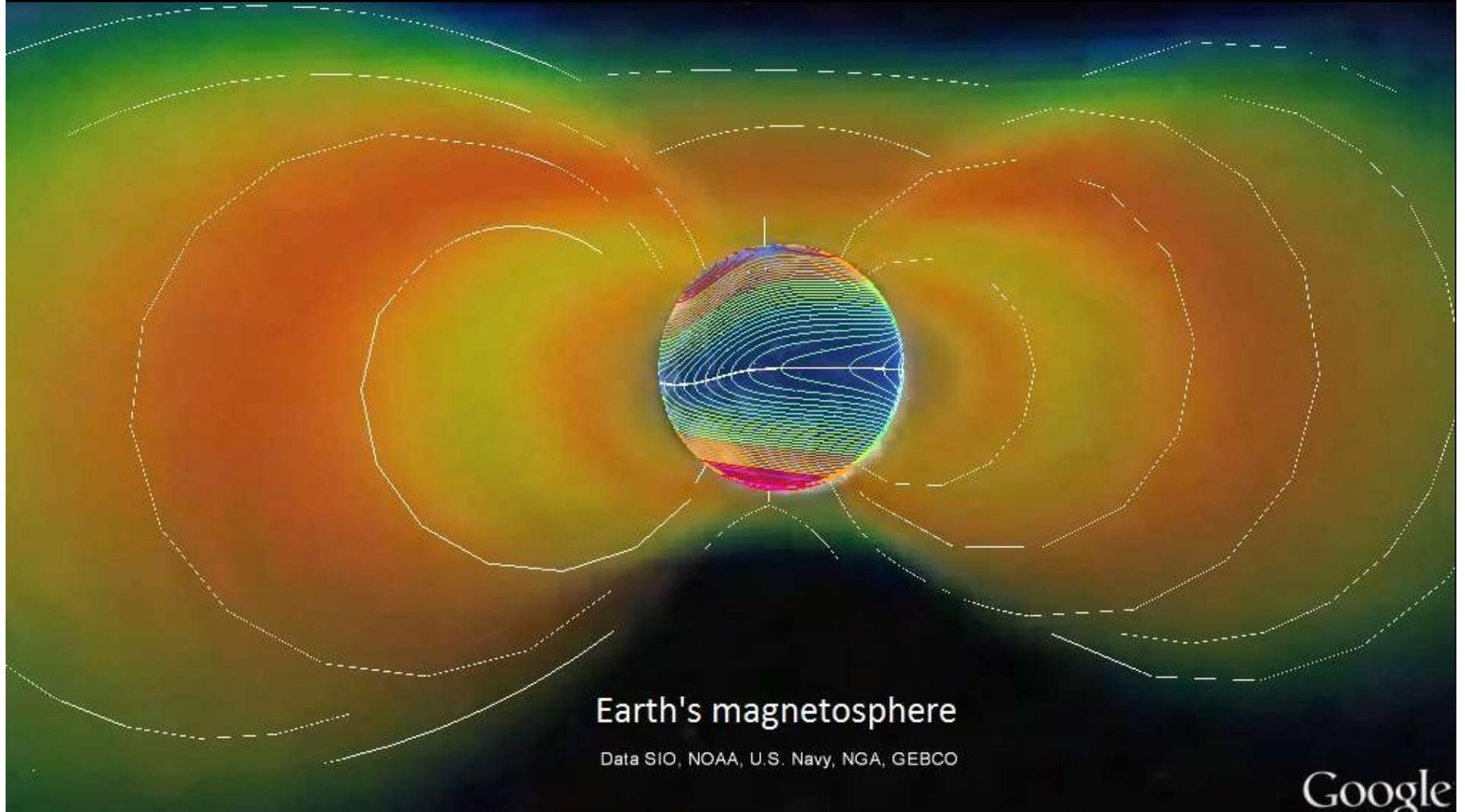


# EARTH'S INTERIOR, GRAVITY, AND MAGNETISM



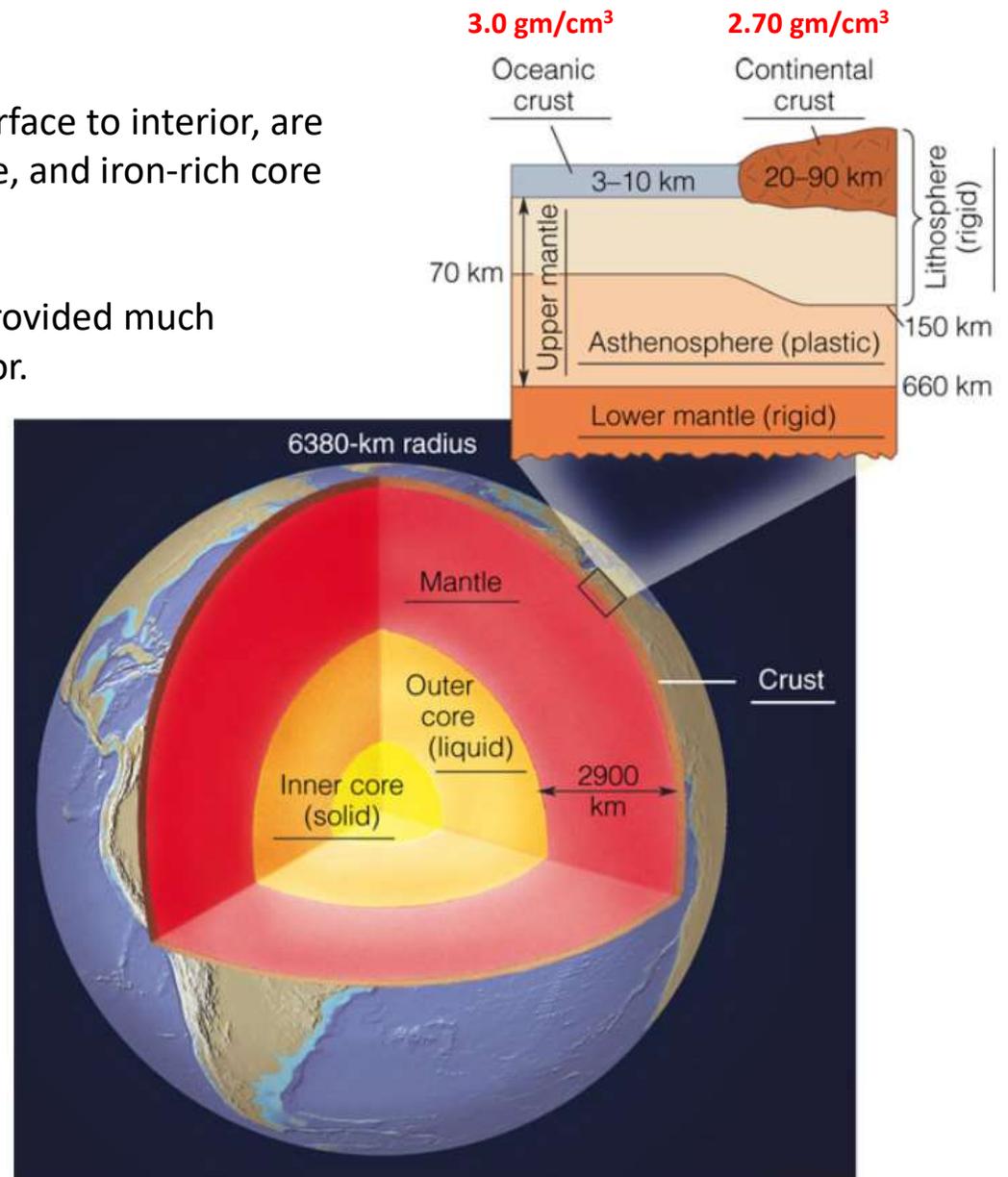
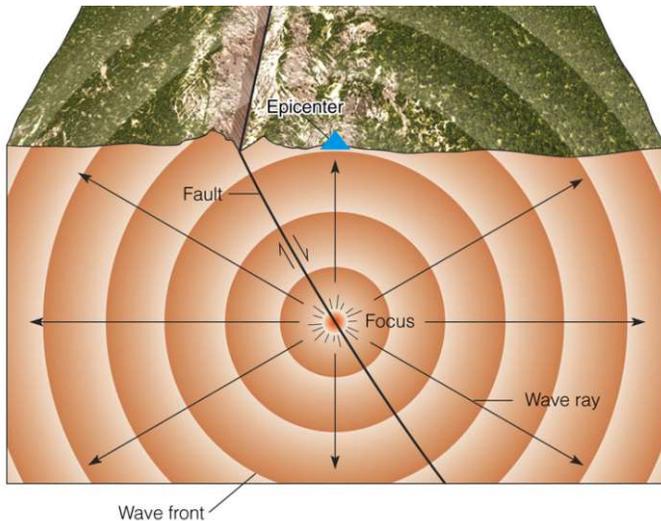
[http://www.impacttectonics.org/KMLZs/2015\\_GCH\\_Earth's\\_magnetosphere\\_aspects.kmz](http://www.impacttectonics.org/KMLZs/2015_GCH_Earth's_magnetosphere_aspects.kmz)

# EARTH'S INTERIOR, GRAVITY, AND MAGNETISM

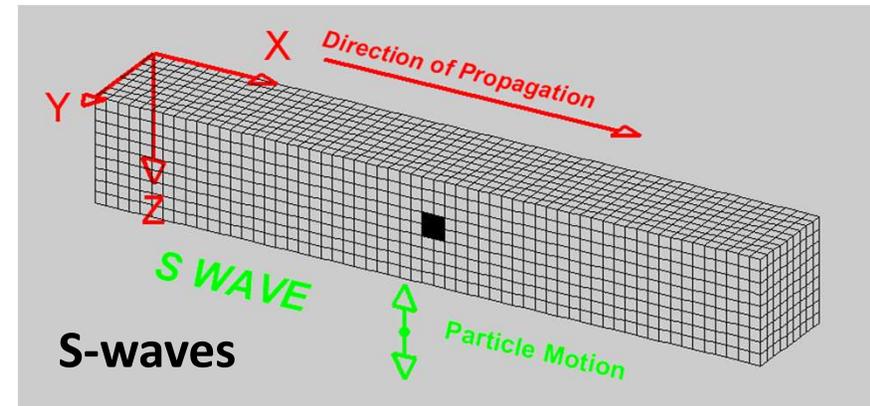
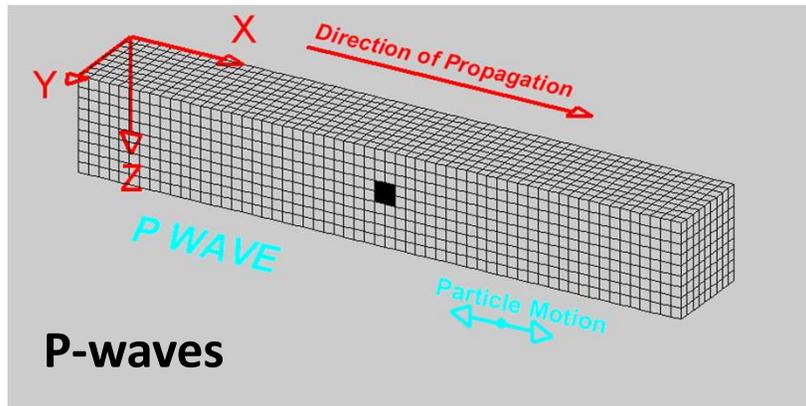
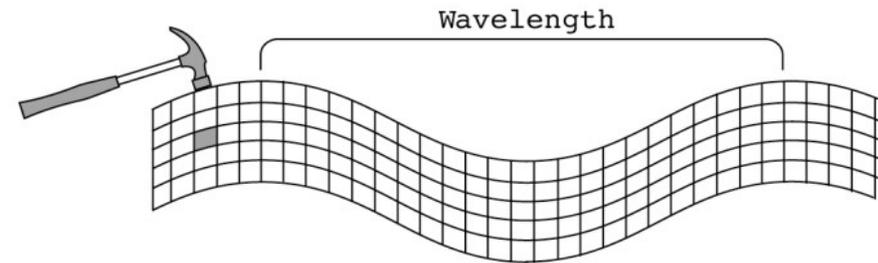
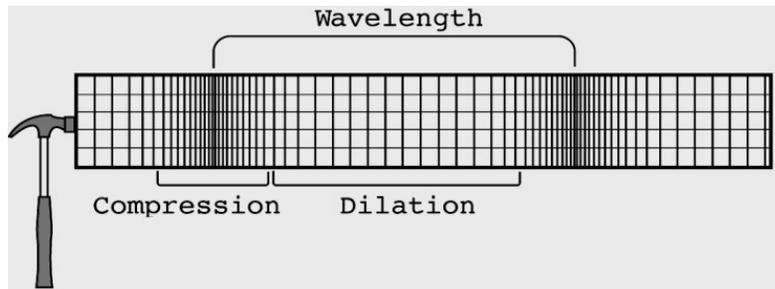
- Earth's Interior
- Seismic waves and phase boundaries
- Seismic P & S waves
- Earth's Internal Heat
- Earth's motion
- Earth's density and gravity
- Gravitational anomalies
- Earth's magnetic core
- Earth's Magnetic Field
- Continents--The Principle of Isostasy
- Snapshot of NY Recess Neotectonics

# EARTH'S INTERIOR

- The concentric layers of Earth, from its surface to interior, are oceanic and continental crust, rocky mantle, and iron-rich core of liquid outer and solid inner parts.
- Studies of P- and S-wave behavior have provided much important information about Earth's interior.
- Additional information has come from comparisons with meteorites, laboratory experiments, and studies of inclusions in volcanic rocks.



