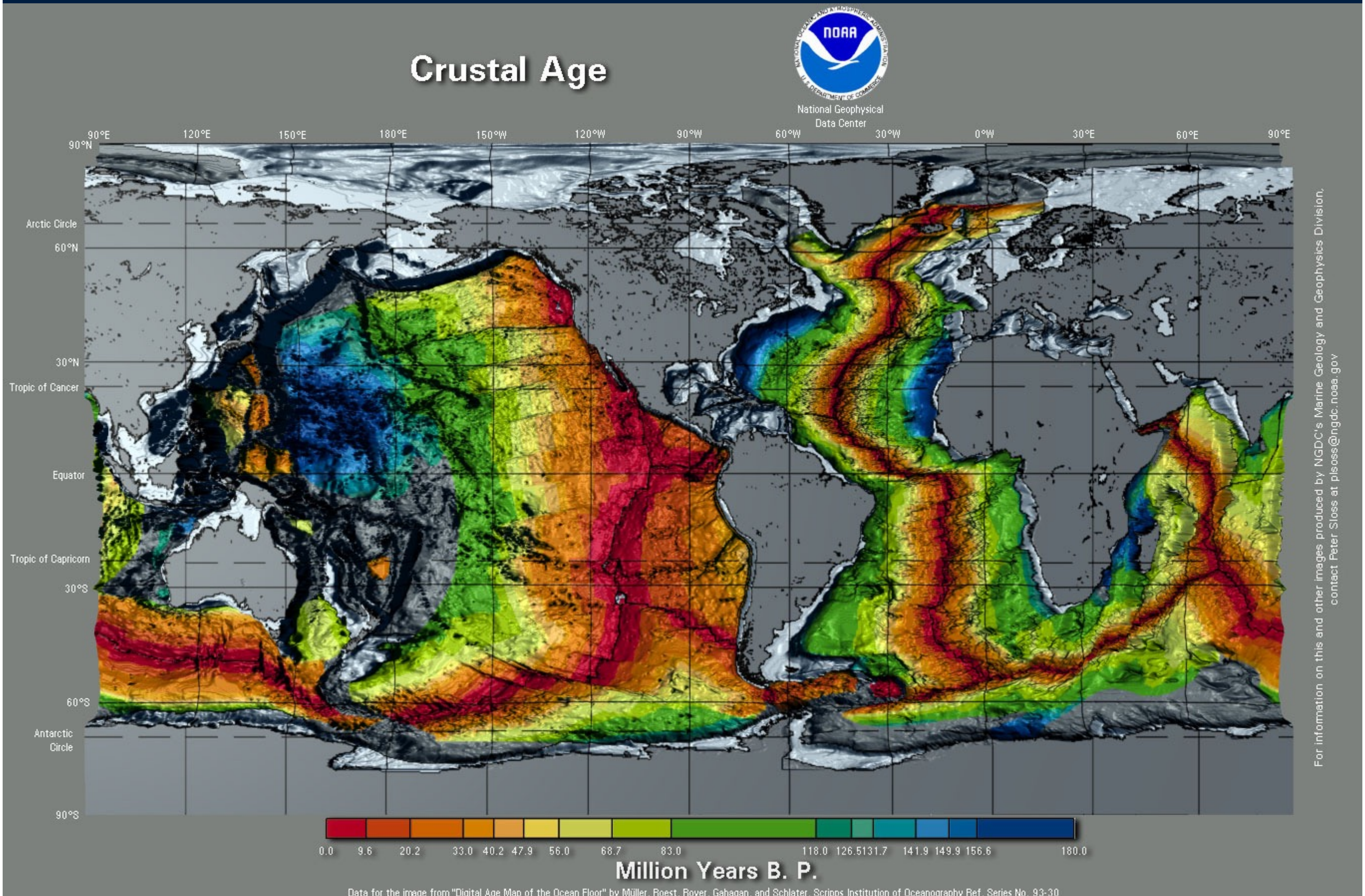
Where plates separate, get *rift*.

Most rifts zones are in oceans. (Though not all – Rio Grande rift!)

New rock forms as lava seeps up from Earth's interior.