# SEISMIC BODY WAVES



1) **Body waves travel through Earth** (*faster than surface waves*)

a. *P-waves* are compressional waves and travel faster than S-waves

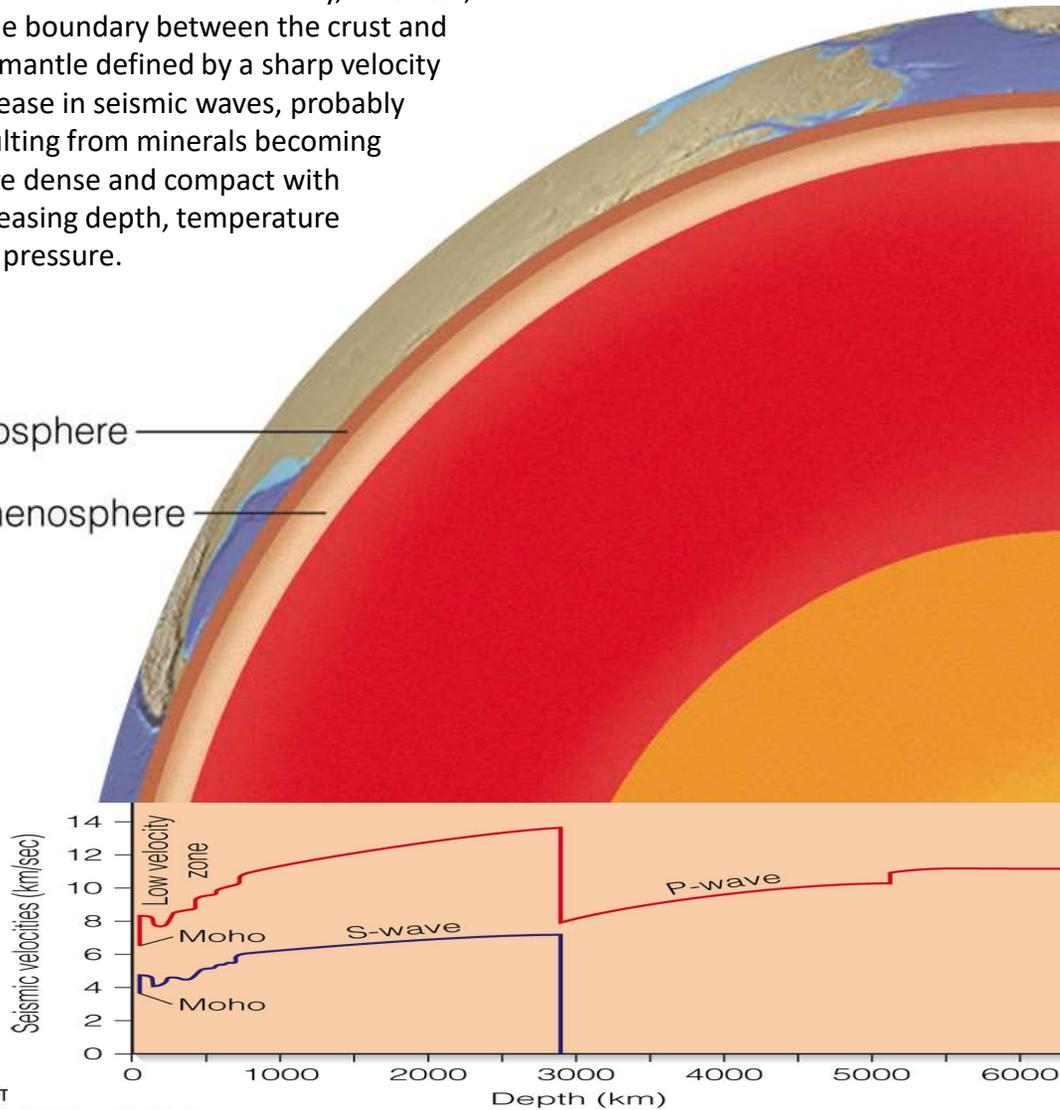
b. *S-waves* are shear waves that cannot travel through liquids

2) **Surface waves travel along or just below the surface** *are slower and more destructive than body waves*

# Earth's crust, lithosphere, asthenosphere, mantle, and Moho

The Mohorovičić discontinuity, or **Moho**, is the boundary between the crust and the mantle defined by a sharp velocity increase in seismic waves, probably resulting from minerals becoming more dense and compact with increasing depth, temperature and pressure.

Lithosphere  
Asthenosphere



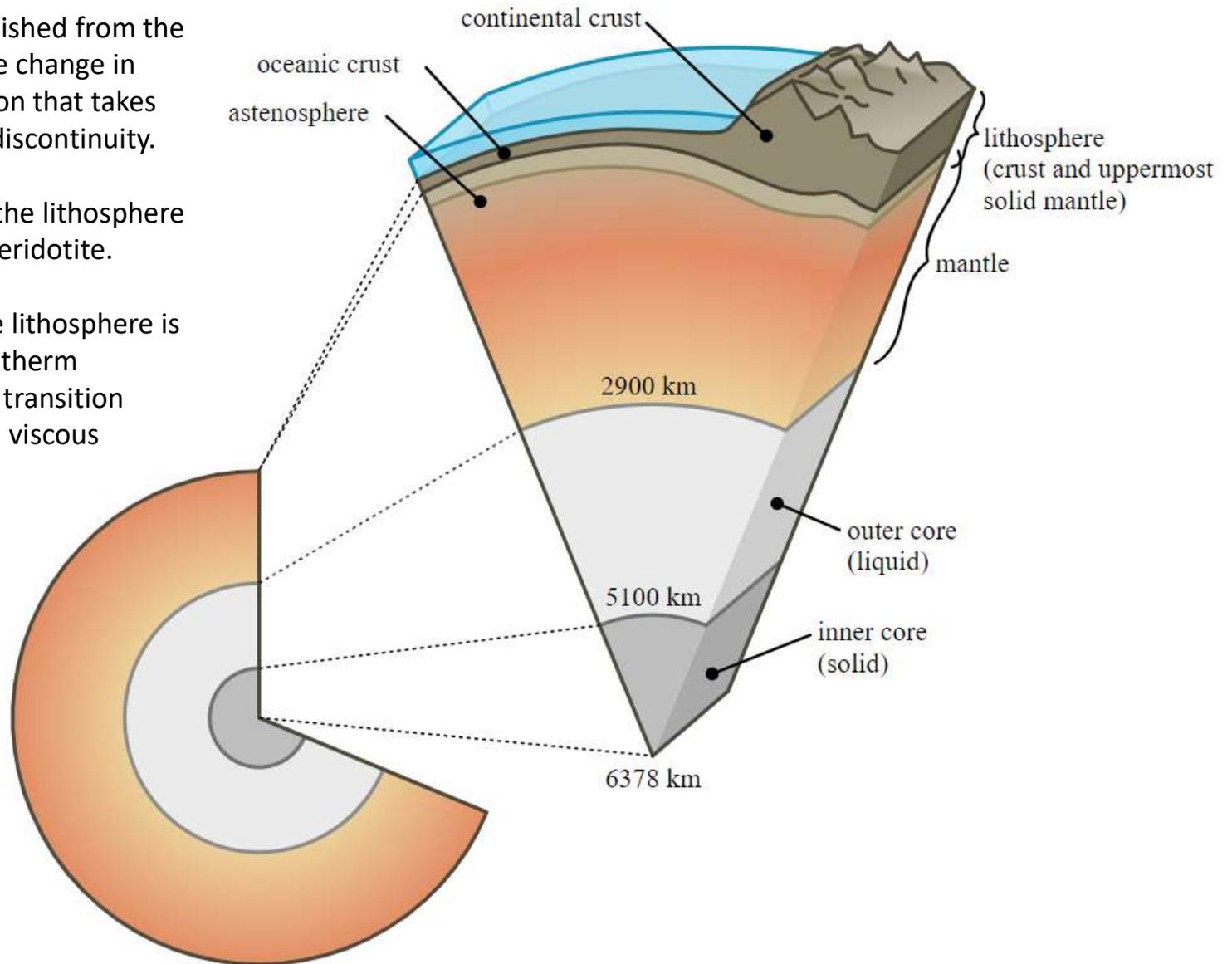
© 2007 T  
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- The lithosphere includes the crust and the uppermost mantle, which constitute the hard outer layer of the Earth that is rigid for very long periods of geologic time in which it deforms elastically and through brittle failure.

- The lithosphere is underlain by the asthenosphere, the weaker, part of the upper mantle that is hotter than the lithosphere, behaves more like plastic, deforms viscously and accommodates strain through plastic deformation.

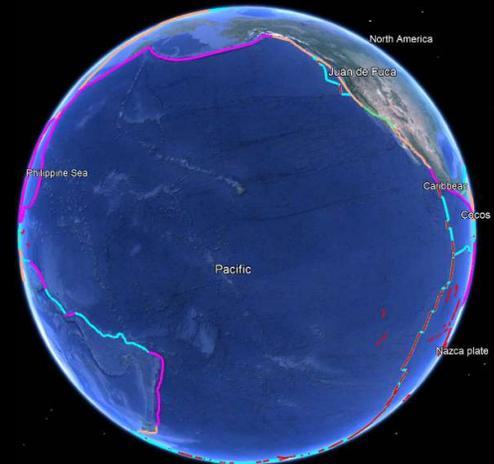
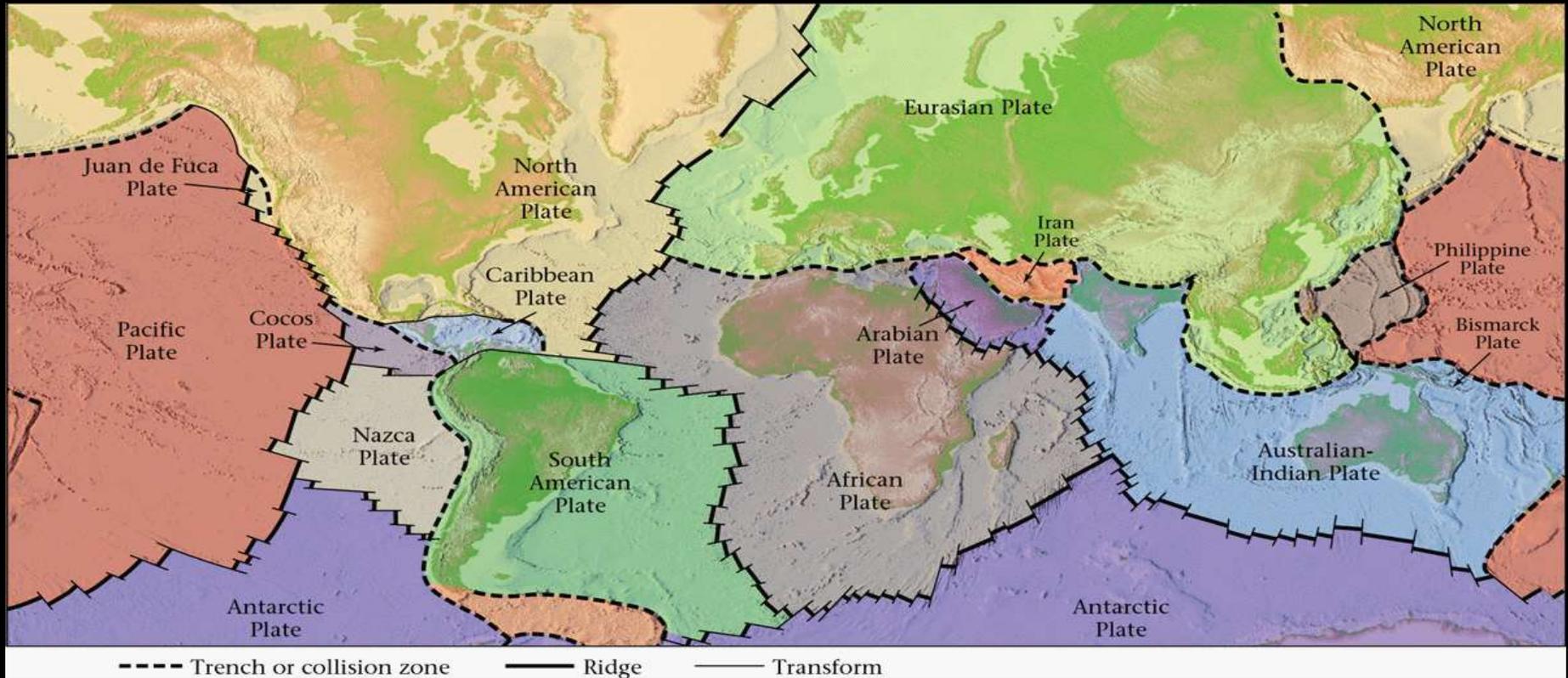
- The lithosphere is broken into tectonic plates.

- The crust is distinguished from the upper mantle by the change in chemical composition that takes place at the Moho discontinuity.
- The mantle part of the lithosphere consists largely of peridotite.
- The thickness of the lithosphere is the depth to the isotherm associated with the transition between brittle and viscous behavior.
- The temperature at which olivine begins to deform viscously (~1000 °C) is often used to set this isotherm because olivine is generally the weakest mineral in the upper mantle.



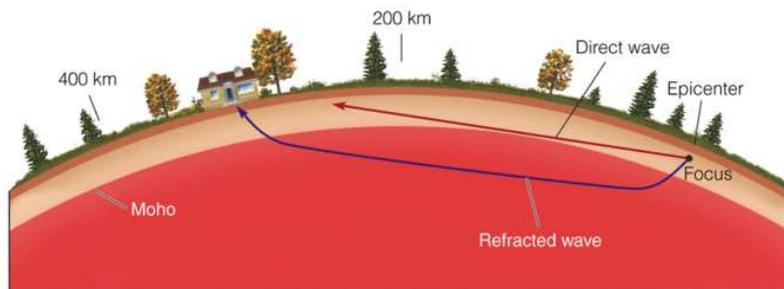
- Oceanic lithosphere is typically about 50–140 km thick but beneath the mid-ocean ridges is no thicker than the crust, while continental lithosphere has a range in thickness from about 50-280 km

# EARTH'S TECTONIC PLATES

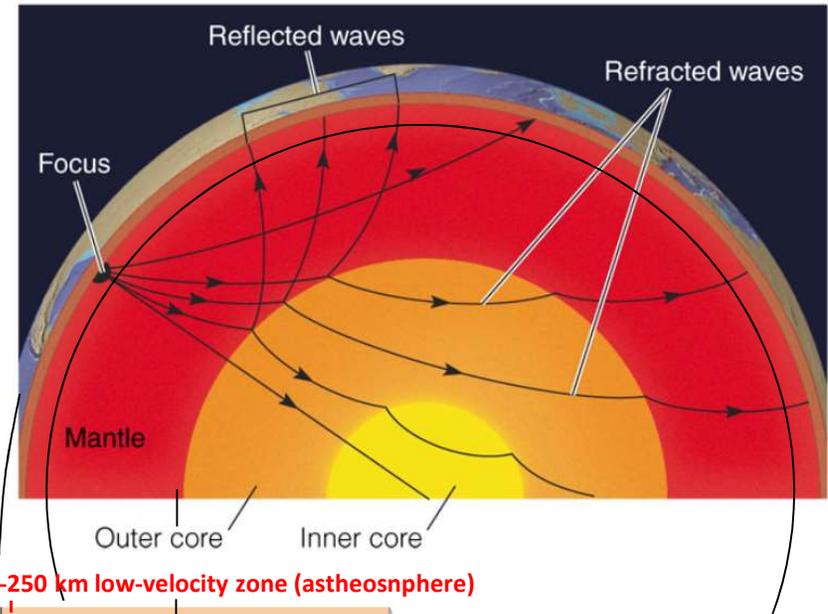
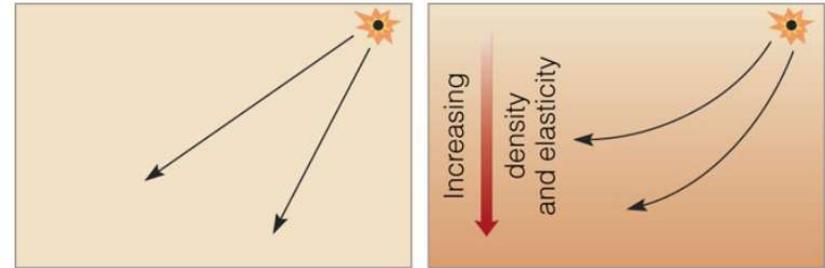


# SEISMIC WAVES AND PHASE BOUNDARIES

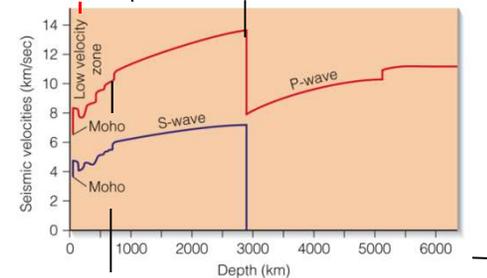
- The velocity of seismic waves is controlled by the density and elasticity of the materials through which they pass
- **Seismic wave refraction** is the change of a wave's travel direction with depth.
- This occurs at boundaries where waves encounter a change in the properties (*phase*) of material.



The boundary between the crust and mantle is **(Moho)**



**100-250 km low-velocity zone (asthenosphere)**

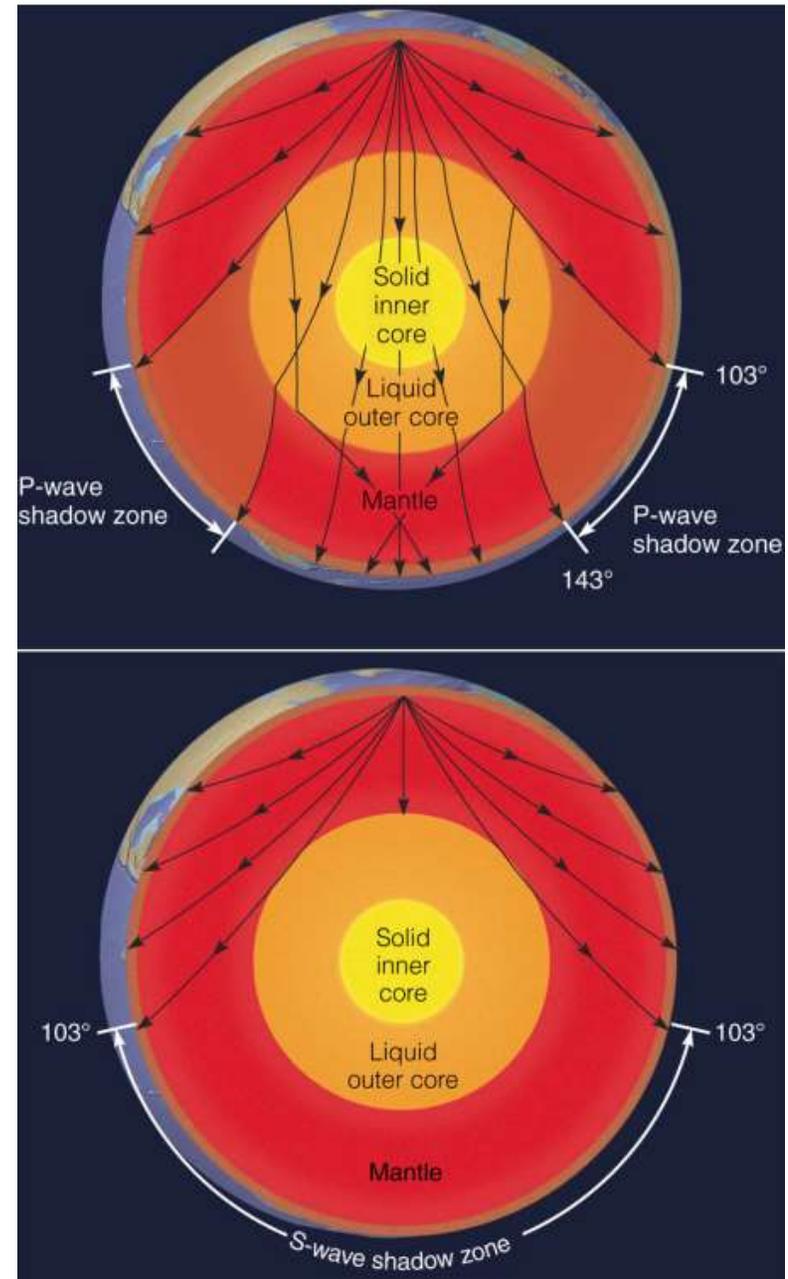


**660 km lower mantle**

- The concentric layers of Earth are recognized by changes in seismic wave velocities at *discontinuities*.

# SEISMIC WAVES AND PHASE BOUNDARIES

- The density, composition, size and depth of concentric layers have been determined by the behavior of P-waves and S-waves, and the *shadow zone* produced by the properties of the core.
- Compositionally, the inner core is thought to be iron and nickel, the outer core iron with 10 to 20% other, lighter substances, and the mantle probably peridotite.
- Peridotite is a ferromagnesium silicate, 60% olivine and 30% pyroxene, with ~10% feldspar.



# SEISMIC P AND S WAVES

PcP – P wave reflection

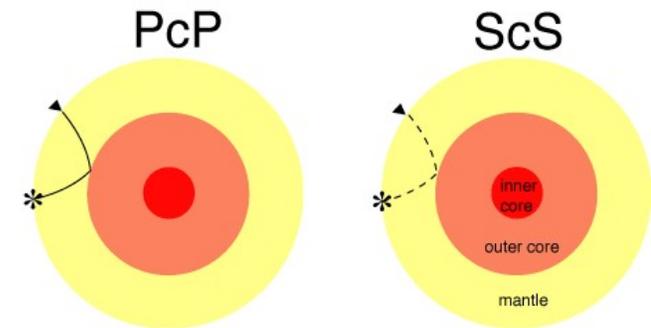
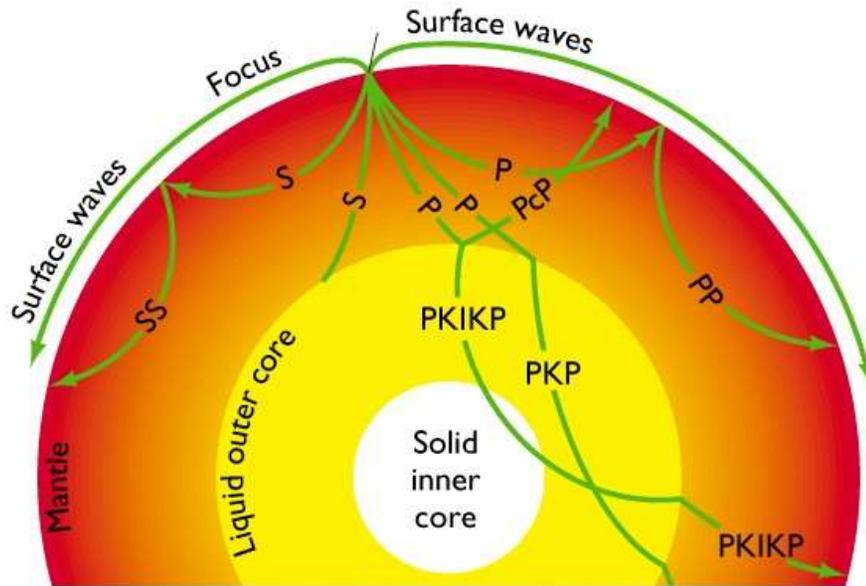
ScS – S wave reflection

PKP – P wave through outer core

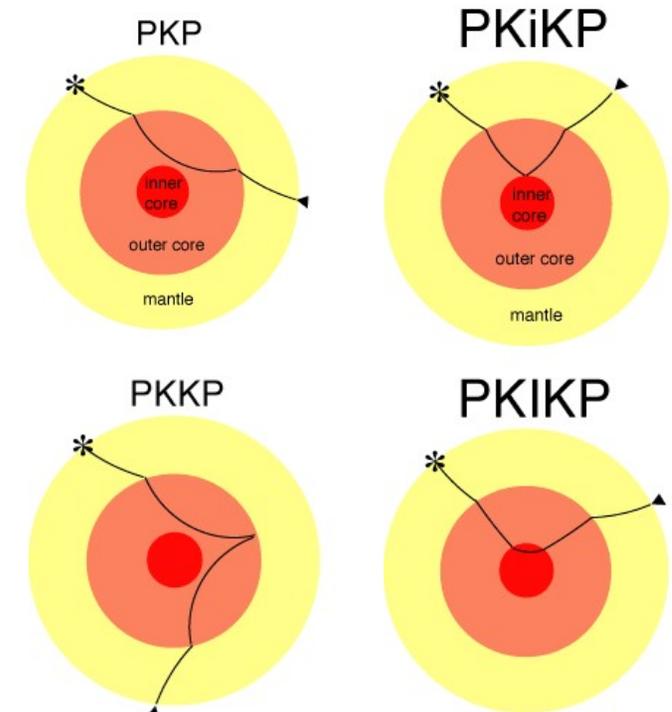
PKKP – P wave in core, reflects off core-mantle boundary

PKIKP – P wave through inner core

PKiKP – P wave reflects core-core boundary



Remember, a little "c" in the name means reflection off of the outer core.



# EARTH'S INTERNAL HEAT –

## 1 of the 3 Principal Agents of Metamorphism

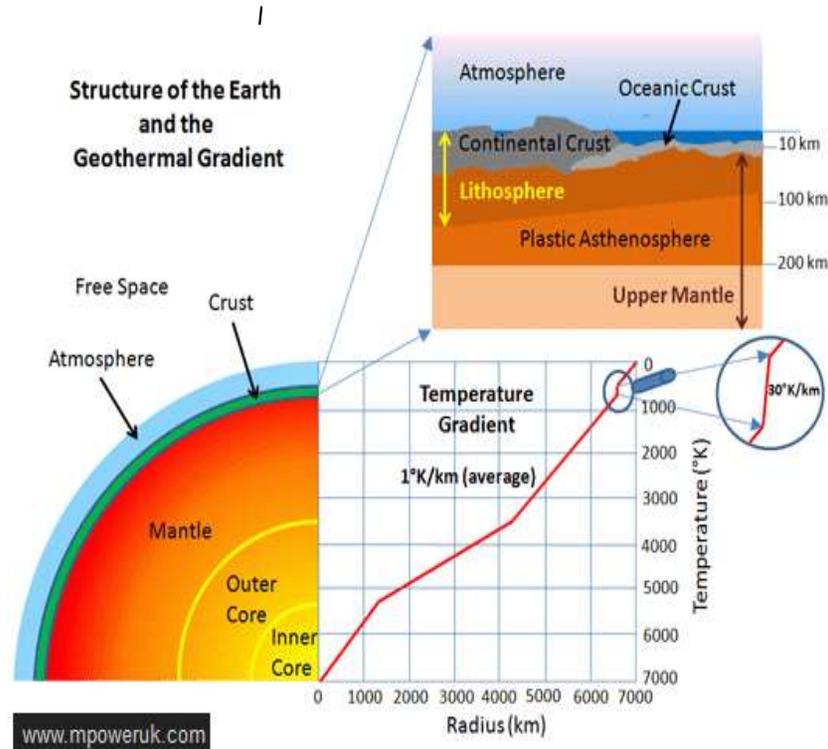
- The upper-most crust has a high geothermal gradient of  $25^{\circ}\text{C}/\text{km}$  in most of the world ( $1^{\circ}\text{F}$  per 70 ft)

- *This must be much less in the mantle and core, probably about  $1^{\circ}\text{C}/\text{km}$ .*

- The center of the inner core temperature is estimated at  $6,500^{\circ}\text{C}$ .