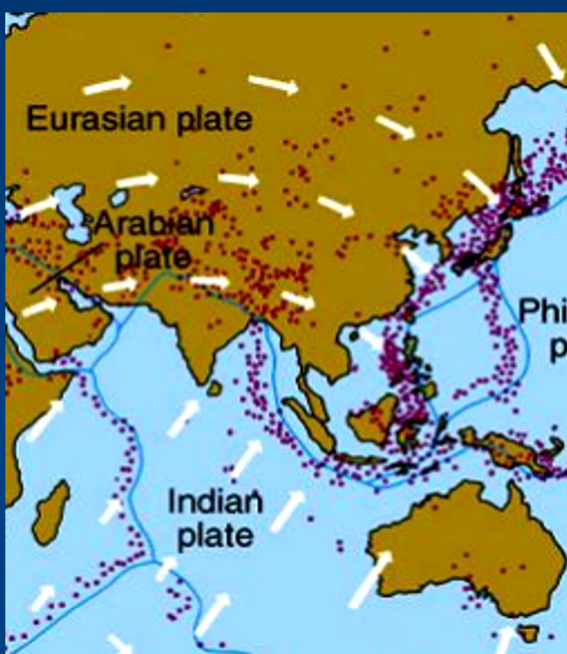


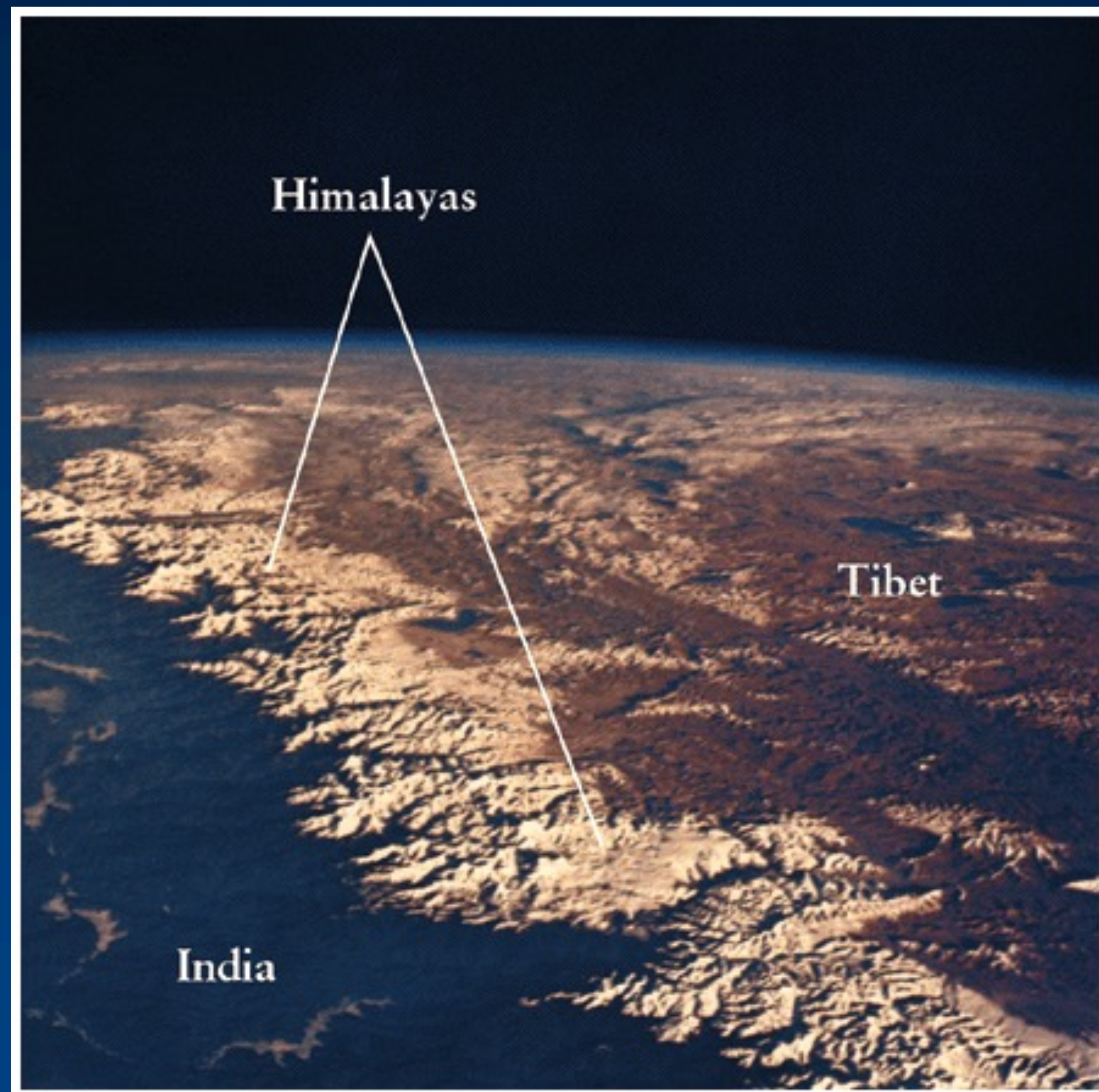



Crustal Age
National Geophysical Data Center
90°E
120°E
150°E
180°E
150°W
120°W
90°W
60°W
30°W
0°W
30°E
60°E
90°E
90°N
Arctic Circle
60°N
30°N
Tropic of Cancer
Equator
Tropic of Capricorn
30°S
60°S
Antarctic Circle
90°S
0.0
9.6
20.2
33.0
40.2
47.9
56.0
68.7
83.0
118.0
126.5
131.7
141.9
149.9
156.6
180.0
Million Years B. P.
Data for the image from "Digital Age Map of the Ocean Floor" by Müller, Roest, Royer, Gahagan, and Schlater, Scripps Institution of Oceanography Ref. Series No. 93-30
For information on this and other images produced by NGDC's Marine Geology and Geophysics Division, contact Peter Sloss at plsoss@ngdc.noaa.gov

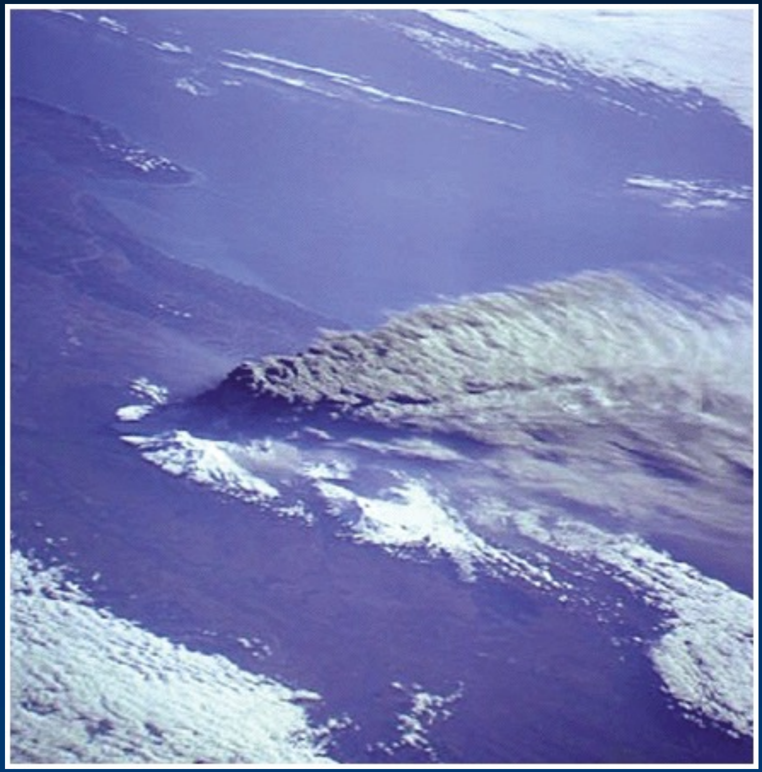
Where continental plates collide head-on, mountains are built.

Here, the Indian plate and Eurasian plate are colliding to form the Himalayas.

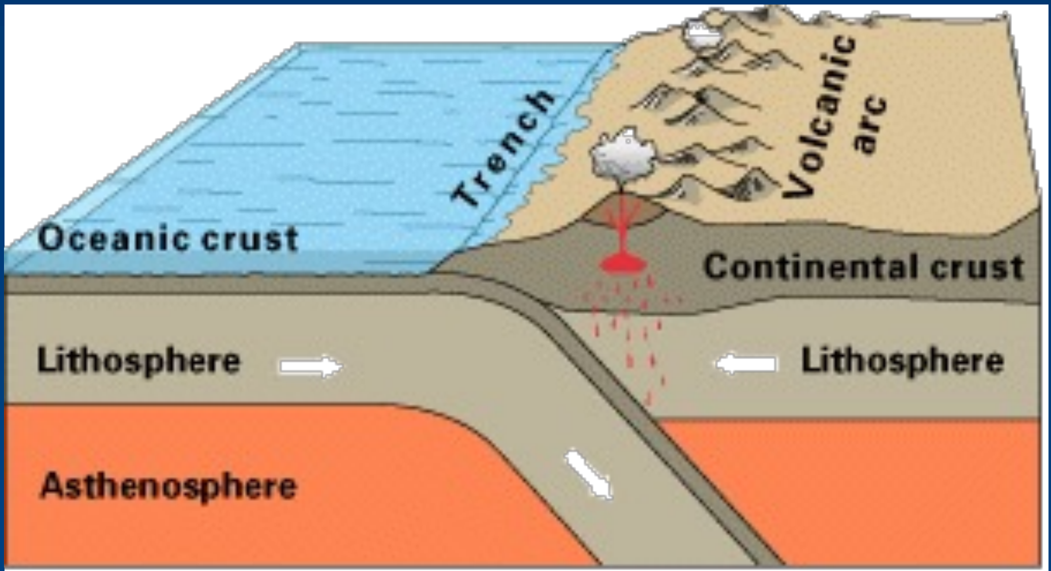




Where one plate slides underneath another, (called a subduction zone) volcanoes are common - here, on boundary of Pacific and Eurasian plates.