- *Most of Earth's internal heat is generated by radioactive isotope decay in the mantle.*

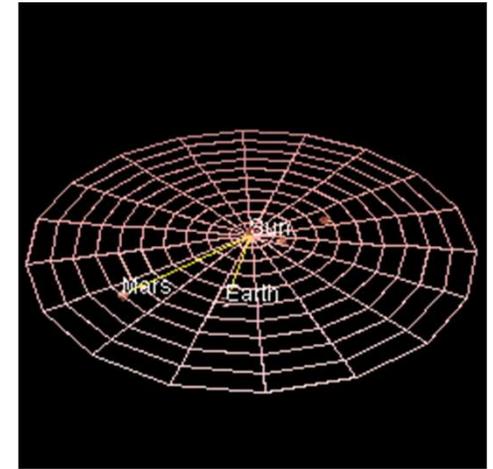
- Heat flow through the crust can be detected at the surface.



**Geothermal gradient**

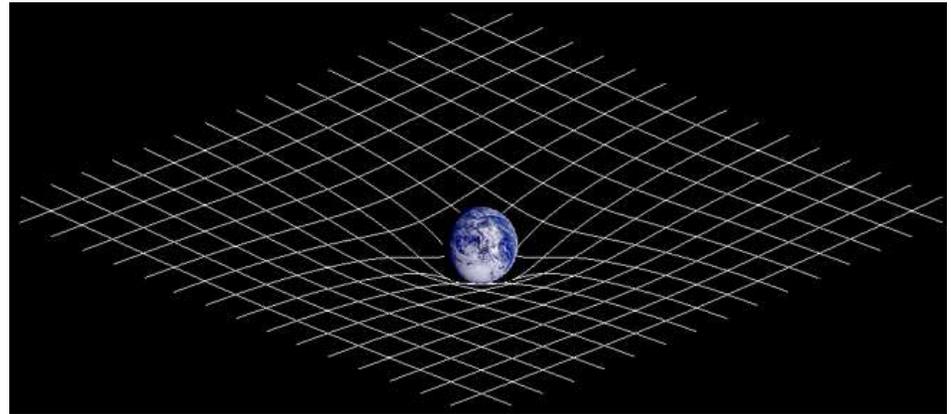
# EARTH'S MOTION

- The Earth is a spheroid about 12,500 km in diameter (6371 km radius) circulating through a solar system at about 30 km/sec. (22 bullet velocity 550 m/sec)
- It's spinning *counterclockwise* at roughly 1 km/sec along the equator about a slow-wobbling axis.
- The metallic core is about one half it's diameter (fig. 3a).
- The core's inner half is a solid, heated metal ball whereas the outer core is a shell of metallic fluid, convecting in cells over one-quarter radius of the body.
- The core is mantled by a viscous, plastic and stony rind for the outer-half diameter.
- The mantle slowly creeps, mixes and periodically belches magma, allowing heat to escape from the core outward and surface ward.
- The stony, plastic and metallic, mantle slowly circulates and creeps from heat driving dynamic convection.
- As this rind slowly circulates, it pushes and pulls the thin veneer of brittle crust around the planet's surface.
- Magma that is generated and migrates upwards within the mantle accretes onto the base of the crust and periodically breaks through to the land surface with volcanic eruptions.



# GRAVITY

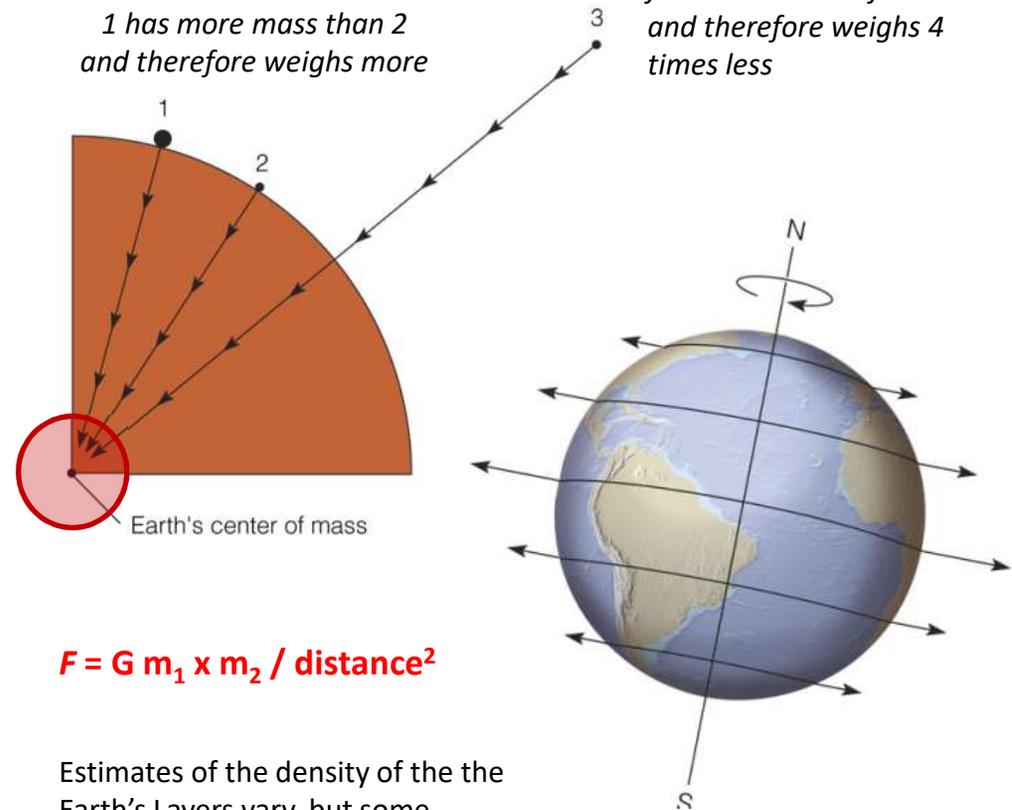
- Gravitation, or gravity, is the natural phenomenon by which physical bodies appear to attract each other with a force proportional to their masses.
- Gravitation is one of the four fundamental interactions of nature, along with electromagnetism, and the nuclear strong force and weak force.
- It is most commonly experienced as the agent that gives weight to objects with mass and causes them to fall to the ground when dropped.
- Newton's law of universal gravitation provides an accurate approximation for most physical situations including calculations as critical as spacecraft trajectory.
- The phenomenon of gravitation itself, however, is a byproduct of a more fundamental phenomenon described by general relativity, which suggests that space-time is curved according to the energy and momentum of whatever matter and radiation are present.



**$F = mg$ , where  $m$  is the mass of the body and  $g$  is a constant vector with an average magnitude of  $9.81 \text{ m/s}^2$**

# EARTH'S DENSITY AND GRAVITY

- Earth's core is at its center of mass, which is what generates our gravitational field.
- The Earth's core was formed very early in Earth's history as heavier molten iron sank toward the center of the planet.
- As the Earth cooled and began dissipating internal heat towards the surface, some molten iron began solidifying in the center of Earth to form the dense, solid inner core at its center.
- Enormous pressure keeps the inner core solid in a region of temperatures in the range of 7,000° F and possibly much higher.
- Fluid iron in the outer core has continued to solidify at the boundary between the solid and molten cores, so that over a billion years, the solid part has grown steadily to its present diameter of ~2500 km (The inner and outer core together are 7960 km wide and the Earth's diameter is about 12,800 km.)



$$F = G m_1 \times m_2 / \text{distance}^2$$

Estimates of the density of the the Earth's Layers vary, but some approximate values are (in gm/cm<sup>3</sup>):

Continental Crust:	2.7 to 3.0
Oceanic Crust:	3.0 to 3.3
Mantle (silicates):	3.3 to 5.7 (increasing with depth?)
Outer Core (liquid):	9.9 to 12.2
Inner Core (solid):	12.6 to 13.0

# GRAVITATIONAL ANOMALIES

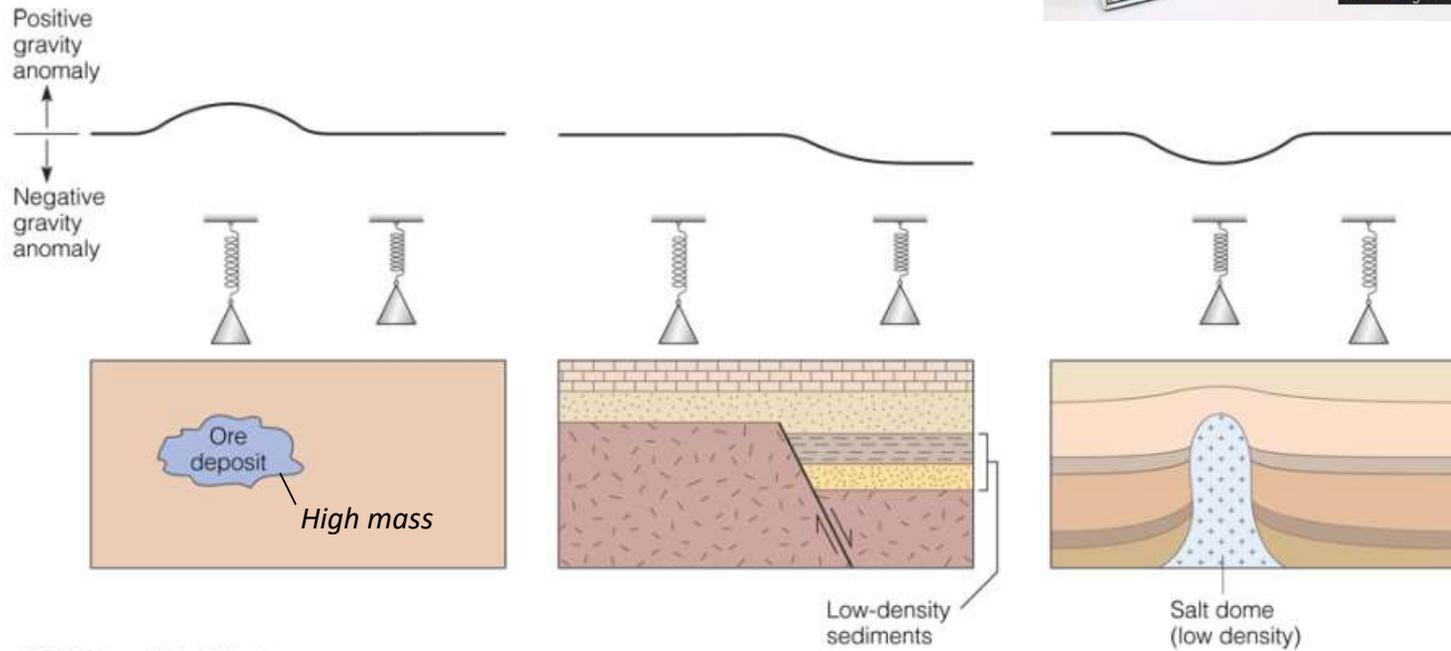
- Gravimeters are used to measure the Earth's gravitational field



[Lsm303dlh 3-axis Accelerometer And 3-axis Magnetometer Digital I2c Module Lsm303](#)

\$25.00 - eBay

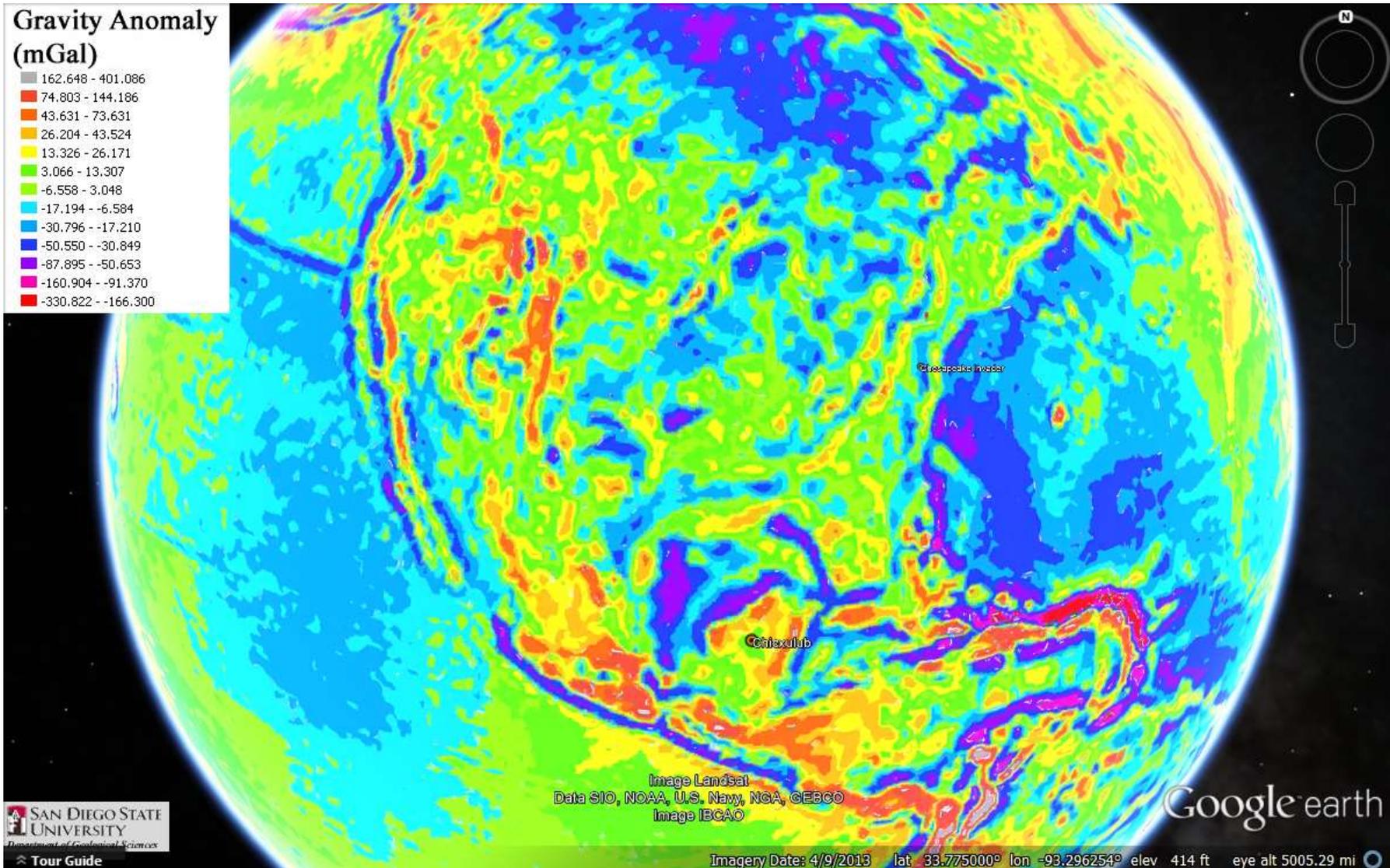
Find great deals on eBay!



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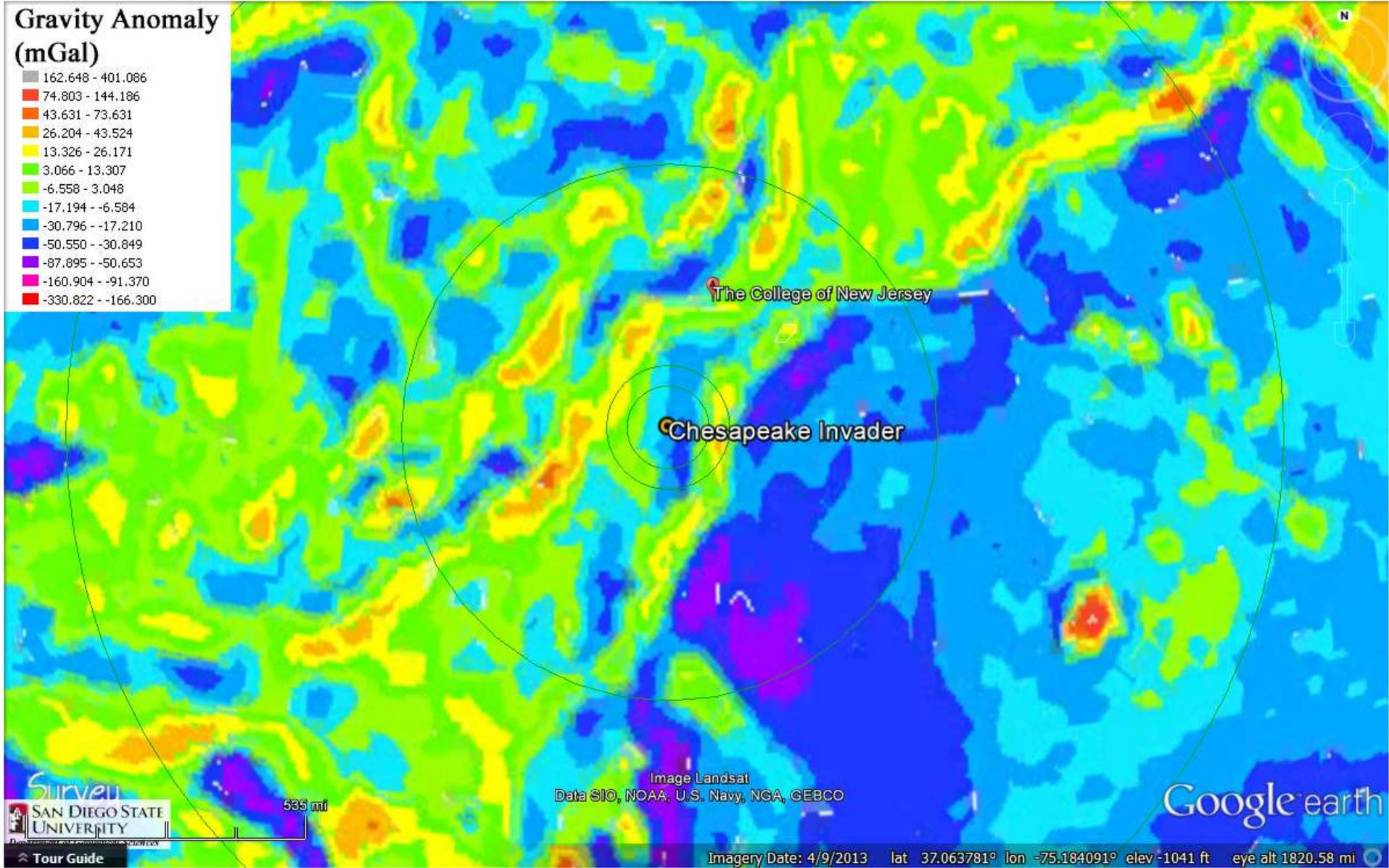
# GRAVITATIONAL POTENTIAL FIELDS AND ANOMALIES

- Excesses and deficiencies of mass can be measured as positive and negative gravity anomalies, respectively.
- Gravity surveys can be used in the exploration for petroleum and minerals.



# Gravity Anomaly (mGal)

- 162.648 - 401.086
- 74.803 - 144.186
- 43.631 - 73.631
- 26.204 - 43.524
- 13.326 - 26.171
- 3.066 - 13.307
- 6.558 - 3.048
- 17.194 - -6.584
- 30.796 - -17.210
- 50.550 - -30.849
- 87.895 - -50.653
- 160.904 - -91.370
- 330.822 - -166.300



Survey  
SAN DIEGO STATE  
UNIVERSITY

535 mi

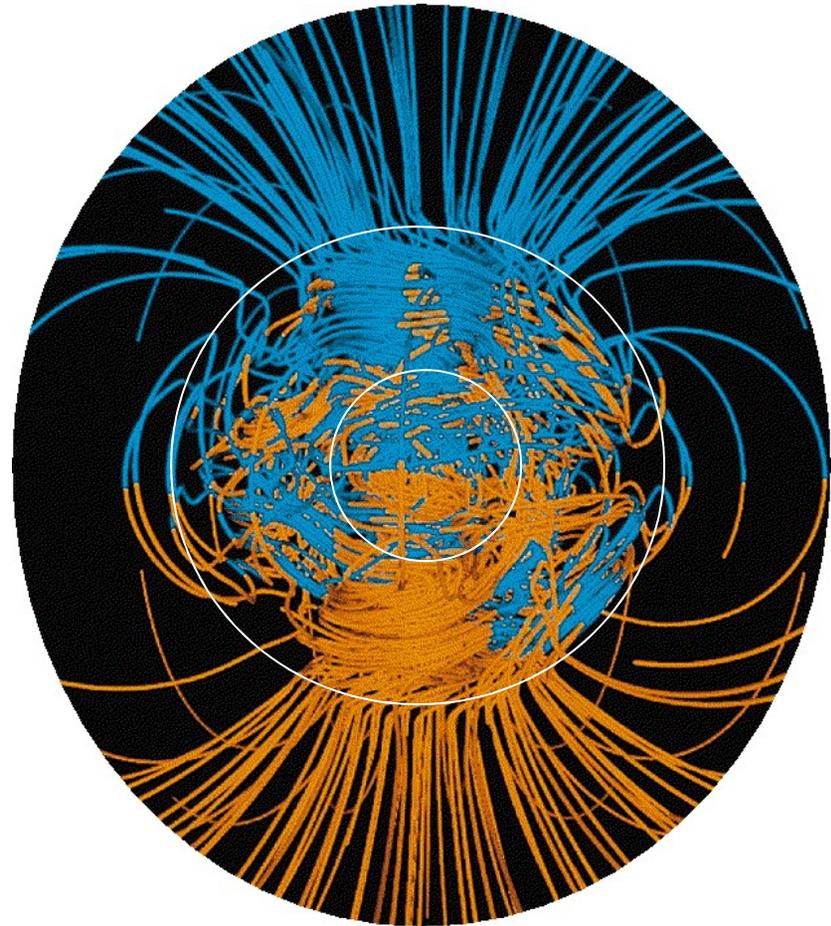
Image Landsat  
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Google earth

Imagery Date: 4/9/2013 lat 37.063781° lon -75.184091° elev -1041 ft eye alt 1820.58 mi

# EARTH'S MAGNETISM

- The electrical currents and convecting movements within the Earth's liquid core generate the planet's powerful magnetic field, which in turn drives the inner core in the way that can now be observed.
- About a billion amps of current is flowing into and out of the inner core, across the boundary between the inner and outer cores.
- This current, in the presence of a magnetic field, results in forces being applied to the inner core, which then rotates.
- Essentially, the inner core rotates because it is part of a vast electric motor.

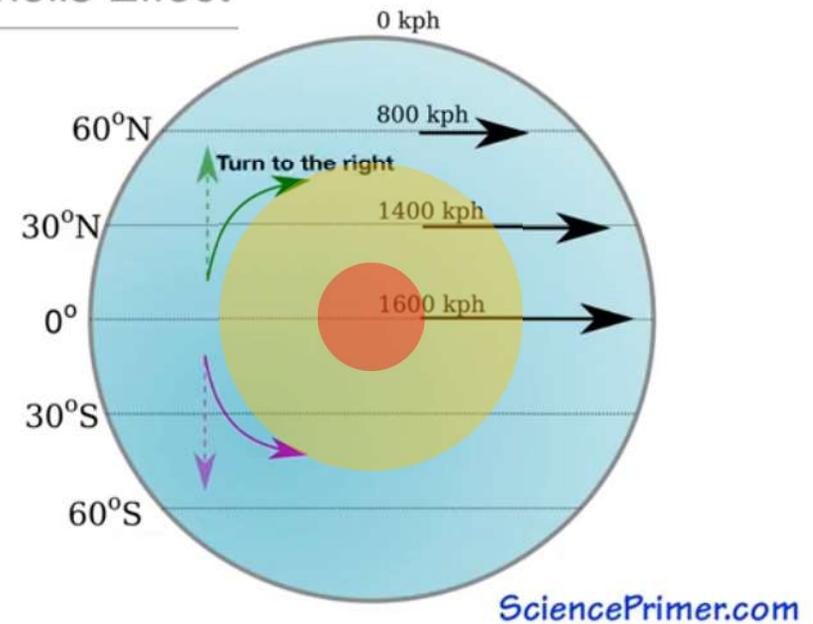


# CORIOLOS EFFECT AND EARTH'S OUTER CORE

Churning molten iron-laden material doth a magnetic field make....

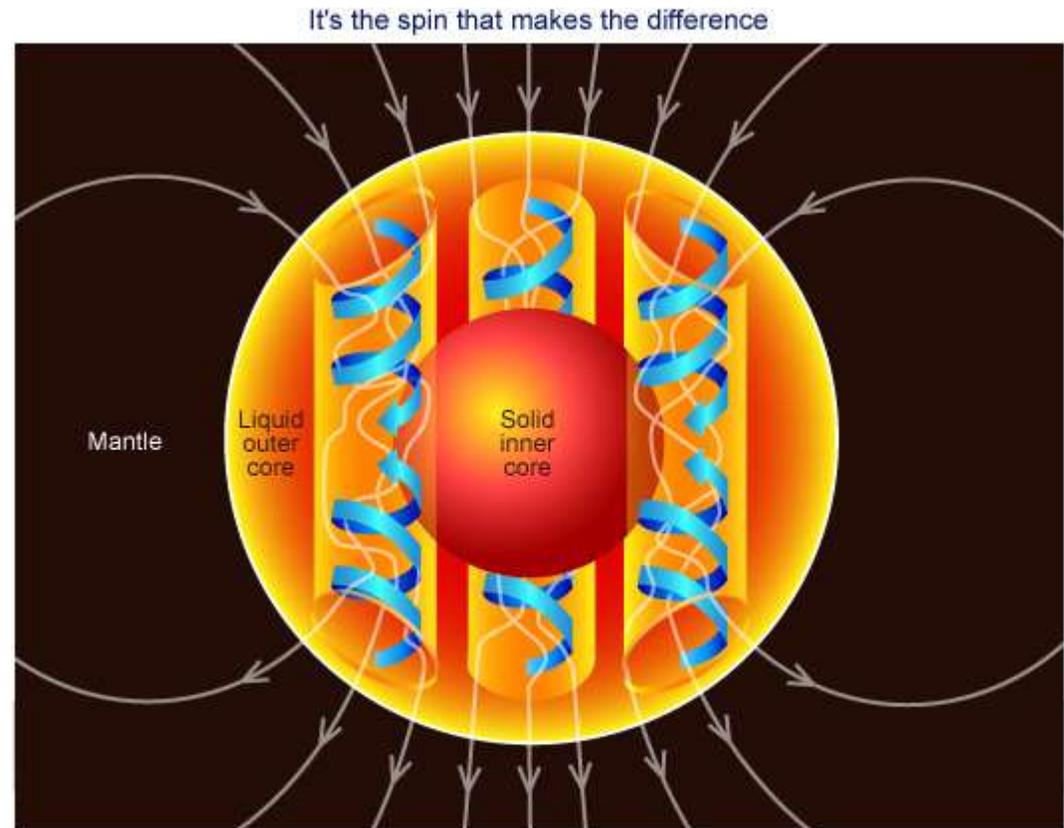
- Convection is about less dense things — like hot air — rising.
- In the liquid outer core, the denser iron freezes onto the solid inner core, leaving less dense material behind and giving off latent heat.
- The combination of the heat and buoyancy means the less dense material rises up through the layer, and a convection current is underway.
- Those convection currents heading up from the entire surface of the inner core are enough to generate some bigger scale magnetic fields.
- But if that was all that was going on, the different magnetic fields generated by the different currents would cancel each other out.
- However, the spin on our planet is fast enough for the Coriolis effect to kick in.