Where one plate goes under, material is "recycled" back into the mantle.



Oceanic-continental convergence

Also, plates can slide past each other. Example: North American and Pacific plates are carrying Los Angeles and San Francisco toward each other. Will be “twin cities” in about 25 million years!

Rate of plate movement: a few cm per year

Source of strong near-surface earthquakes (eg. 1906 San Francisco)

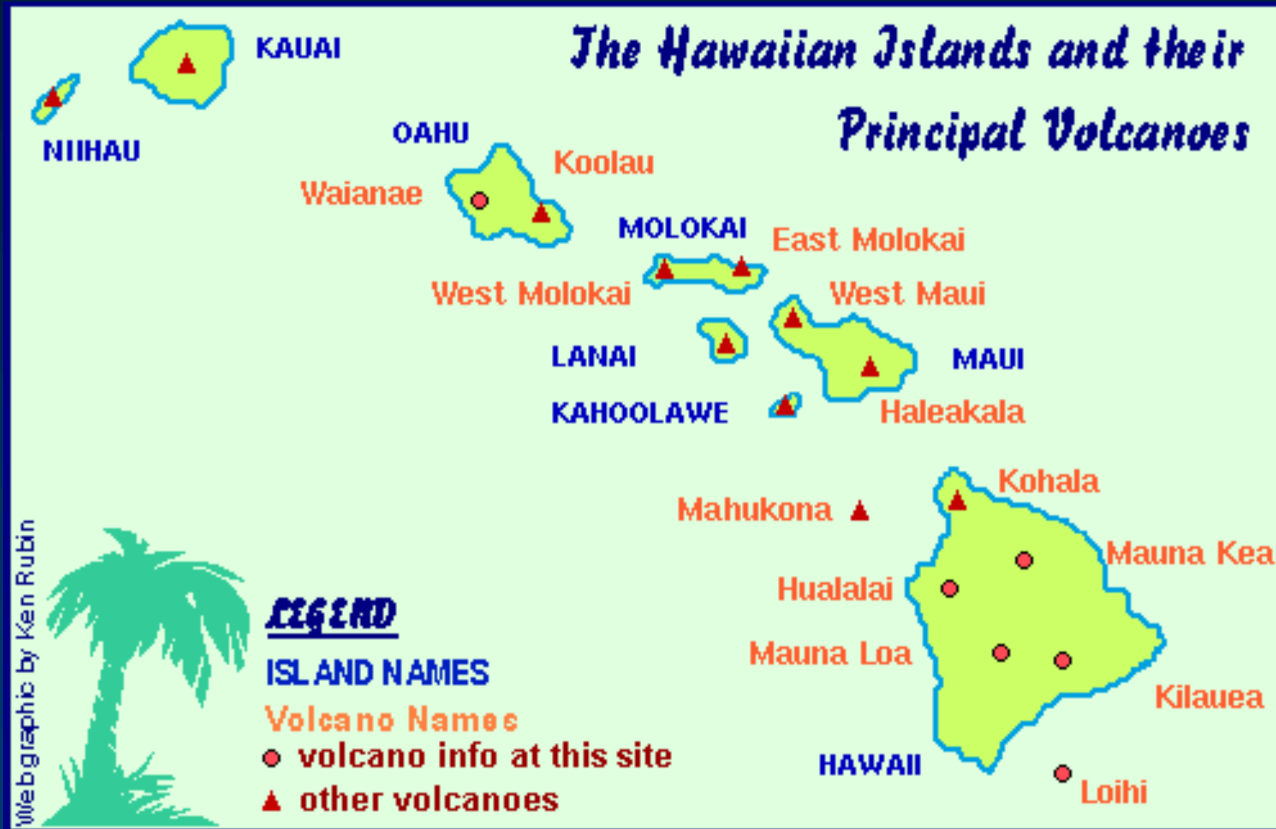
Figure 13. The above photograph was taken near Bolinas, CA, shortly after the San Francisco earthquake on April 18, 1906. The fence line was continuous before the earthquake.

(modified from U.S.G.S. Photographic Library, Gilbert, G.K., ggk02845, http://libraryphoto.cr.usgs.gov/index.html)

Can find hot spots located in the middle of the plates: Plumes of magma from plate/mantle transition wells up.