## Coriolis Effect



# CORIOLOS EFFECT AND EARTH'S OUTER CORE

- The **Coriolis effect**<sup>1</sup> is what makes cyclones spin clockwise in the southern hemisphere and anti-clockwise up north.
- But down in the planetary interior the Coriolis effect makes molten convection currents twist in spirals, lining up lengthwise roughly north/south and converging near the equatorial plane.
- The aligned spiraling and twisting currents form an overall planet-wide magnetic field having opposite poles currently aligned closed to Earth's rotation axis.



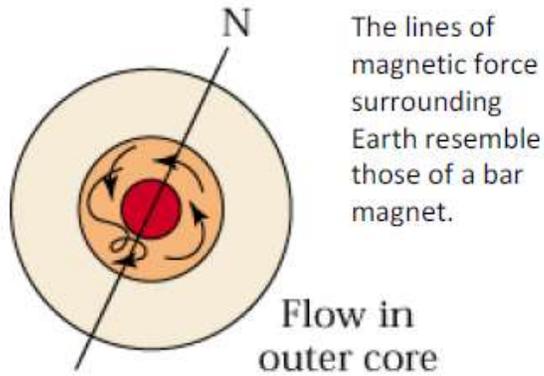
The planet's spin adds a twist to the convection currents in the molten outer core. Those spirals mean the magnetic fields of the convection currents no longer cancel each other out, and we've got a place for our compasses to point to.

- The system is called a *geodynamo*, and, being based on such convoluted interdependent effects, it's no wonder the magnetic poles have a tendency to wander and occasionally flip with pole reversal.

<sup>1</sup>The Coriolis effect is a deflection of the flow direction and flow-lag of non-rigid material due to friction between a solid and a nonsolid material when viewed in a rotating reference frame (e.g., atmosphere and oceans experience the Coriolis effect when moving over Earth's surface). The flow lag and Coriolis effect within the outer core is partly responsible for the generation of Earth's magnetic field. What possibilities for creep effects are there for the plastic mantle subject to these same forces?

# EARTH'S MAGNETISM

- The magnetic poles do not coincide with the geographic poles, though they are close.

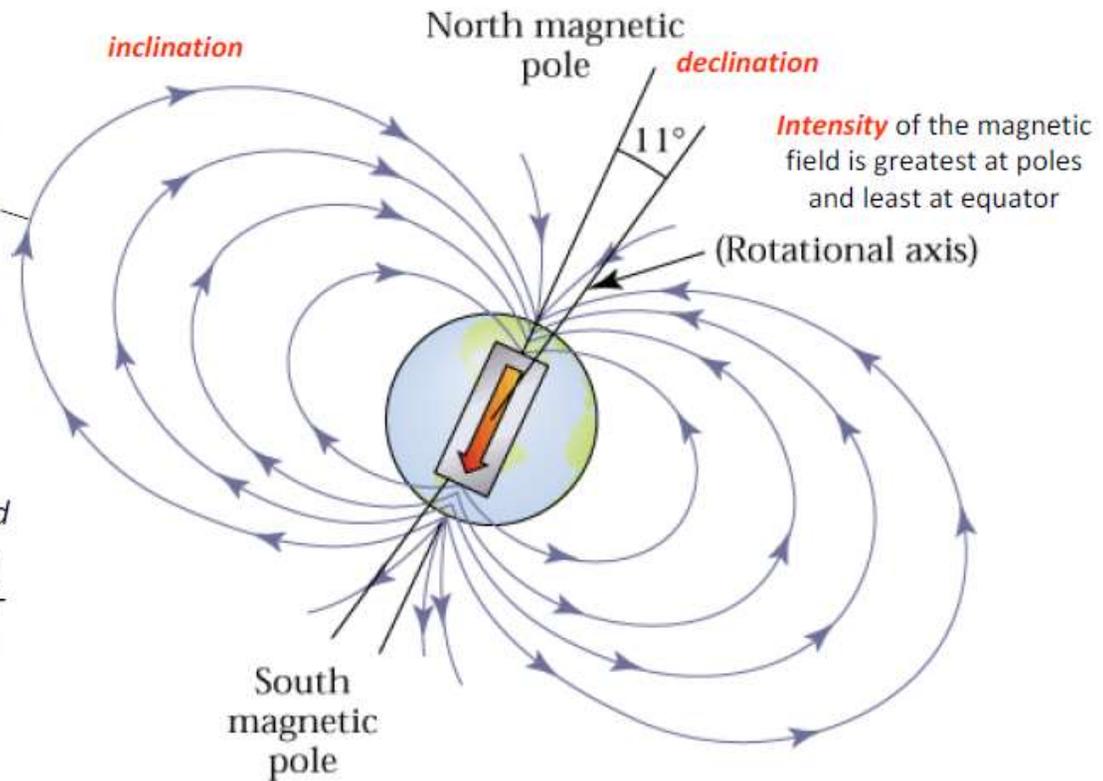


- The Earth's magnetic field is generated by iron-rich, magnetic fluids in the outer core circulating around a spinning, solid-iron inner core, creating a "self-exciting dynamo".

- Negative and positive departures from the normal magnetic field are detected with a magnetometer.

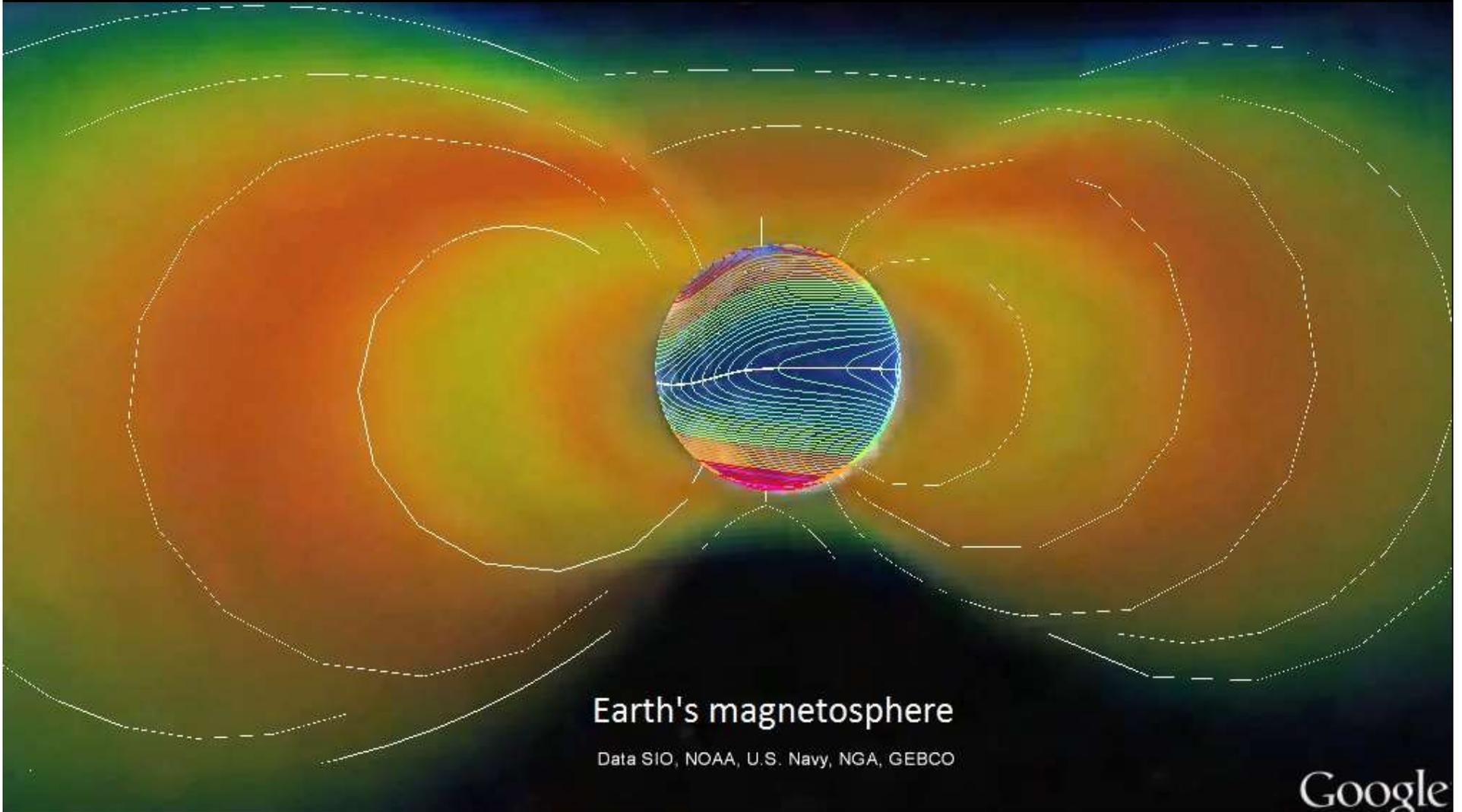
- The cause of magnetic reversal is not clearly understood, however it is known that the magnetic field has reversed itself many times in the geologic past as is recorded by the remnant magnetism of rocks

- For any given point on Earth, the angle between lines drawn toward the magnetic and geographic poles is known as **magnetic declination**.



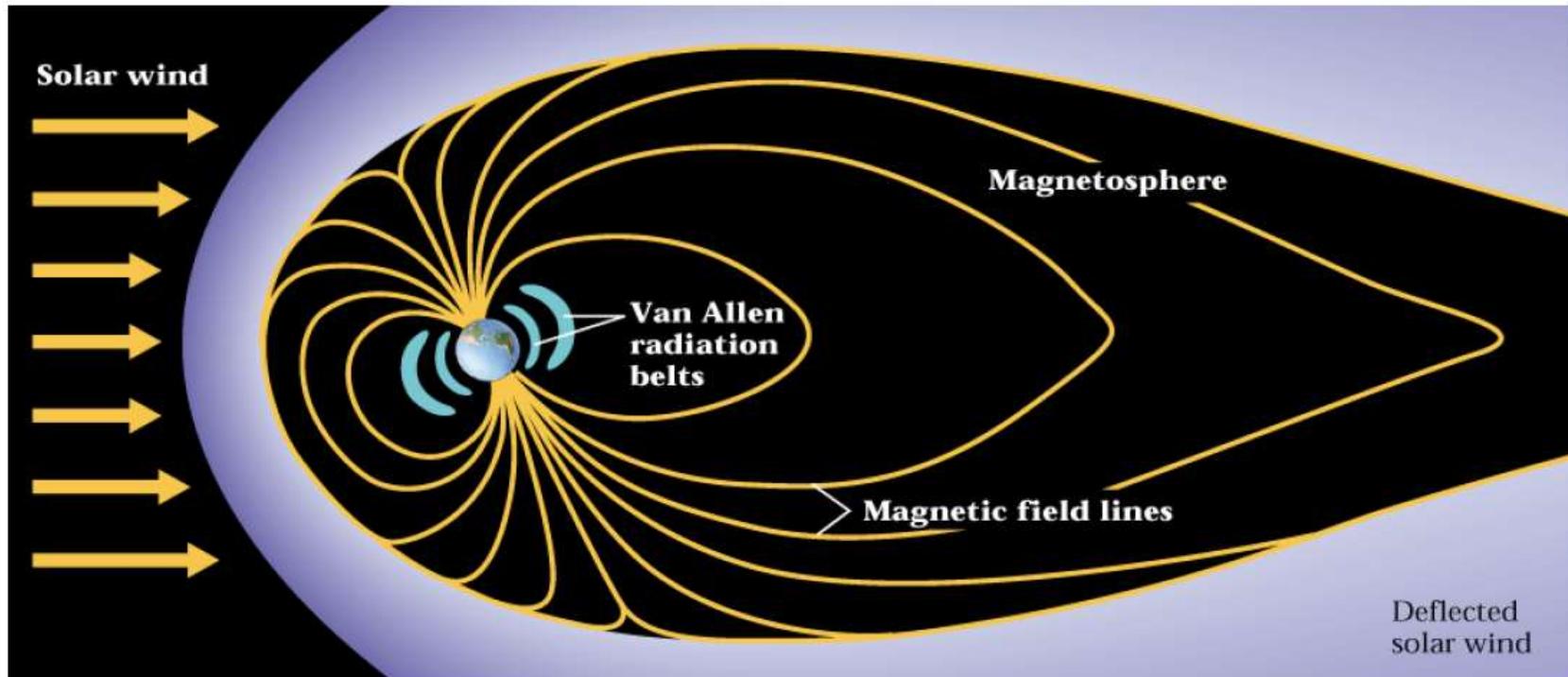
- Except at the equator, these lines of force are inclined toward the surface and produce the inclination of magnetic minerals in rocks and sediments.