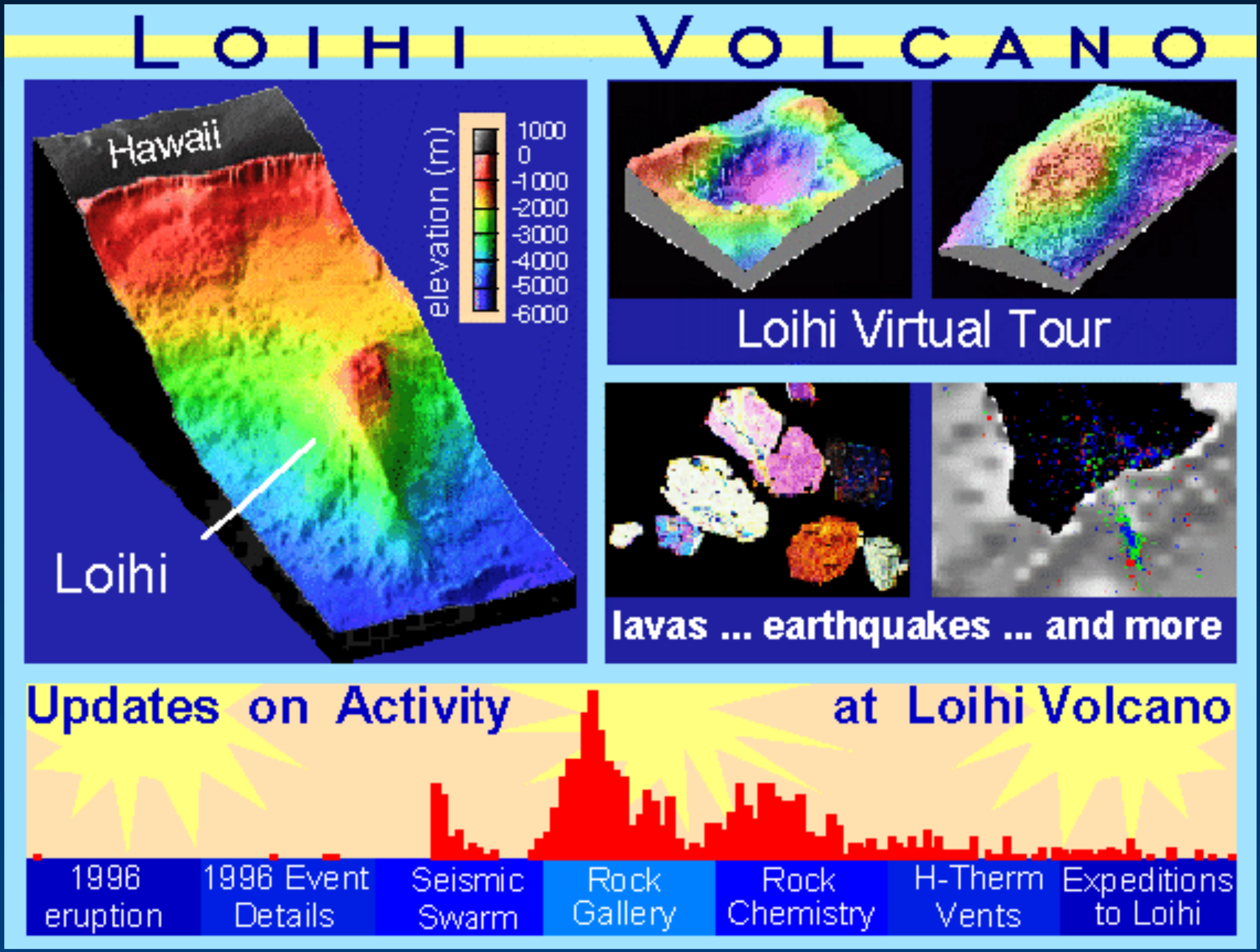
Hot spot fixed => chain of volcanoes

Example: Hawaii. Picture from space shuttle Discovery, 1988


The Hawaiian Islands and their Principal Volcanoes
KAUAI
NIIHAU
OAHU
Koolau
Waianae
MOLOKAI
East Molokai
West Molokai
West Maui
LANAI
MAUI
KAHOOLAWE
Haleakala
Kohala
Mahukona
Mauna Kea
Hualalai
Mauna Loa
Kilauea
HAWAII
Loihi
LEGEND
ISLAND NAMES
Volcano Names
volcano info at this site
other volcanoes
Webgraphic by Ken Rubin


The Island of Hawaii
50 km
Mahukona
Kohala
Mauna Kea
Hualalai
Mauna Loa
Kilauea
Loihi
Volcano Summit
Contour Interval = 1 km
N


Kilauea May 27, 2017



Loihi volcano rises 3000m above the sea floor, though not above sea level.

Other Geological Features

- Scarp is a step or offset, often caused by a fault

The dynamic Earth

- Surface is shaped and reshaped over billions of years (plate tectonics, wind, erosion)
- Much of the surface is young (10-100 Myr)
- Oldest parts are 4 billion years old (parts of Canada, Greenland)
- Active today (interior still molten and hot, from formation and from radioactive decay)
- Young surface => not many craters

Impact craters exist but are wiped out by wind and water erosion and plate tectonics. This is not a typical landscape on Earth!

Meteor Crater, AZ

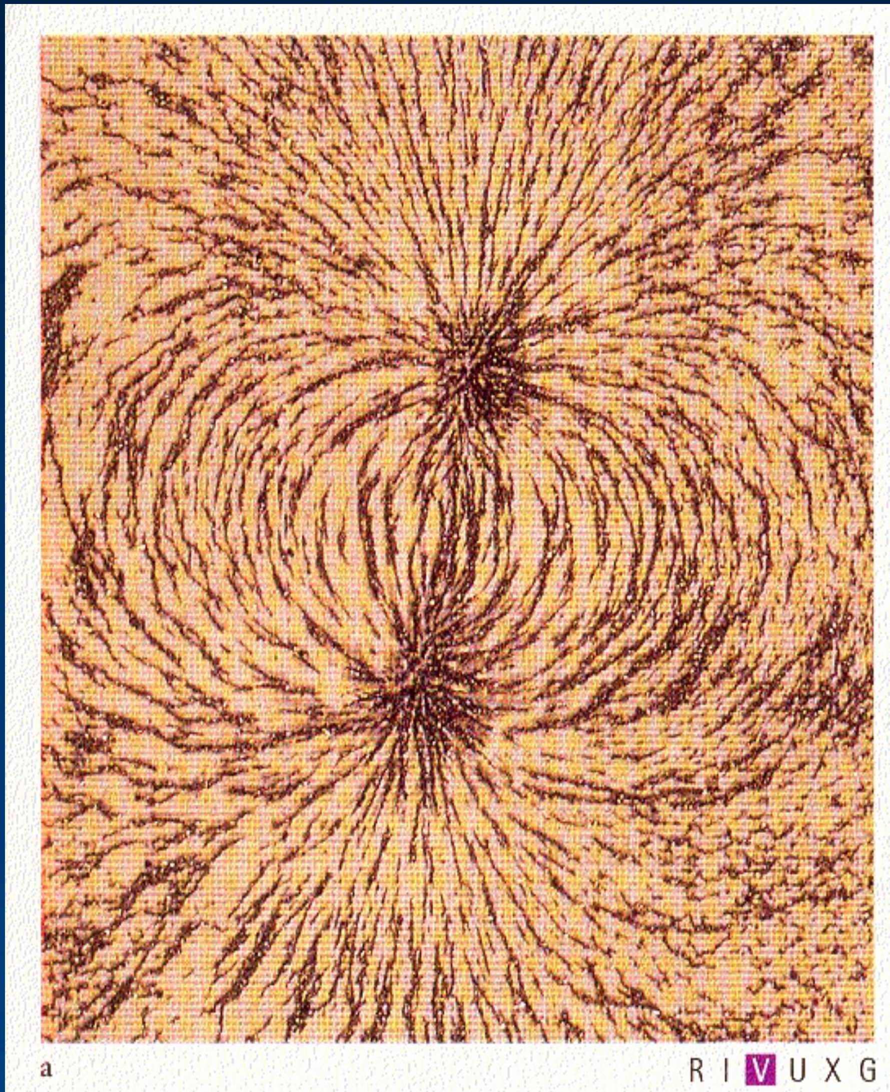
A consequence of the Earth's partially molten metal interior, plus the Earth's rotation:

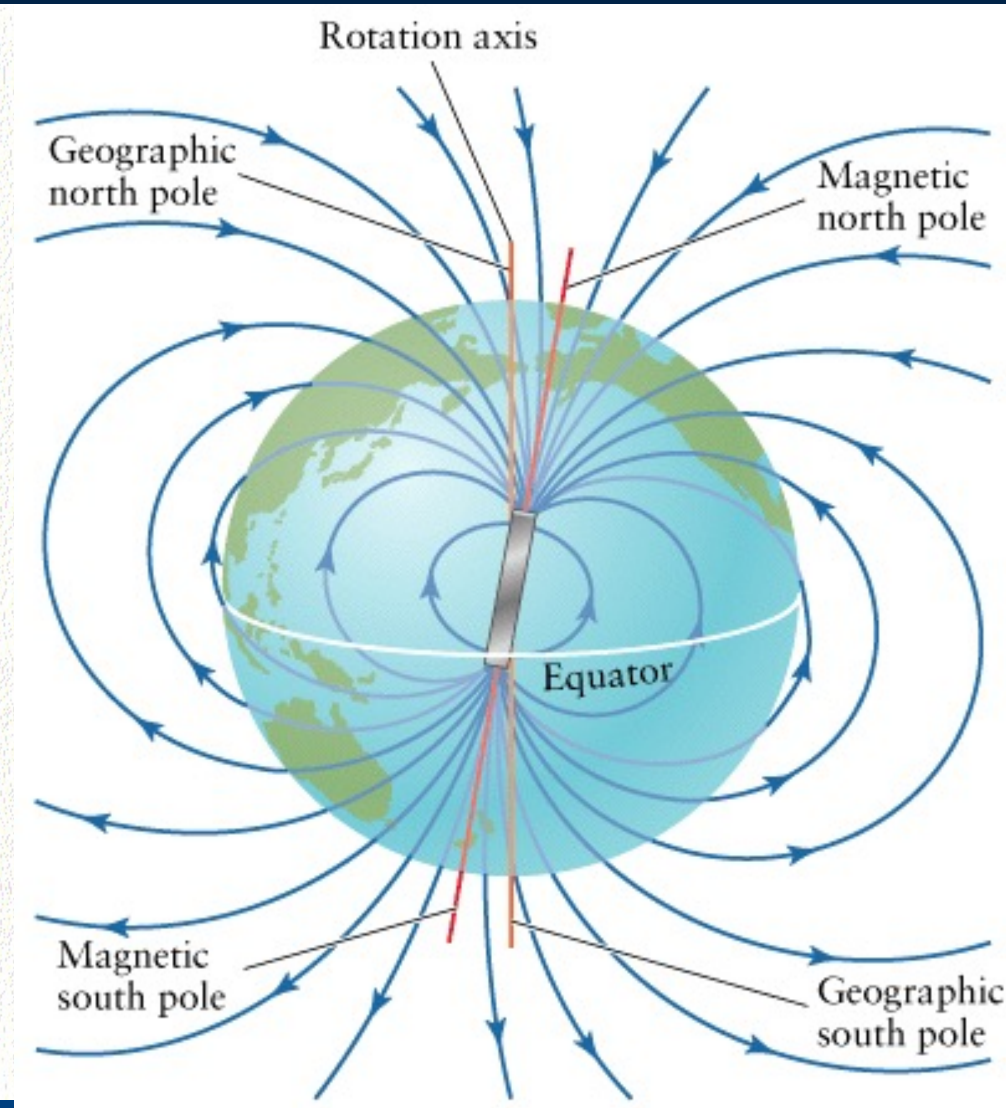
The Earth has a **magnetic field**

Why? Electrically charged particles in motion produce a magnetic field.

Electric currents flow in liquid metal outer core.

Magnetic field around Earth has *dipole* shape.





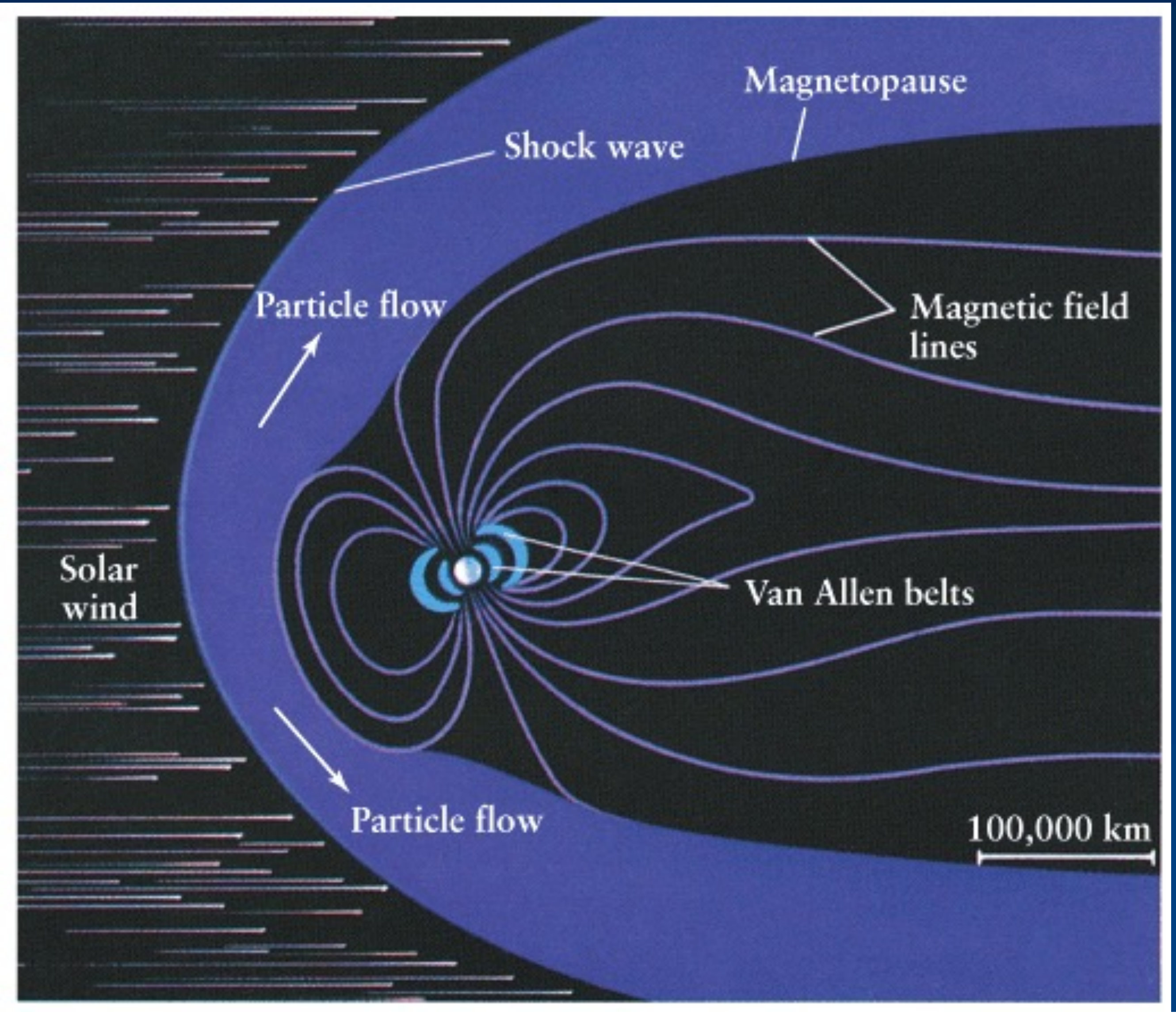
A compass needle points toward north magnetic pole, not true geographic North Pole – tilted by 11.5° .