[2015 GCH Earth's magnetosphere aspects.kmz](#)

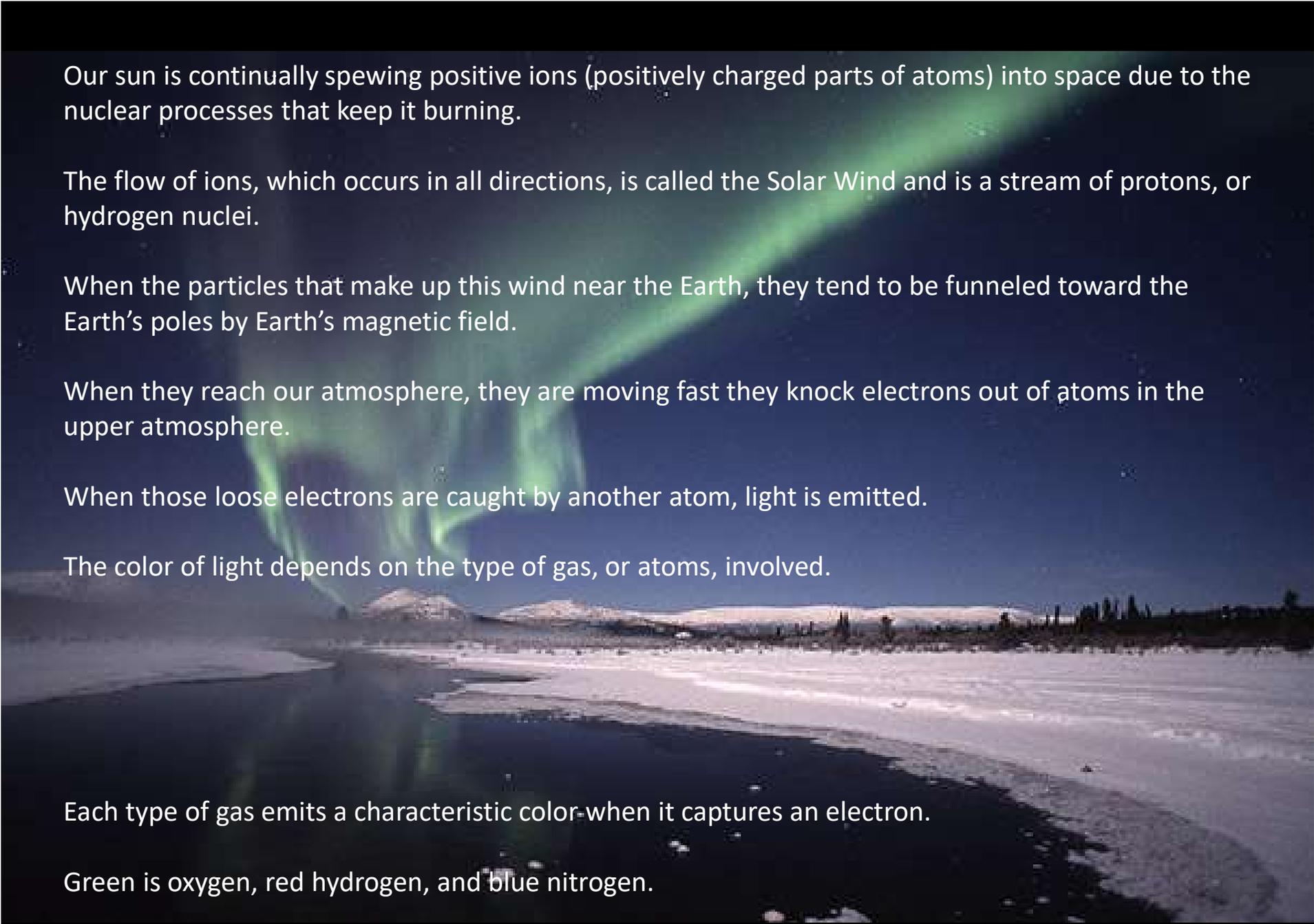


[http://www.impacttectonics.org/KMLZs/2015 GCH Earth's magnetosphere aspects.kmz](http://www.impacttectonics.org/KMLZs/2015_GCH_Earth's_magnetosphere_aspects.kmz)

Our magnetic field protects us from UV radiation by deflecting low-energy charged particles *around* the Earth, but some particles become trapped in outer [Van Allen radiation belts](#).



Other high-energy particles are steered into vertical fields above N and S magnetic poles where they collide with ions in Earth's atmosphere and produce...



Our sun is continually spewing positive ions (positively charged parts of atoms) into space due to the nuclear processes that keep it burning.

The flow of ions, which occurs in all directions, is called the Solar Wind and is a stream of protons, or hydrogen nuclei.

When the particles that make up this wind near the Earth, they tend to be funneled toward the Earth's poles by Earth's magnetic field.

When they reach our atmosphere, they are moving fast they knock electrons out of atoms in the upper atmosphere.

When those loose electrons are caught by another atom, light is emitted.

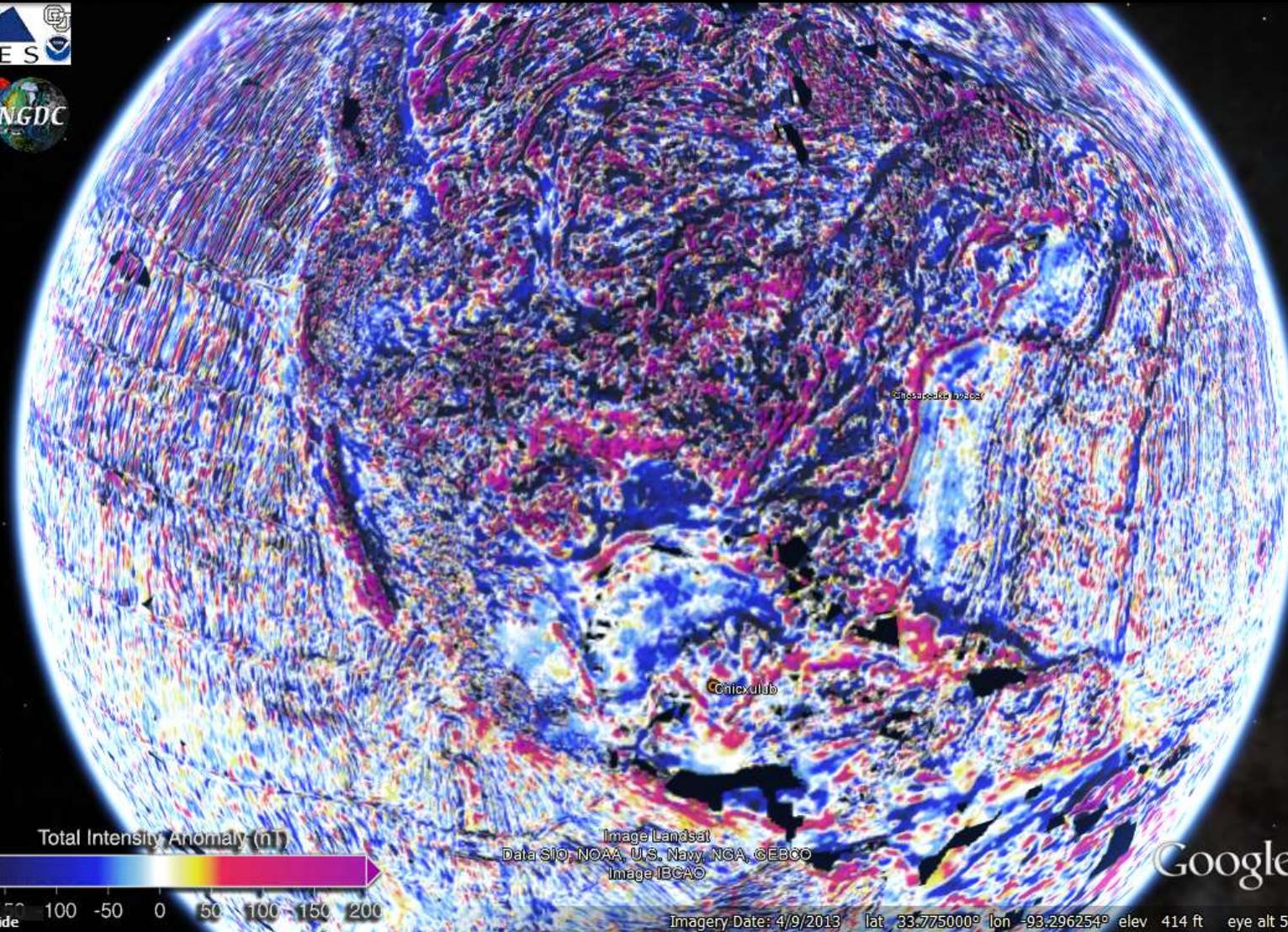
The color of light depends on the type of gas, or atoms, involved.

Each type of gas emits a characteristic color when it captures an electron.

Green is oxygen, red hydrogen, and blue nitrogen.

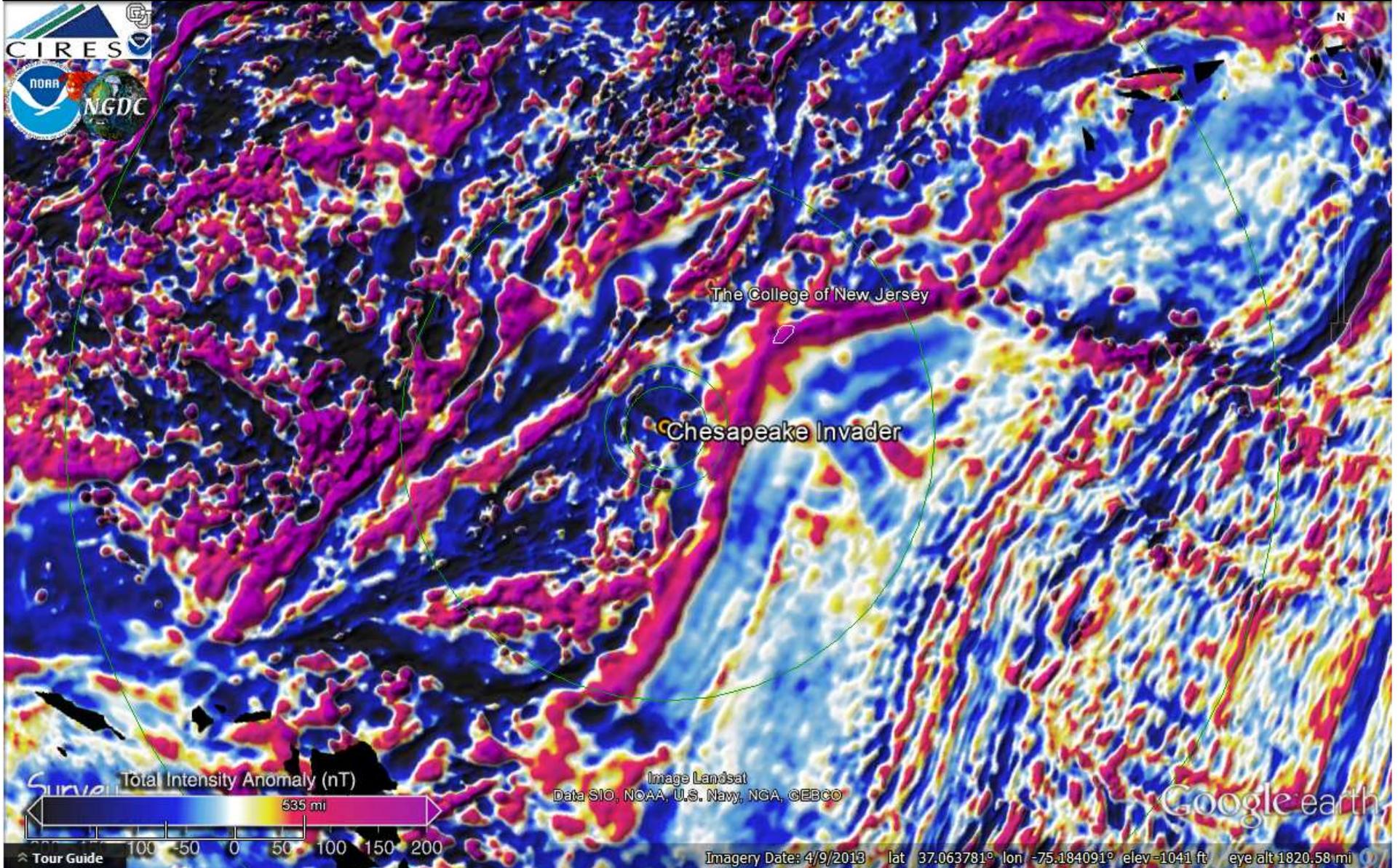
# MAGNETIC POTENTIAL FIELDS AND ANOMALIES

- Magnetic anomalies can be either negative or positive, and occur at the local to regional scale
- *Magnetic anomalies are caused by excesses and deficits of iron near Earth's surface*