Earth's magnetic field interacts with the charged particles from the Sun (solar wind) – flow of mostly protons and electrons.

The Earth's Magnetosphere – A Good Thing

Some charged particles get trapped in the Van Allen belts.

Q: What is true shape of Van Allen belts?



Earth's magnetic field interacts with the charged particles from the Sun (solar wind) – flow of mostly protons and electrons.

The Earth's Magnetosphere – A Good Thing

Some charged particles get trapped in the Van Allen belts.

Q: What is true shape of Van Allen belts?

William Pickering James Van Allen Werner van Braun

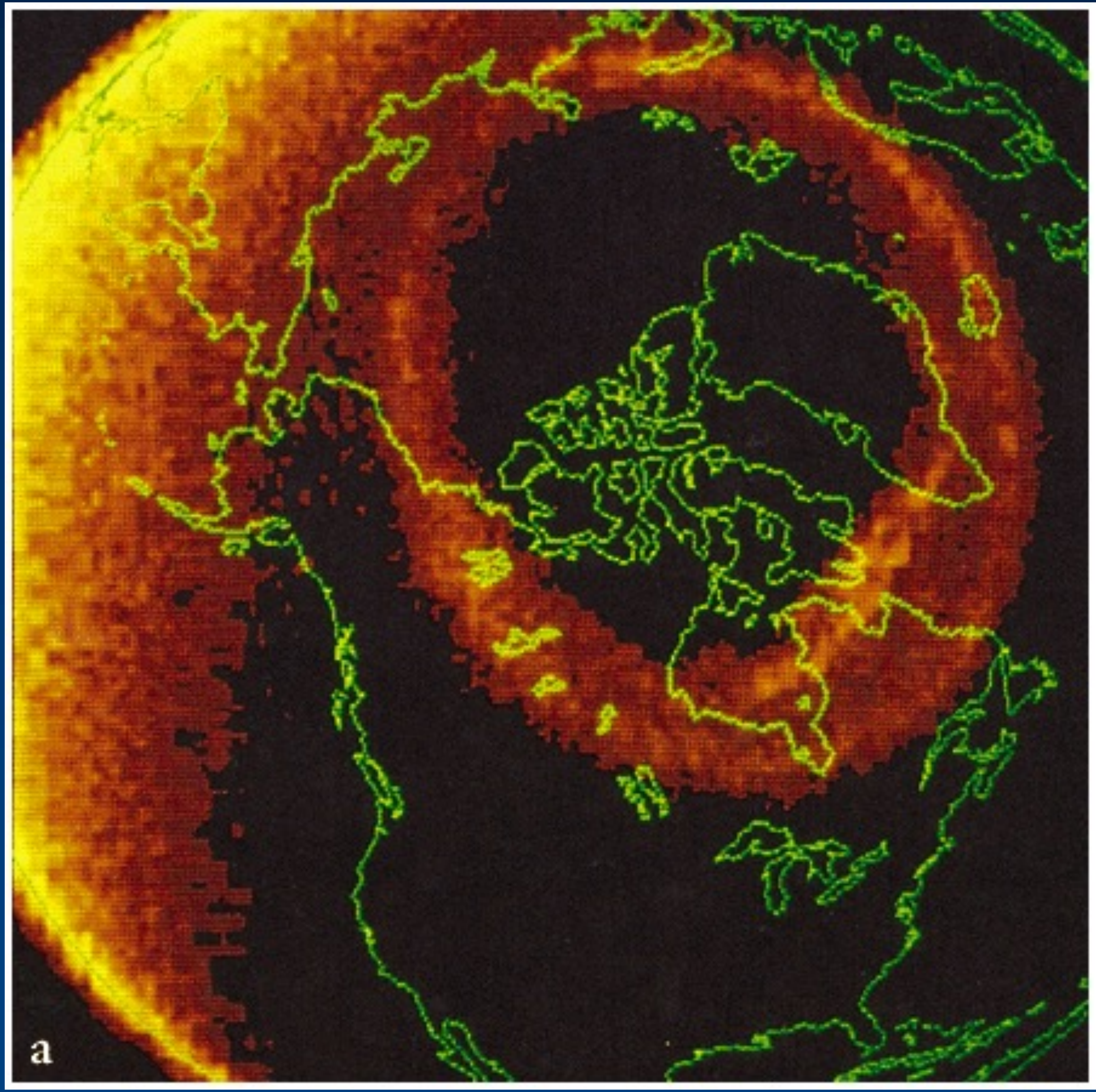
If charged particles leak through magnetic field, they can hit upper atmosphere. Mostly at poles.

⇒ Produce *northern lights* (aurora borealis) or *southern lights* (aurora australis).

Energetic charged particles excite atoms in the upper atmosphere, which emit light as electrons drop back toward ground state