# MAGNETIC POTENTIAL FIELDS AND ANOMALIES

## West-central Atlantic Margin of North America

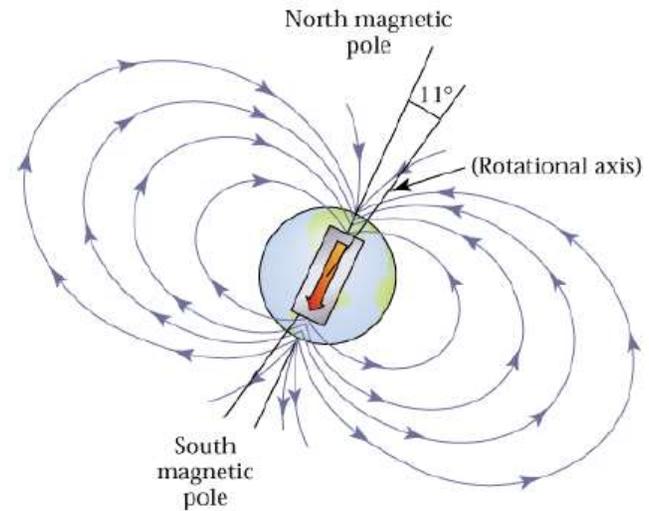


# EARTH'S MAGNETISM

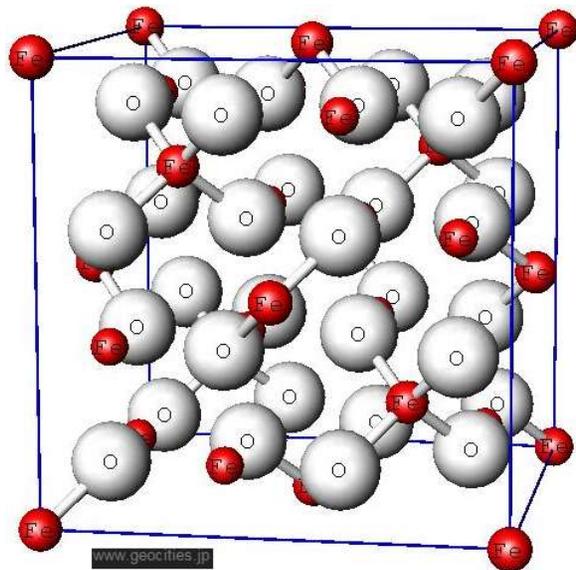
**Misconception:** A magnetic compass always points due north.

**Fact:** Because the magnetic north pole does not coincide with the geographic north pole, a magnetic compass will, from almost any location, NOT point due north, but rather to one side or the other of true north.

The angular difference is the declination for the given location.



# MAGNETITE $\text{Fe}_3\text{O}_4$

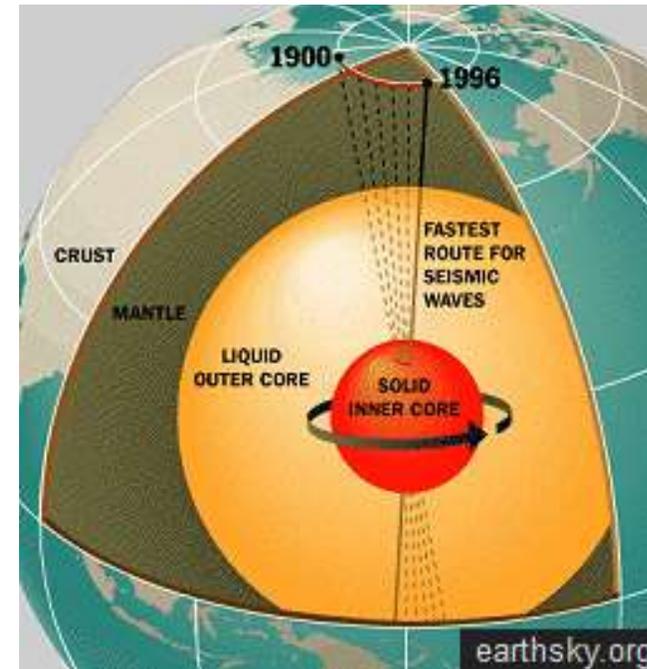


- Magnetite, surprisingly, ranks as the third or fourth most diverse mineral product formed biochemically by living organisms.
- Magnetite was discovered in the teeth of mollusks over 30 years ago, in some bacteria almost 20 years ago, in honey bees and homing pigeons nearly 15 years ago.
- Research has found a cell type loaded with crystals of biogenic magnetite, which have been named "magnetocytes".
- These are present in human tissue, including the brain, where they are present in clumps, with a minimum of 50 particles per clump.
- The biological function of these magnetocytes in the human brain is unknown.
- They are not used to detect the geomagnetic field, as they can be in magnetotactic bacteria, protozoans, migratory fish, and birds.
- The best guess is that they may be important for biochemistry.
- Magnetic biomineralization evolved nearly 2 billion years ago, so evolution has had ample opportunity to incorporate magnetically controlled reactions into biochemistry.

EOS, April 12, 1994.

# EARTH'S INNER CORE

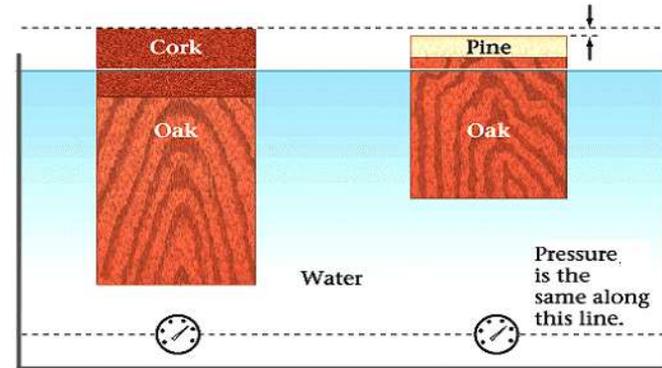
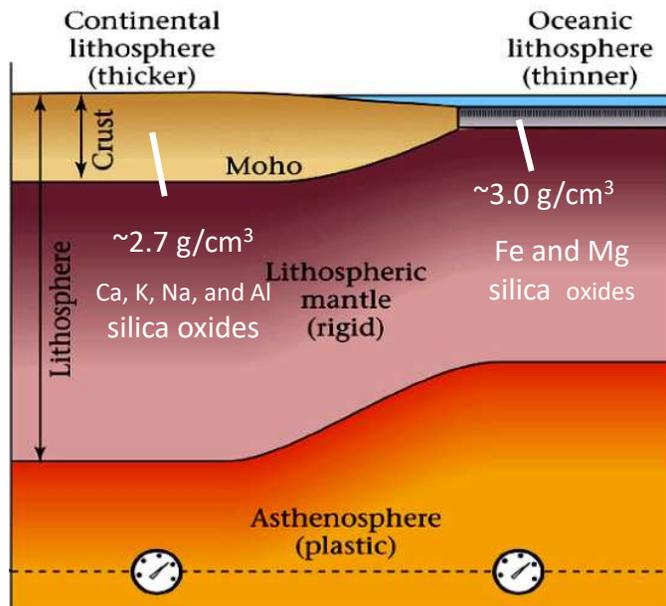
- The inner core has a diameter about three-quarters that of the moon, and a mass density almost 13 times greater than the density of water.
- The mass of the inner core is about one hundred million million tons -- which is about 30 per cent greater than the mass of the moon.
- The innermost core of Earth appears to rotate slightly faster than the rest of the planet, though in the same direction.
- Seismologists from the Lamont-Doherty Earth Observatory have calculated that the inner core spins about two-thirds of a second faster than its surroundings in one day.
- This would advance a given point on the outer surface of the core almost 19 km farther ahead of a point on the surface of the crust.
- This movement is about 100,000 times faster than the movement of the plates, meaning the core essentially laps Earth's surface every 400 years.



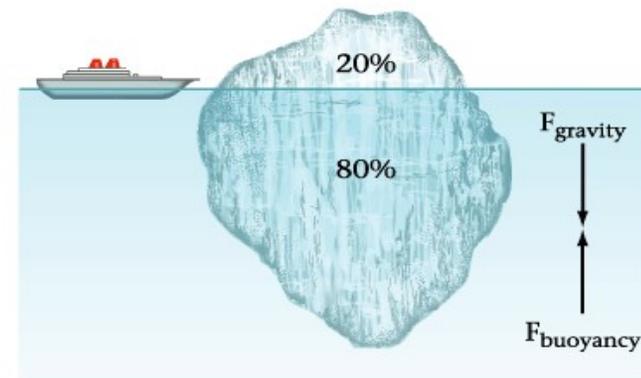
EOS, July 30, 1996.

# CRUSTAL ISOSTASY

- Oceanic crust has an average elemental composition like that of basalt, mostly of iron (Fe) and magnesium (Mg) silica ( $\text{SiO}_2$ ), that are more dense and heavy than continental crust that is compositionally similar to granite with abundant sodium (Na), calcium (Ca), potassium (K), and Aluminum (Al) silica oxides



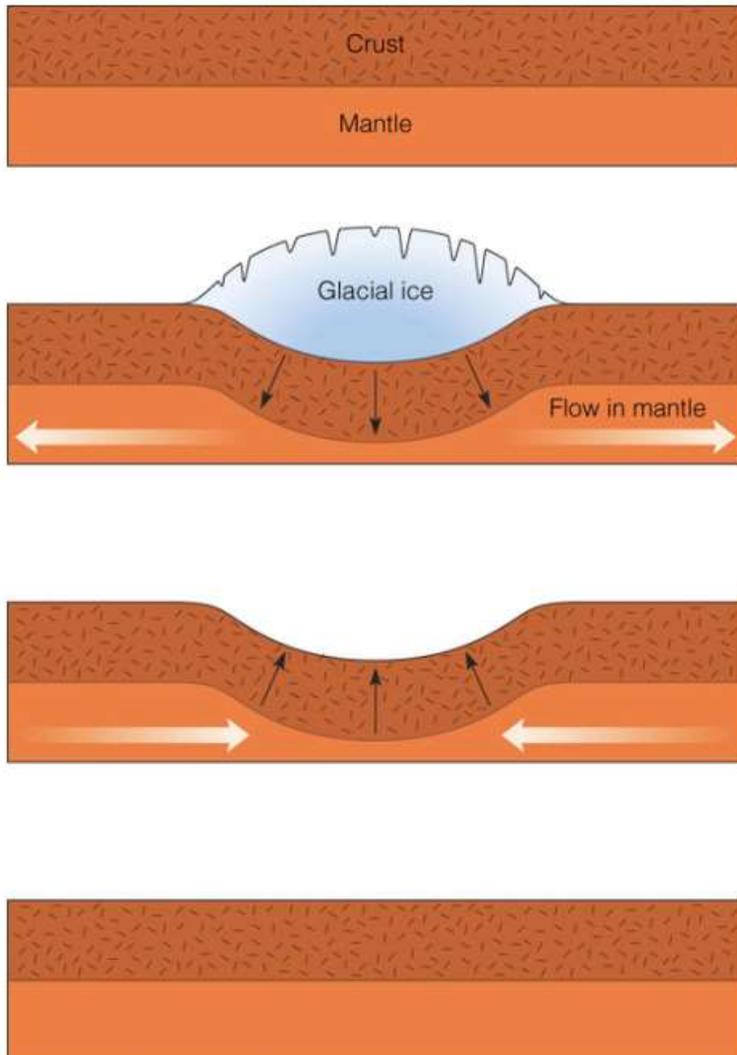
Continental crust has higher elevations and deeper roots than oceanic crust because of gravity and buoyancy.



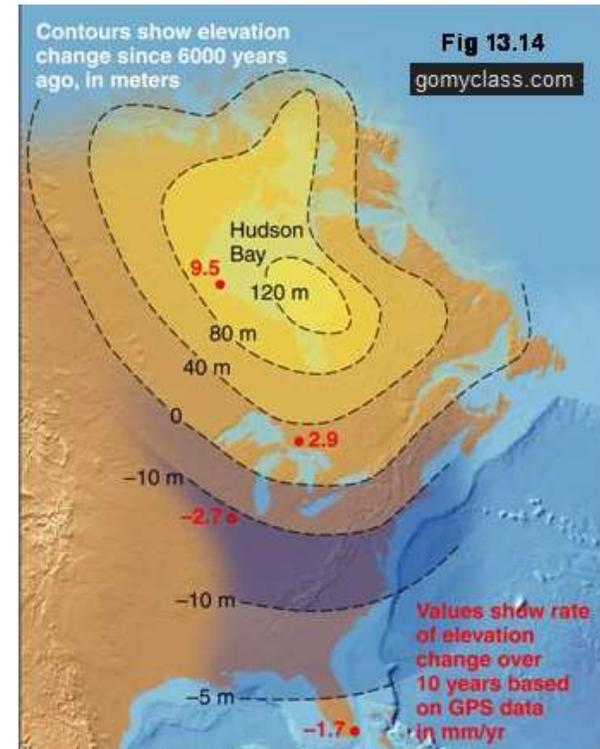
W. W. Norton. Modified from Sloss, NOAA

- The principle of isostasy and the densities and behavior of the crust indicate that the crust floats in equilibrium with the denser underlying mantle.
- Because it is thinner and denser than the continental crust, the oceanic crust floats at a lower elevation.

# CRUSTAL ISOSTASTIC REBOUND



# CRUSTAL ISOSTASTIC REBOUND



# NEOTECTONICS AND FRACTURE DIP

New Jersey – New York USA historical seismicity (Sykes, 2006), vertical crustal motion (mm/yr) based on continuously-operated receiving stations in 2010 (CORS), and predicted neotectonic fracture strike and dip directions