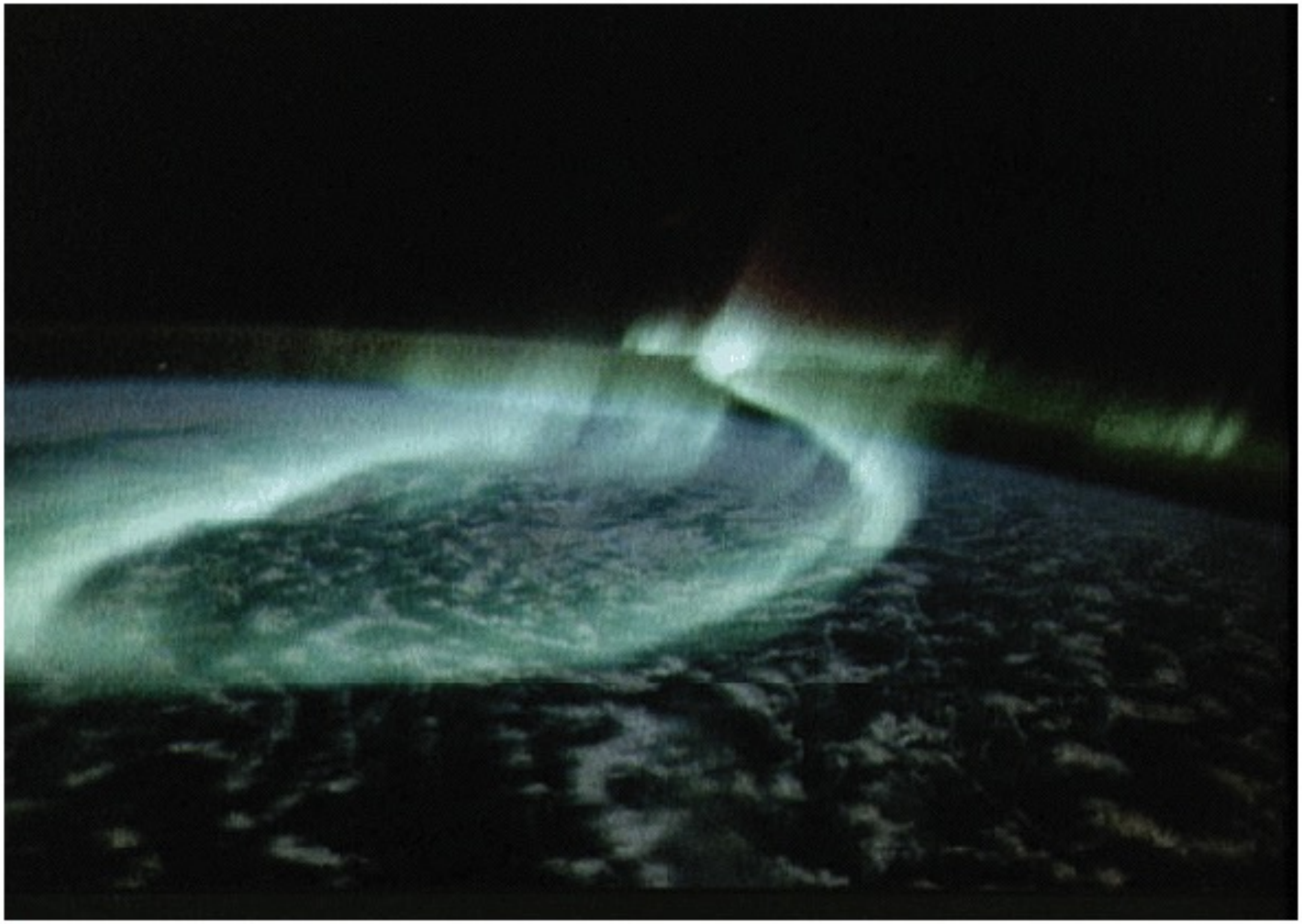
Question: what kind of spectrum?

Aurora borealis from space:



UV image
spacecraft

Space Shuttle photo:



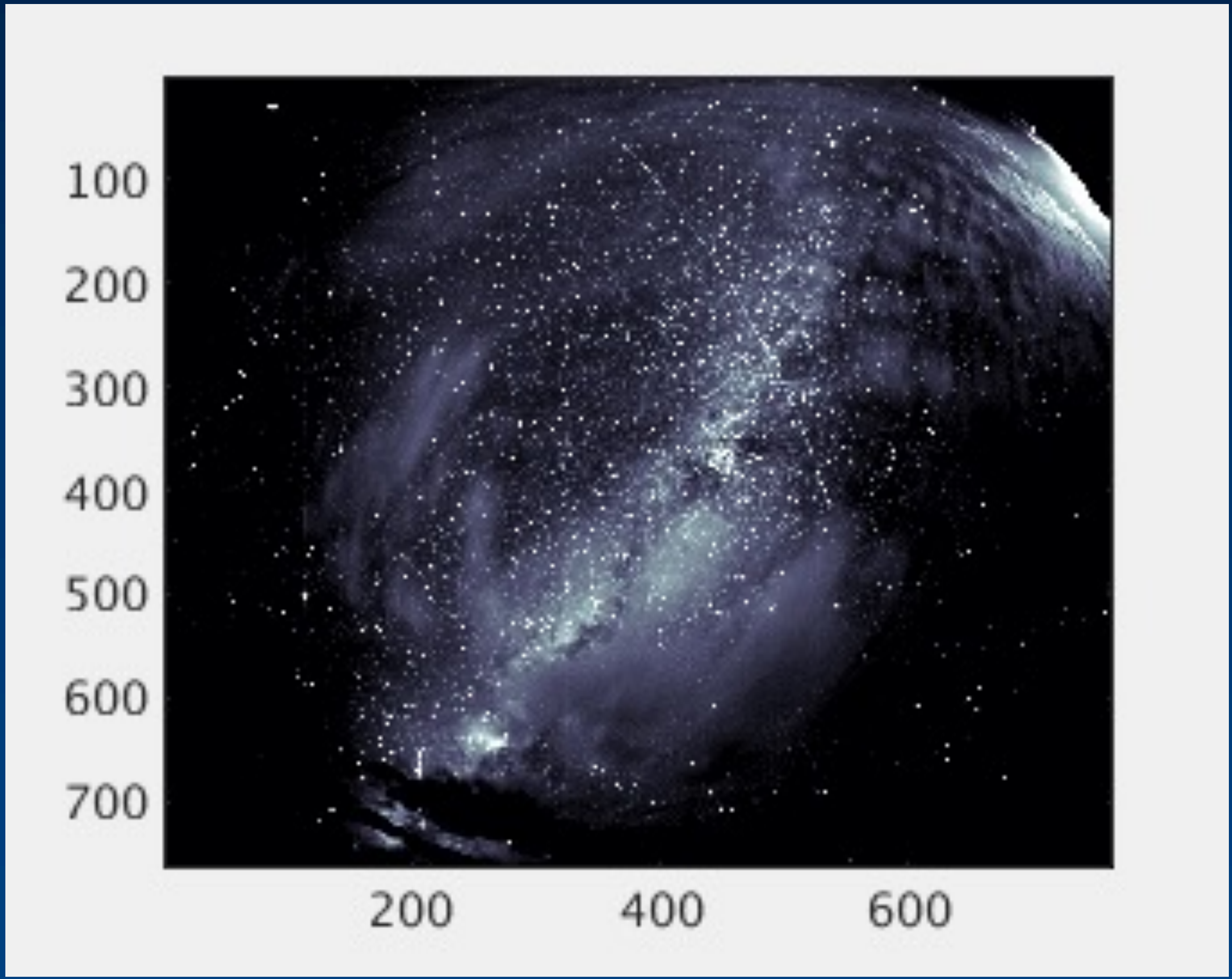
b

Aurora from ISS

Aurora over clouds

Aurora and volcano in Iceland

Airglow over New Mexico



Sevilleta NWR – Ken Obenberger

Earth's surface

- 71% water
- Rocks – solids containing one or more minerals.
  Example 1: feldspar (potassium, aluminum, silicon, oxygen).

  Example 2: granite contains feldspar and quartz (mineral containing silicon and oxygen).

Geologic processes create three major categories of rocks:

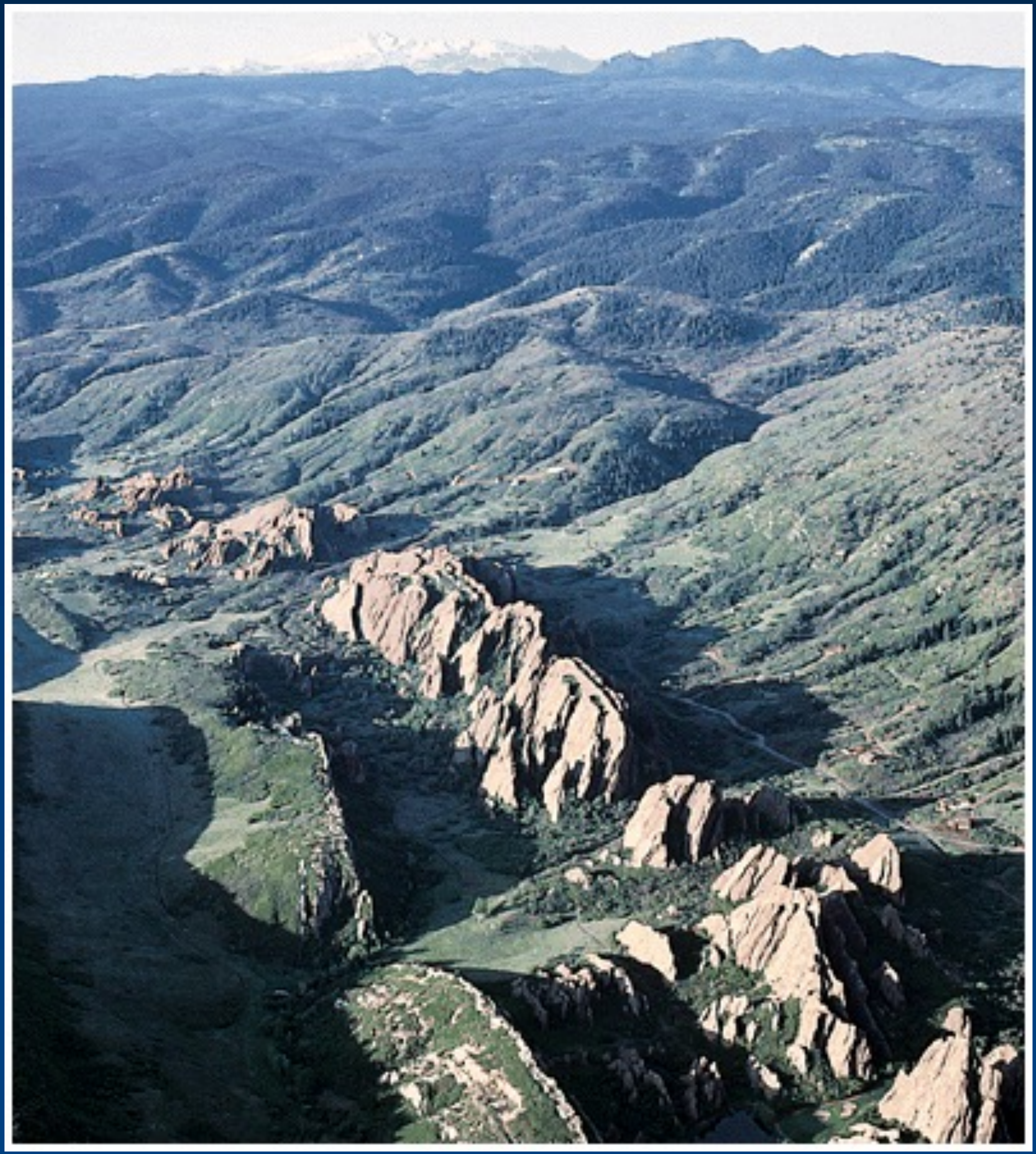
Igneous: rock cooled from molten state. Basalt, mixture of feldspar and iron-rich minerals, is most common. Ocean floor is mostly basalt.


a

Sedimentary: compressed layers of sand or soil, produced by wind, water, or ice, cemented by other minerals. Examples: sandstone (shown), limestone. Often created on ocean floors.

b

These sedimentary rocks are in the Rockies. How did they get there???



Metamorphic: produced when igneous or sedimentary rocks are buried beneath surface, and subjected to great heat and pressure. Examples: marble, schist. Tectonic activity sometimes lifts up material from deep within the crust. Often found in mountain ranges.

c

Notes

- Interested in geology? *This Dynamic Earth* (Kious & Tilling)

  http://pubs.usgs.gov/gip/dynamic/dynamic.html

Earthrise, Apollo 8, 1968

Earth from Apollo 17, 1972

71% water, 29% continents

The Earth's atmosphere - unique in Solar System

Table 9-4 Chemical Compositions of Three Planetary Atmospheres

	Venus	Earth	Mars
Nitrogen (N_2)	3.5%	78.08%	2.7%
Oxygen (O_2)	almost zero	20.95%	almost zero
Carbon dioxide (CO_2)	96.5%	~~0.035%~~	95.3%
Water vapor (H_2O)	0.003%	about 1%	0.03%
Other gases	almost zero	almost zero	2%

0.041%

Earth's atmosphere has changed over time

Evolution of Earth's atmosphere

1. Original gases in vicinity would have been dominated by H & He.
2. Earth's gravity too weak to retain H & He, but could retain H_2O. Dominant constituent of early atmosphere.
3. Earth cooled, Sun also dimmer - H_2O condensed to oceans. Would remain frozen for long time, except for:
4. New atmosphere from compounds "outgassed" from volcanic activity and collisions with comets (mostly H_2O and CO_2). Almost all CO_2 dissolved into oceans and formed carbonate rocks (e.g. limestone) after one billion years.

5. Life forms, starting at 400 million years (algae at first, then plants and oceanic creatures with shells) absorb CO_2 and release O_2 (photosynthesis).
6. Respiratory life at about 2 billion years started to stabilize the O_2 level.
7. Nitrogen liberated from rocks by bacteria. Also outgassed from interior.
8. O_2 level set by balance of photosynthetic and respiratory life.

Left with 78% N_2, 21% O_2 and 1% other

This process did not happen on Venus or Mars!

Structure of the atmosphere

Pressure = Force/Area

Units: 1 atm = 1atmosphere = 14.7 lbs/in^2

= 1.01 x 10^5 N/m^2

Atmospheric pressure is due to weight of overlying air at that height.

In water pressure increases by 14.5 psi every 10 m

Atmospheric pressure decreases smoothly with increasing altitude (drops by ½ every 5.5 km). Temperature is more complicated: