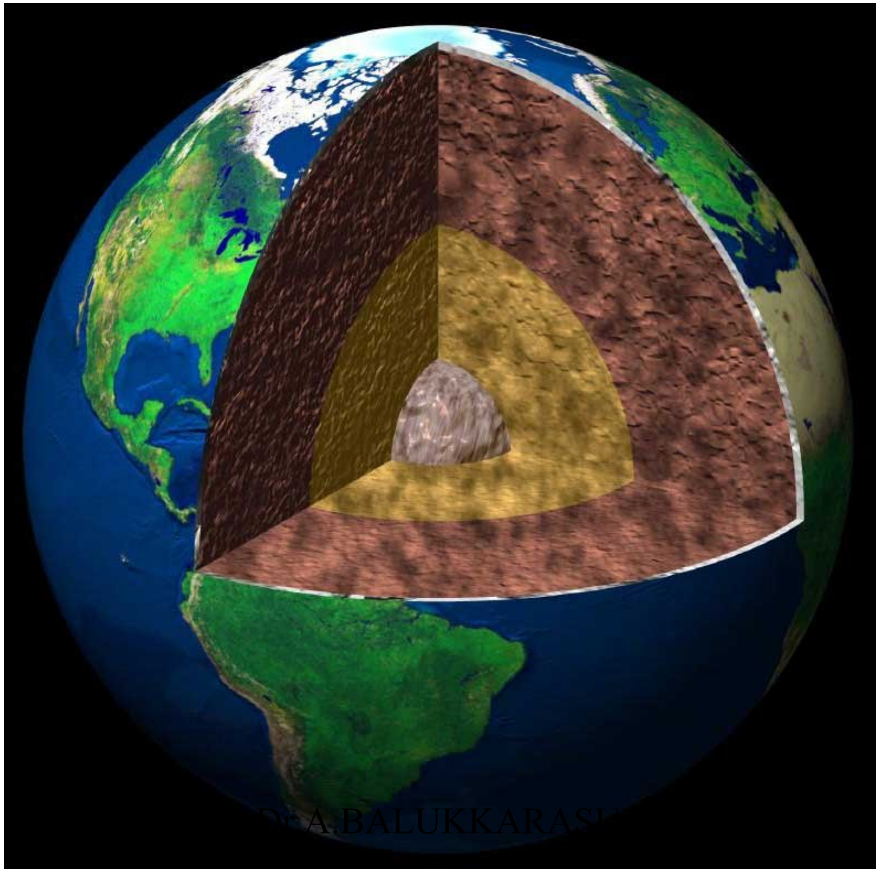
Earth’s Interior and Geophysical Properties



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Introduction – Can we just go there ?

- Deep interior of the Earth must be studied ***indirectly***
  - Direct access only to crustal rocks and small upper mantle fragments brought up by volcanic eruptions or slapped onto continents by subducting oceanic plates
  - Deepest drillhole reached about 12 km, but did ***not*** reach the mantle
- ***Geophysics*** is the branch of geology that studies the interior of the Earth

SE Germany – 10 km drill hole

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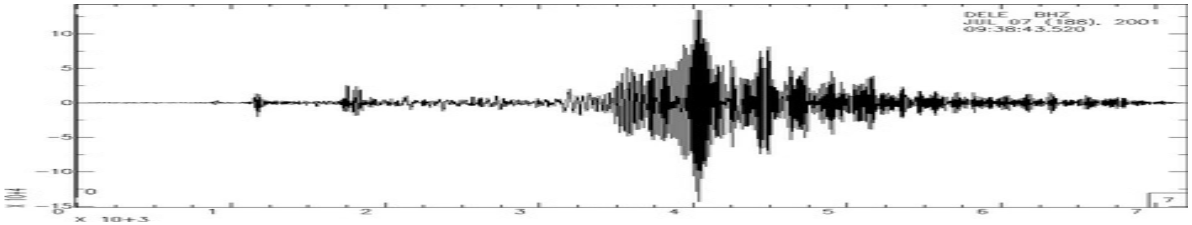
Indirect Study of the Earth's Interior - Geophysics

- Seismic Waves
- Gravity
- Heat Flow
- Magnetic Field



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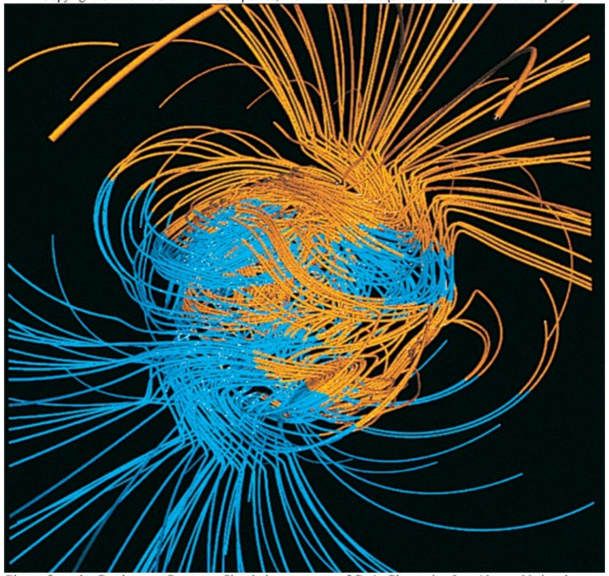

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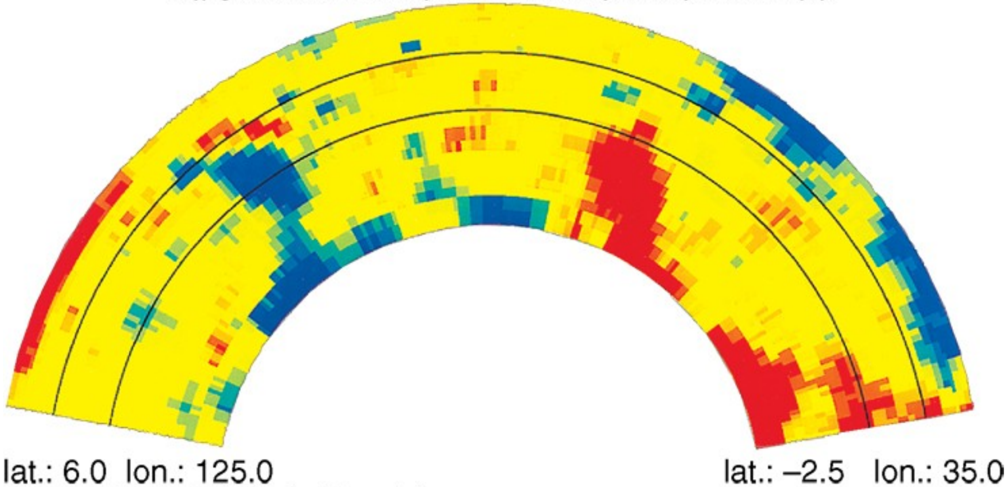

Photo courtesy of Stephen Grand, University of Texas at Austin

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Evidence from Seismic Waves

- ***Seismic waves*** or vibrations from a large earthquake (or underground nuclear test) will pass through the entire Earth

- ***Seismic reflection*** - the return of some waves to the surface after bouncing off a rock layer boundary
  - Sharp boundary between two materials of different densities will reflect seismic waves

- ***Seismic refraction*** - bending of seismic waves as they pass from one material to another having different seismic wave velocities

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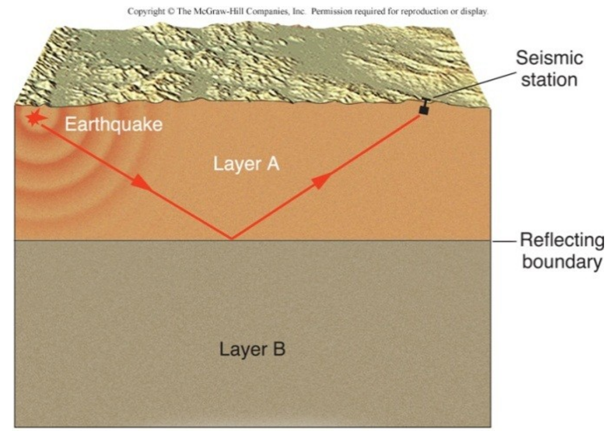

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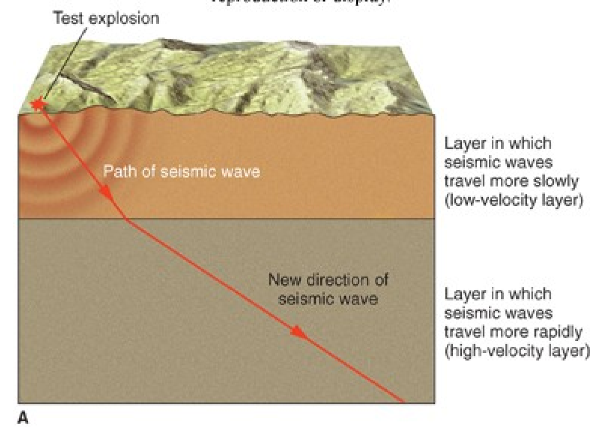

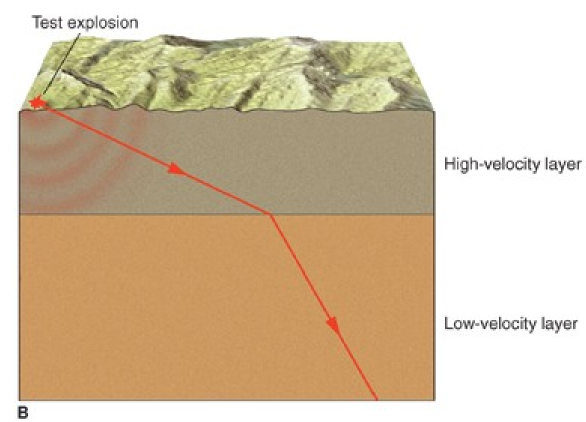

Earth's Internal Structure

- ***Seismic waves*** have been used to determine three main layers of the Earth: the ***crust***, ***mantle*** and ***core***

- The ***crust*** is the outer layer of rock that forms a thin skin on Earth's surface

  (***granite, feldspars, quartz***)

- The ***mantle*** is a thick shell

  of dense rock that separates

  the crust above from the core below

  (***olivine composition***)

- The ***core*** is the metallic central zone of the Earth (***metallic***)

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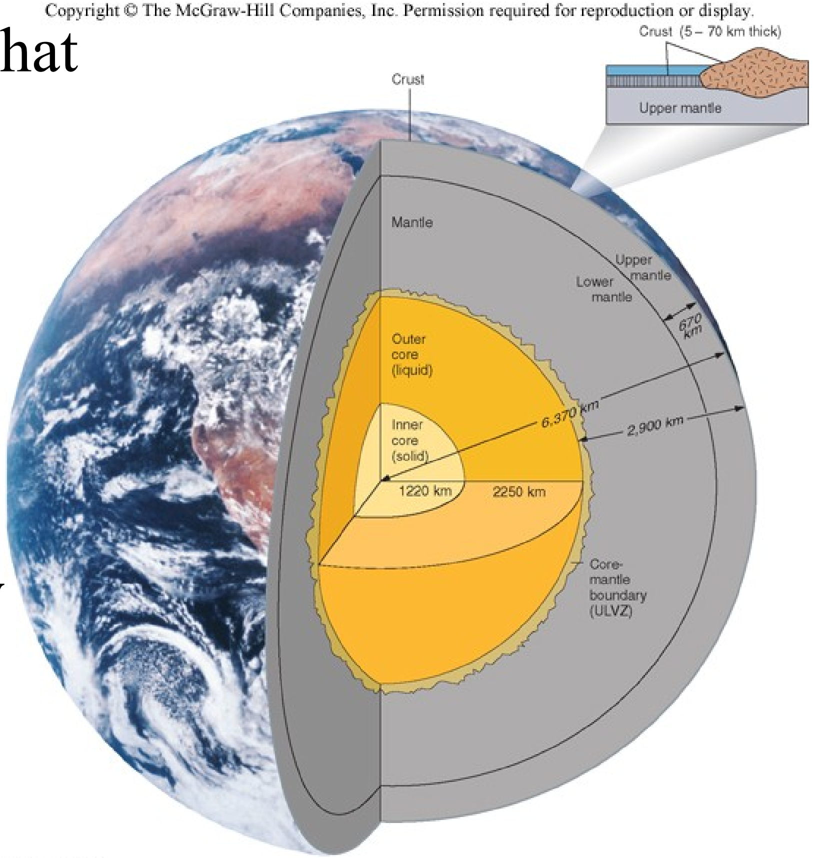

Photo by NASA

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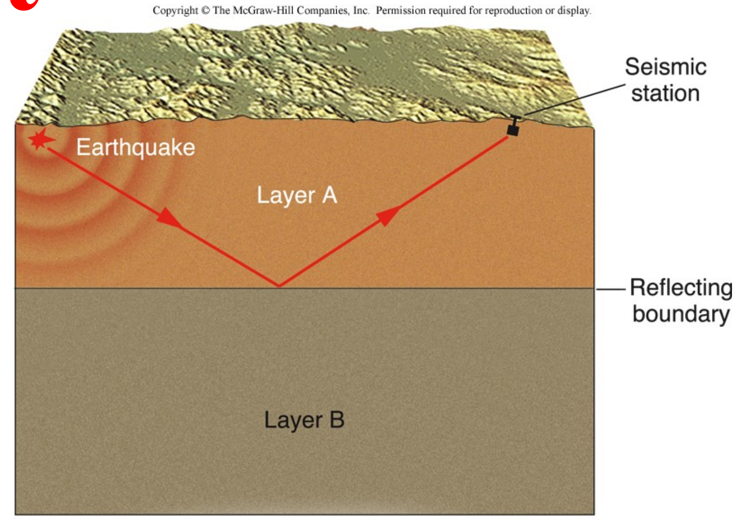
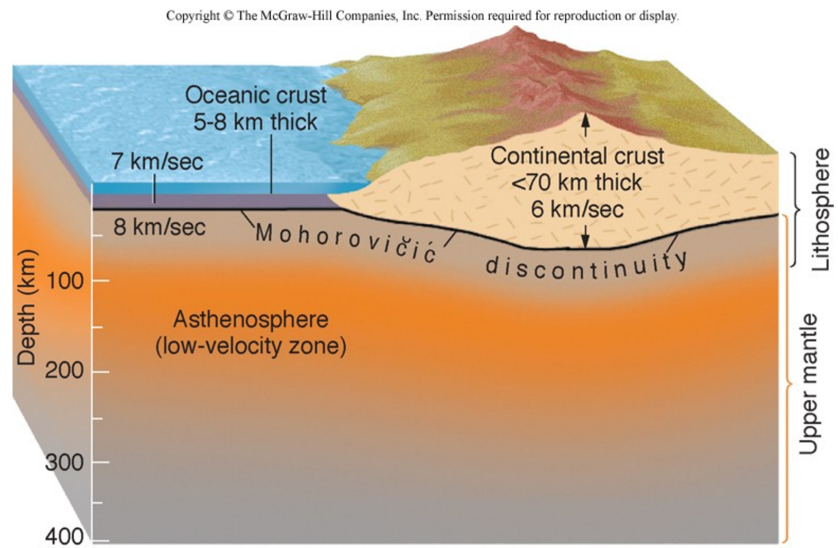
The Crust

- ***Seismic wave*** studies indicate crust is thinner and denser beneath the oceans than on the continents



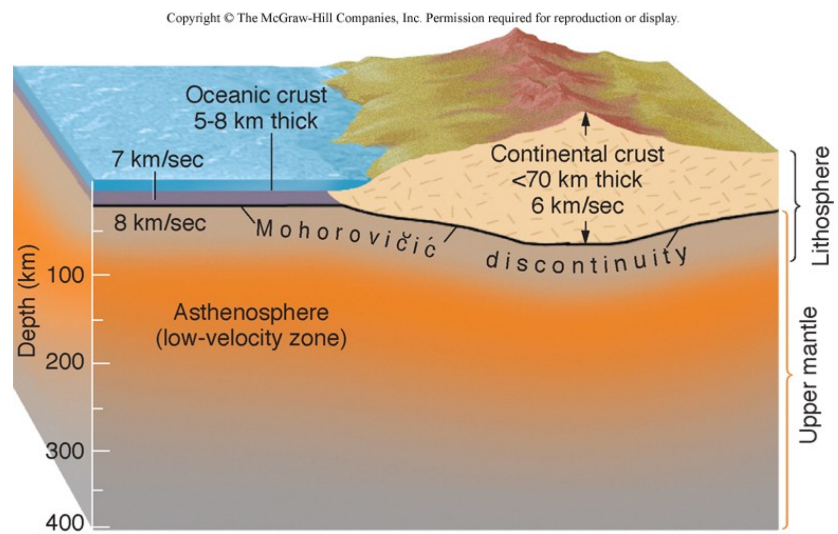
- Different seismic wave velocities in oceanic (7 km/sec) vs. continental (~6 km/sec) crustal rocks are indicative of different compositions



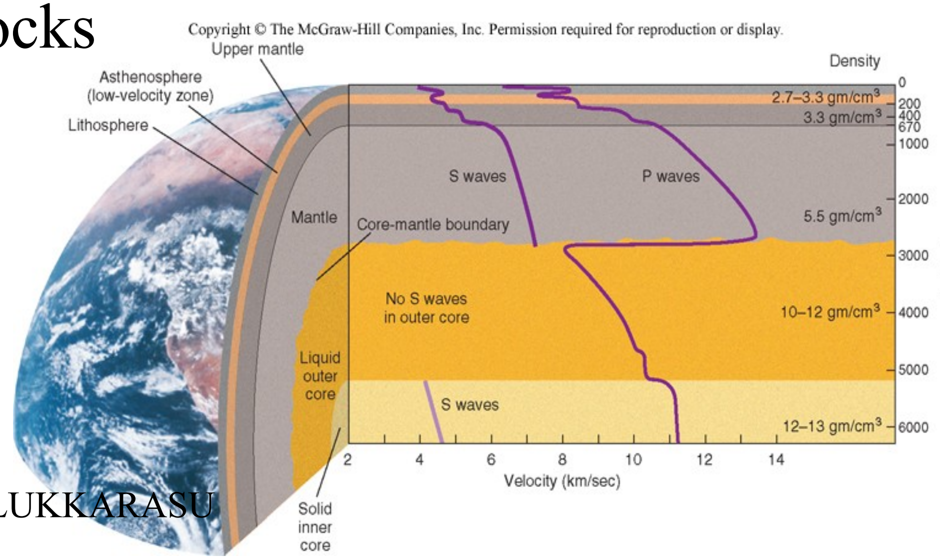
- Oceanic crust is ***mafic***, composed primarily of basalt and gabbro
- Continental crust is ***felsic***, with an average composition similar to granite

The Mantle

- ***Seismic wave*** studies indicate the mantle, like the crust, is made of solid rock with only isolated pockets of magma



- Higher seismic wave velocity (8 km/sec) of mantle vs. crustal rocks indicative of denser, ***ultramafic*** composition



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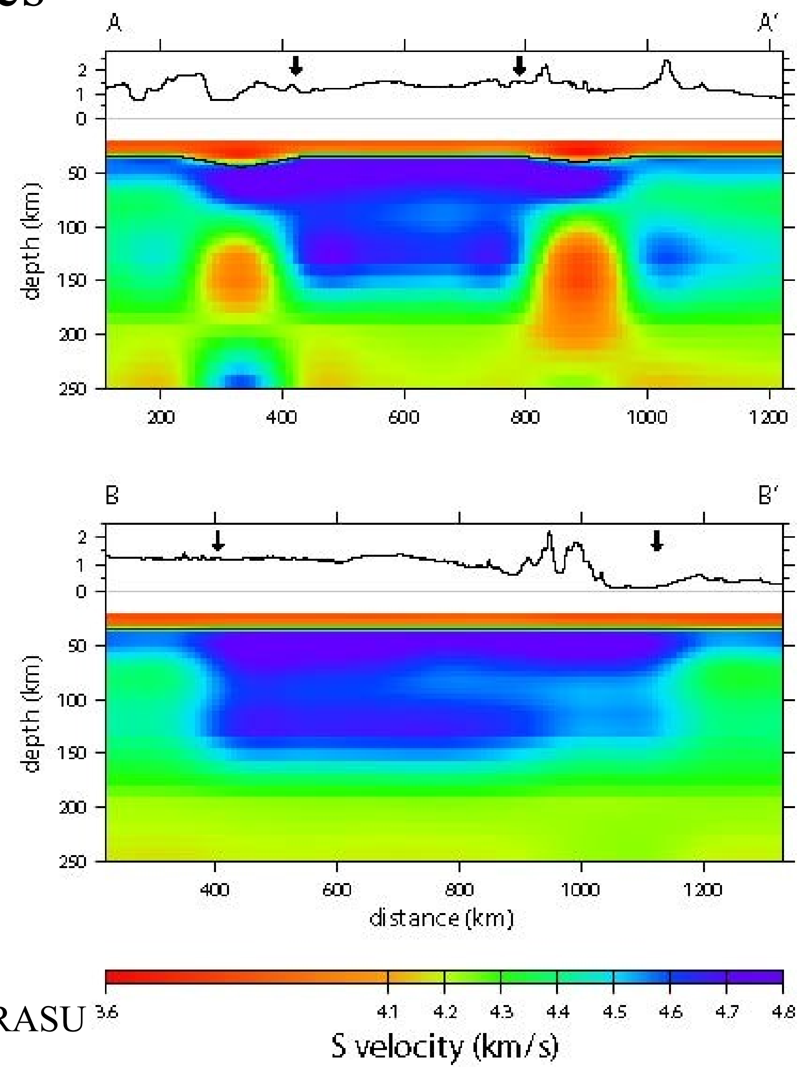
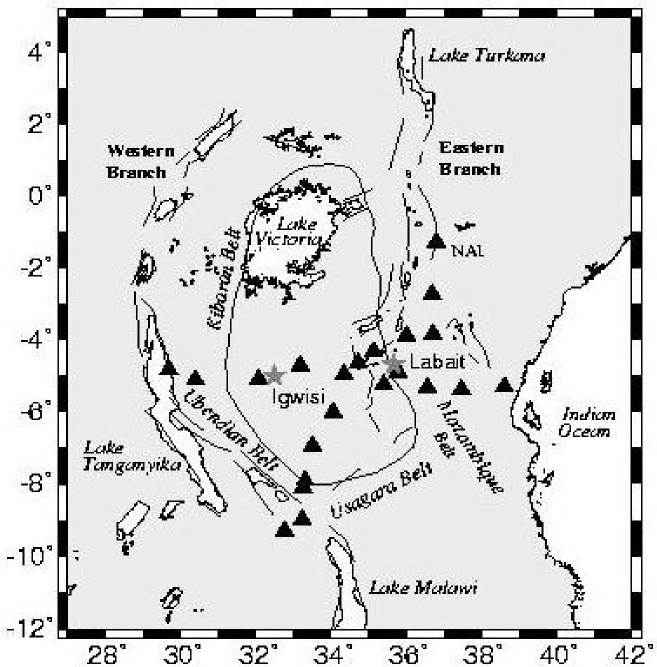
The Mantle Lithosphere

- Crust and upper mantle together form the ***lithosphere***, the brittle outer shell of the Earth that makes up the tectonic plates
  - Lithosphere averages 70 km thick beneath oceans and 125-250 km thick beneath continents





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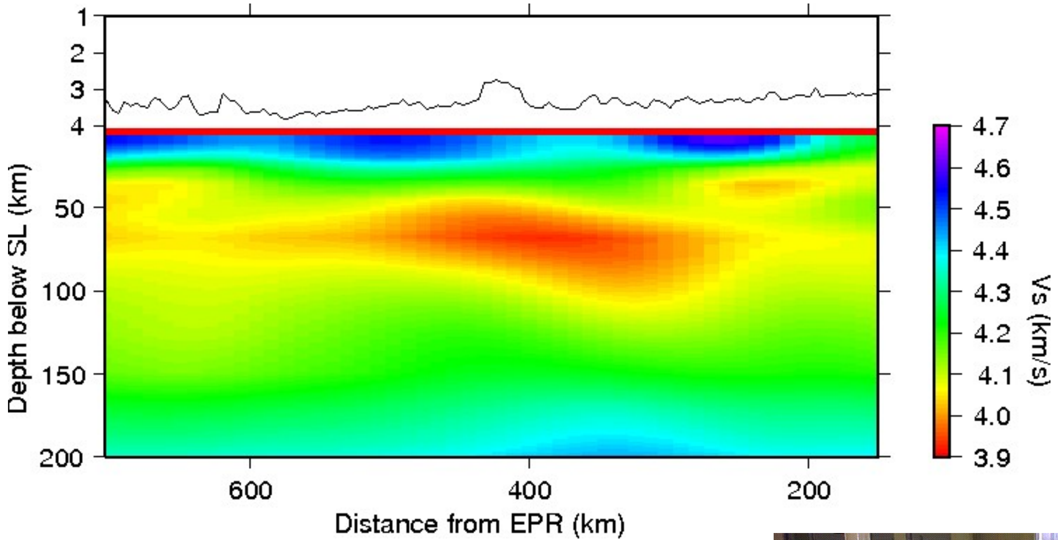
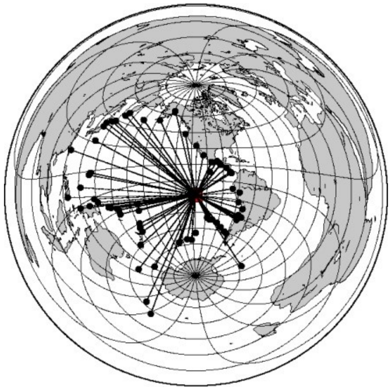
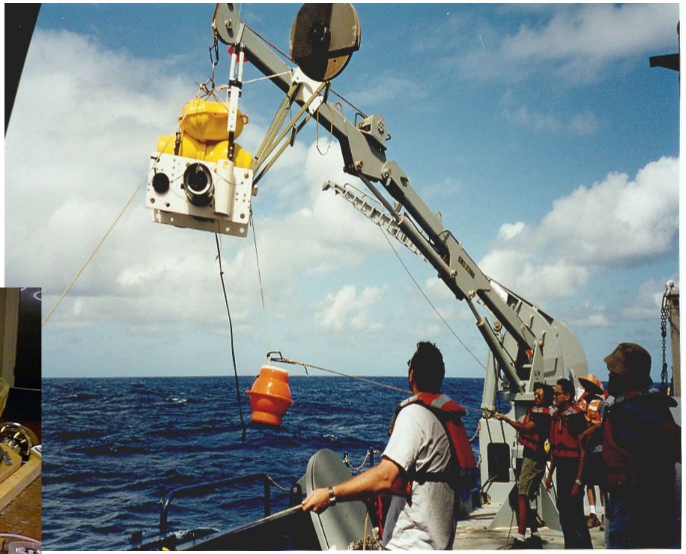
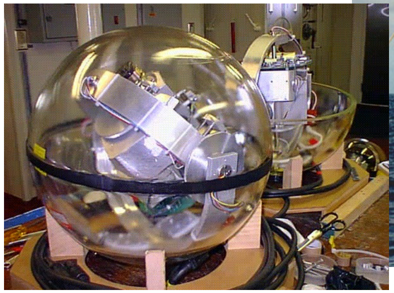
The Asthenosphere





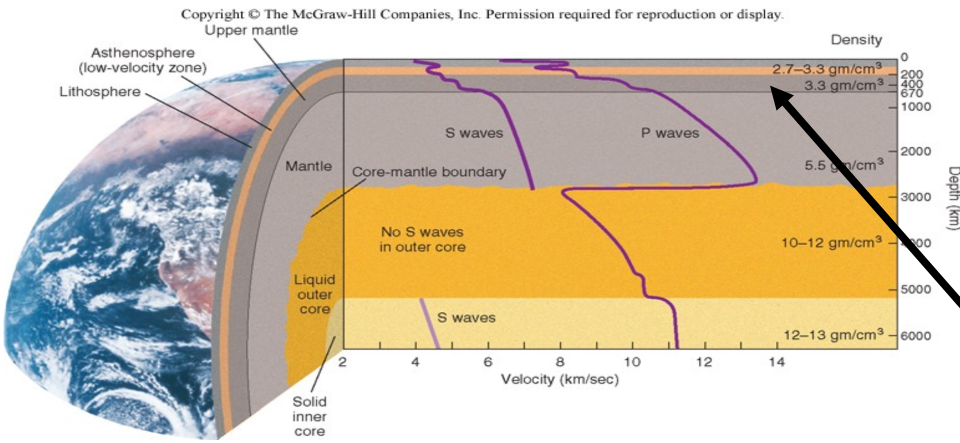


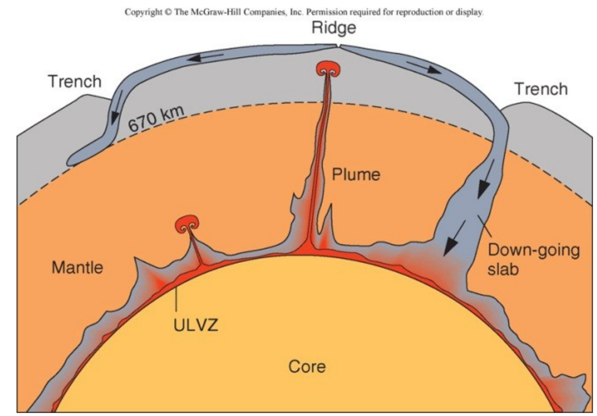


- Beneath the lithosphere, seismic wave speeds abruptly decrease in a plastic (ductile) ***low-velocity zone*** called the ***asthenosphere***

- Are low seismic velocities caused by partial melt, water, density?

Upper/Lower Mantle Boundary
410 km and 660 km Discontinuity

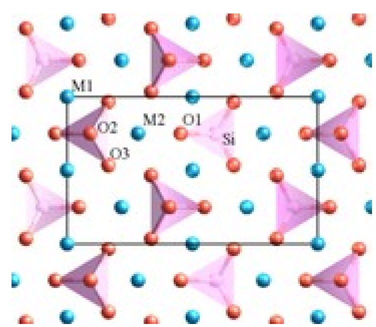




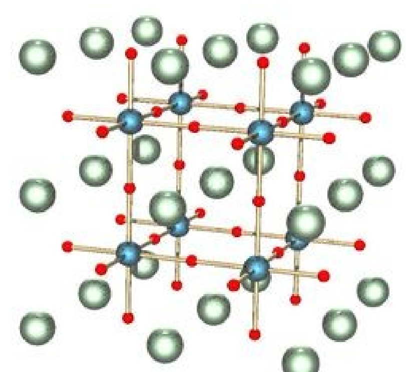
Major seismic discontinuities observed at 410 km and 660 km depth.

- Due to change in packing structure of olivine molecules
- Influenced by increasing pressures
- Composition unchanged

$(Mg,Fe)_2\ SiO_4$



olivine



perovskite

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The Core

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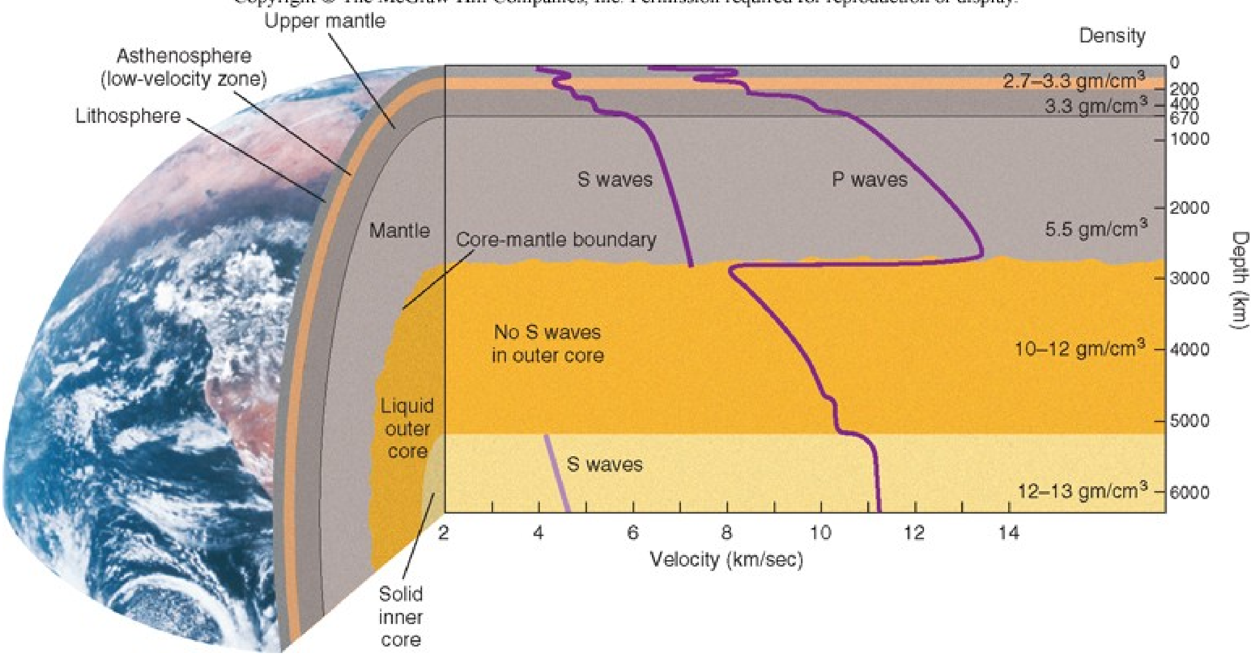

- ***Seismic wave*** studies have provided primary evidence for existence and nature of Earth's core

- Specific areas on the opposite side of the Earth from large earthquakes do not receive seismic waves, resulting in ***seismic shadow zones***

How Do We Know the Composition of the Core?

- Density of crust (2.7 g/cm^3) and mantle (3.3 g/cm^3)
- By considering volumes of each – core must be ~10 g/cm^3)
- What can seismic waves tell us?

P waves

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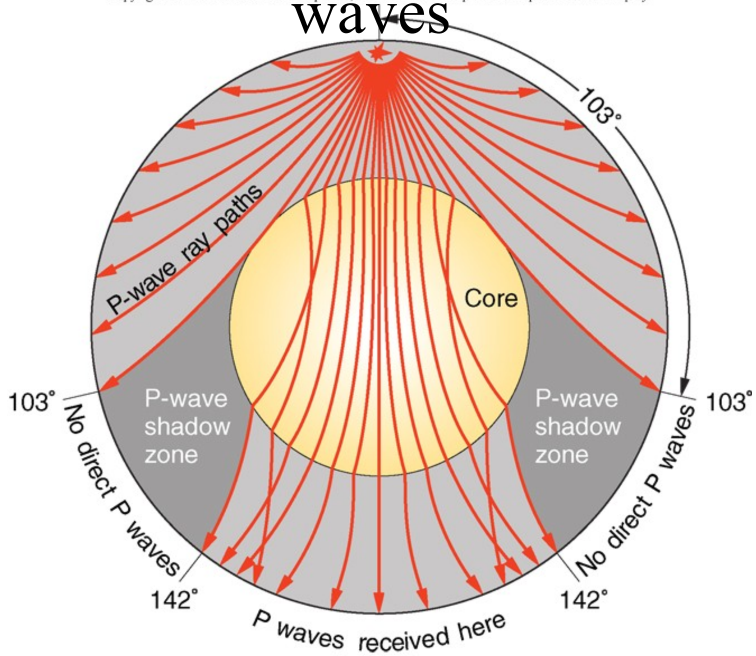

S waves

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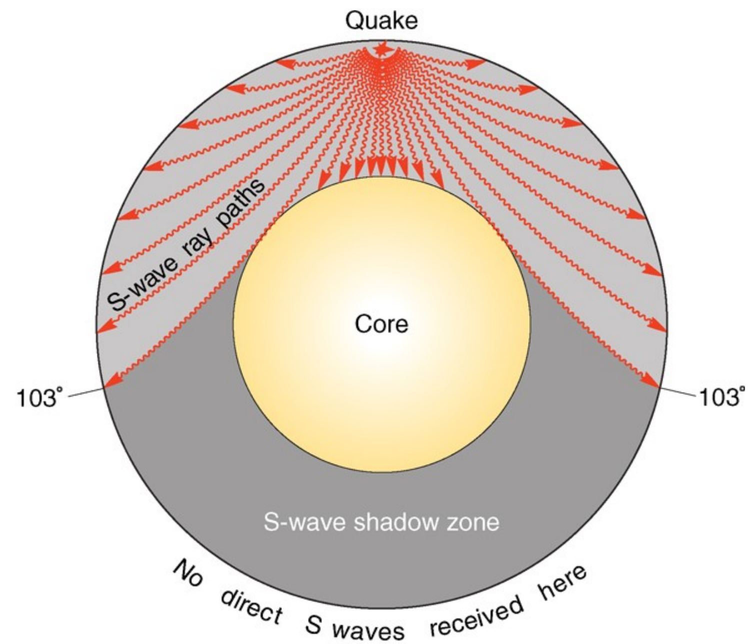
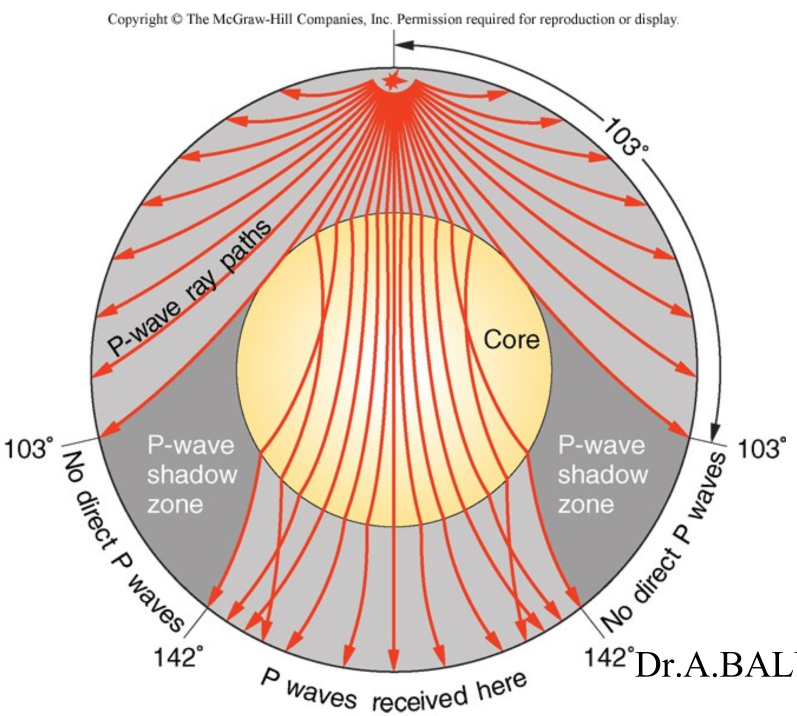


From what you know about P and S waves, what do these shadow zones tell you ?

Seismic Shadow Zones

- ***P-wave shadow zone*** (103°-142° from epicenter) explained by refraction of waves encountering core-mantle boundary
- ***S-wave shadow zone*** (≥103° from epicenter) suggests outer core is a liquid



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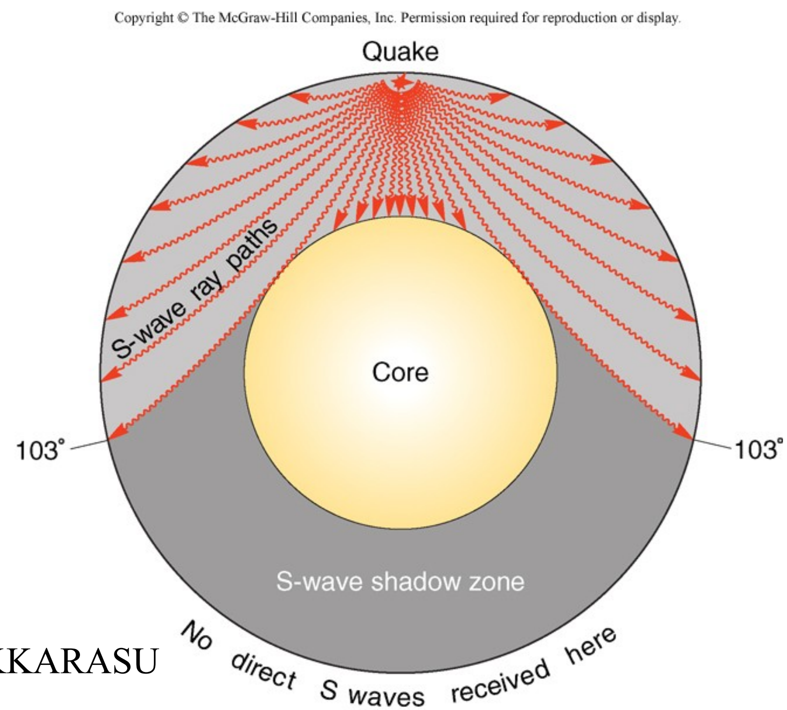
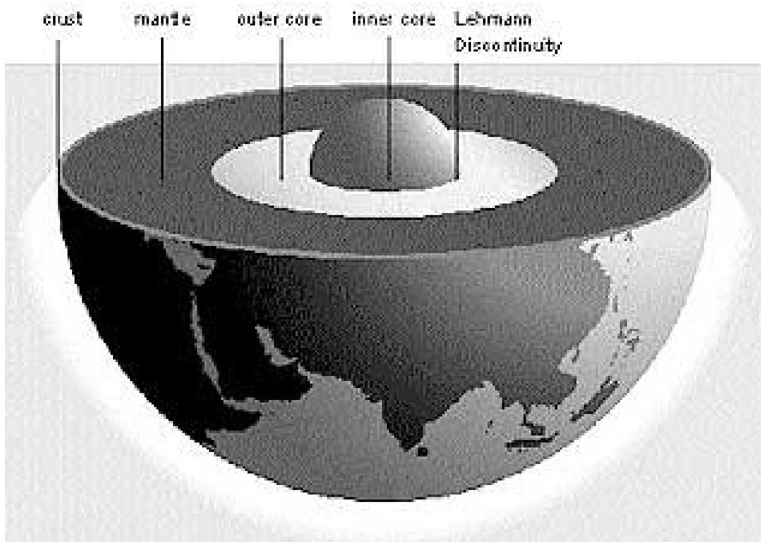
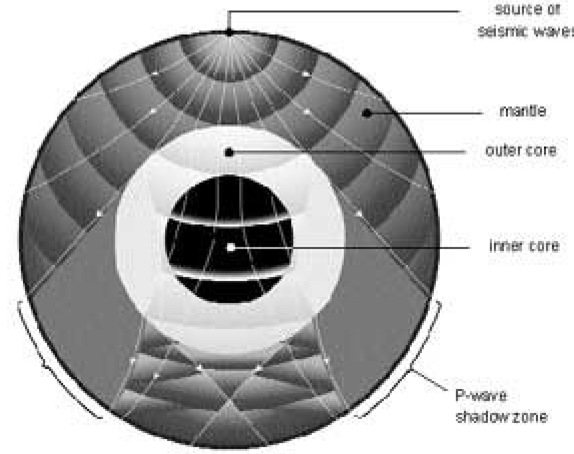


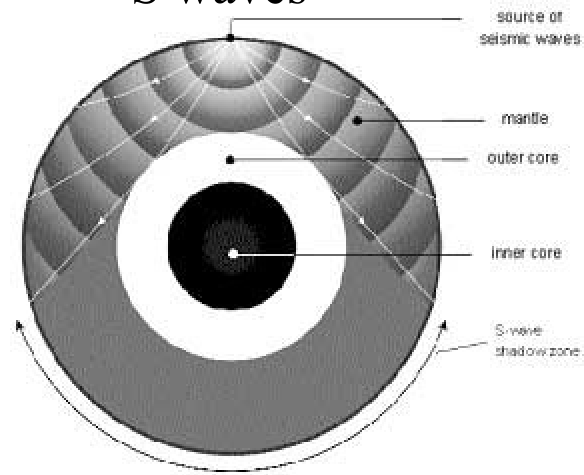
The Inner Core



P waves



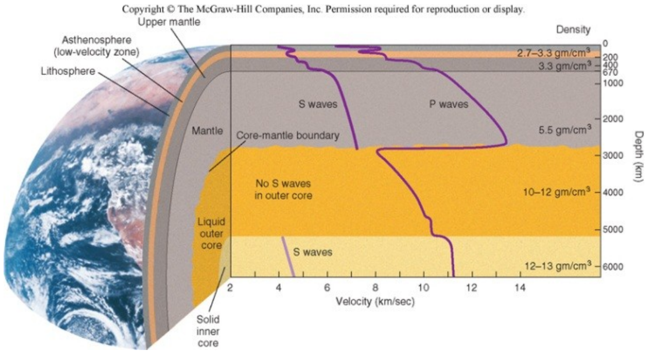
S waves



- Inge Lehmann discovered that the inner core was solid in 1936 by careful observations of *P-wave* refraction patterns through the inner core.

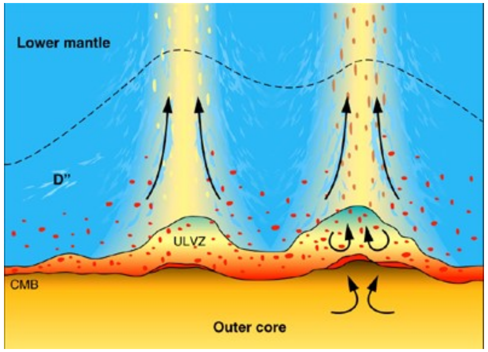
The Core

- Core composition inferred from its calculated density, physical and electro-magnetic properties, and composition of ***meteorites***



  – *Iron metal* (liquid in outer core and solid in inner core) best fits observed properties
  – Iron is the only metal common in meteorites

- ***Core-mantle boundary*** (D” layer) is marked by great changes in seismic velocity, density and temperature
  – Hot core may melt lowermost mantle or react chemically to form iron silicates in this seismic wave ***ultralow-velocity zone (ULVZ)***



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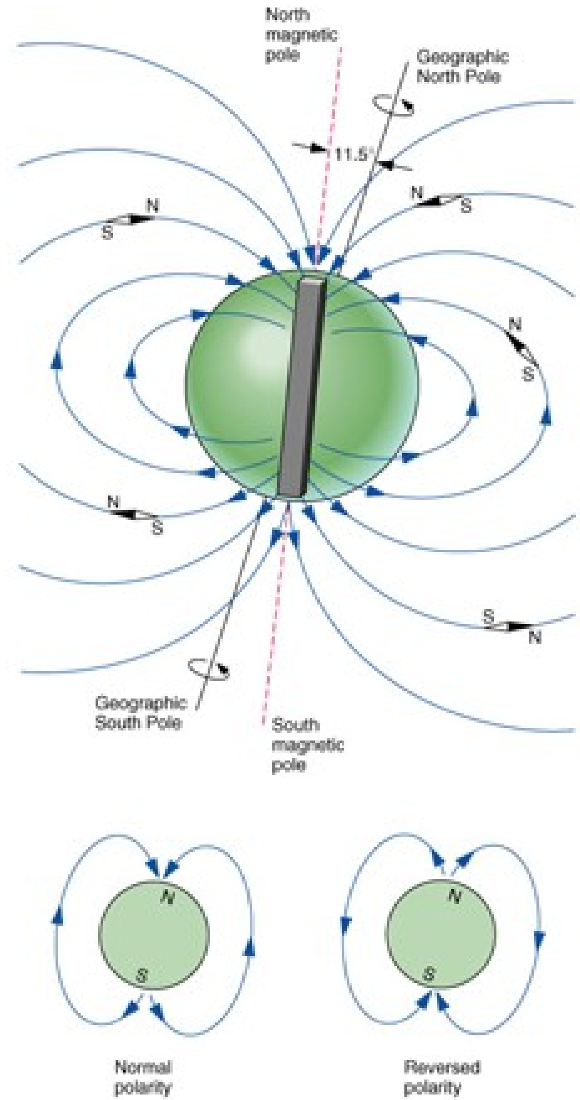
Earth’s Magnetic Field

- A *magnetic field* (region of magnetic force) surrounds the Earth
  - Field has north and south *magnetic poles*
  - Earth’s magnetic field is what a compass detects
  - Recorded by magnetic minerals (e.g., magnetite) in igneous rocks as they cool below their ***Curie Point***



In physics and mn physics and materials science, the **Curie temperature** (T_C), or **Curie point**, is the **temperature**above which certain materials lose their permanent magnetic properties, to be replaced by induced magnetism. The **Curie temperature** is named after Pierre **Curie**, who showed that magnetism was lost at a critical **temperature**aterials science, the **Curie temperature** (T_C), or **Curie point**, is the **temperature**above

What is the Curie effect?

The **curie effect** usually refers to a magnetic phenomenon discovered by Pierre**Curie**. He discovered that ferromagnetic substances exhibited a critical temperature transition, above which the substances lost their ferromagnetic behaviour. This is now known as the **Curie** point

Why does metal lose magnetism when heated?

A piece of iron ordinarily will be attracted to a magnet, but when you **heat** the iron to a high enough temperature (called the Curie point), it **loses** its ability to be magnetized. **Heat** energy scrambles the iron atoms so they can't line up and create a magnetic field—this Snack is a simple demonstration of this effect

What is the Curie point for iron?

The **Curie temperature** of **iron** is about 1043 K. At temperatures below the **Curie point**, the magnetic moments are completely aligned within magnetic domains in ferromagnetic materials. ... Above the **Curie point**, the material is purely paramagnetic

What temperature do magnets lose their magnetism?

When heated above **176° Fahrenheit (80° Celsius**), magnets will quickly lose their magnetic properties. The magnet will become permanently demagnetized if exposed to these temperatures for a certain length of time or heated at a significantly higher temperature (Curie temperature)

What temperature does iron lose its magnetism?

It is magnetic at normal temperatures, but critical temperature (**about 1420° F** for simple carbon steel) also makes steel non-magnetic. But it doesn't become magnetic again until it drops to about 500° F

How does temperature affect a magnet?

When exposed to extreme temperatures, however, this balance is destabilised; magnetic properties are then **affected**. While cold strengthens **magnets**, **heat** can result in the loss of magnetic properties. In other words, too much **heat** can completely ruin a **magnet**

Why are magnets stronger cold?

In extremely **cold** temperatures the atoms will move more slowly and less randomly. This creates a more controlled alignment of the atoms that produce the magnetic field and a slightly **stronger** magnetism. If you haven't done the experiment on**magnets** in heat you can find it here

Paleomagnetism

1. the branch of geophysics concerned with the magnetism in rocks that was induced by the earth's magnetic field at the time of their formation.

Paleomagnetism (or **palaeomagnetism** in the United Kingdom) is the study of the record of the Earth's magnetic field in rocks, sediment, or archeological materials. Certain minerals in rocks lock-in a record of the direction and intensity of the magnetic field when they form

What is paleomagnetism and what is its importance?

Paleomagnetism. **The** record of **the** strength and direction of Earth's magnetic field (**paleomagnetism**, or fossil magnetism) is an **important** source of our knowledge about **the** Earth's evolution throughout **the** entire geological history. This record is preserved by many rocks from **the** time of **their** formation

How does paleomagnetism support seafloor spreading?
Magnetic reversals show up as bands of alternating polarity in the slowly **spreading seafloor**. ... This explanation of magnetic striping by **paleomagnetism** convinced scientists that new oceanic crust was being continually formed at mid-oceanic ridges. **Seafloor spreading** was accepted as a reality

Earth’s Magnetic Field

- ***Magnetic reversals*** - times when the poles of Earth’s magnetic field switch
  - Recorded in magnetic minerals
  - Occurred many times; timing appears chaotic
  - After next reversal, a compass needle will point toward the south magnetic pole
- ***Paleomagnetism*** - the study of ancient magnetic fields in rocks
  - allows reconstruction of plate motions over time.

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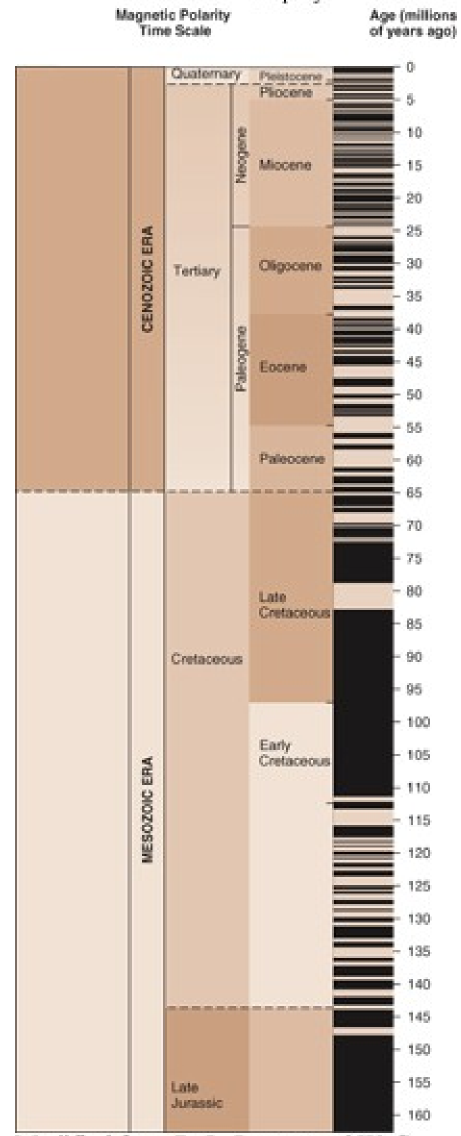

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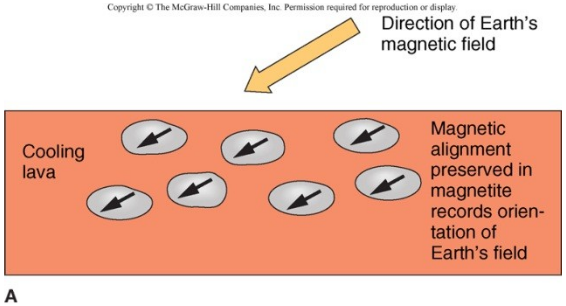

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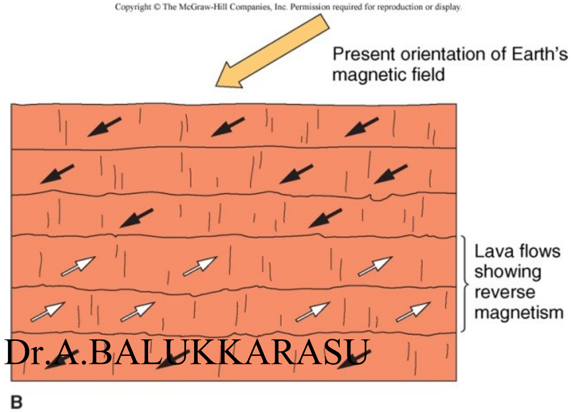

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magnetic field **reversals**. Changes in direction or orientation of the **magnetic** field of the Earth that have occurred from time to time. (Several hundred are known in the geological record.) Sometimes the north **magnetic** pole is near the geographic North Pole and sometimes near the South Pole in Antarctica

Magnetic Field Reversals

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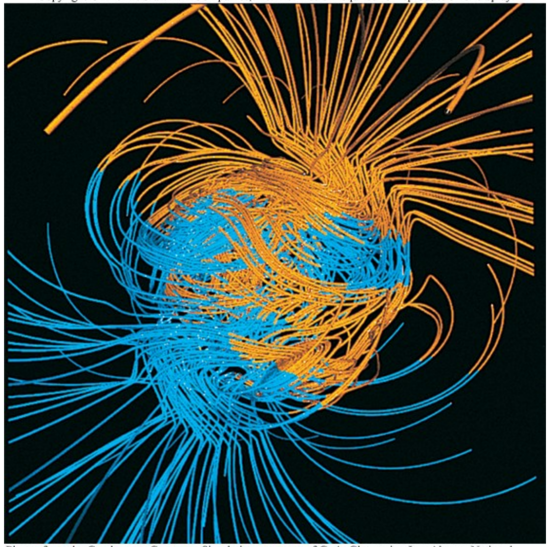

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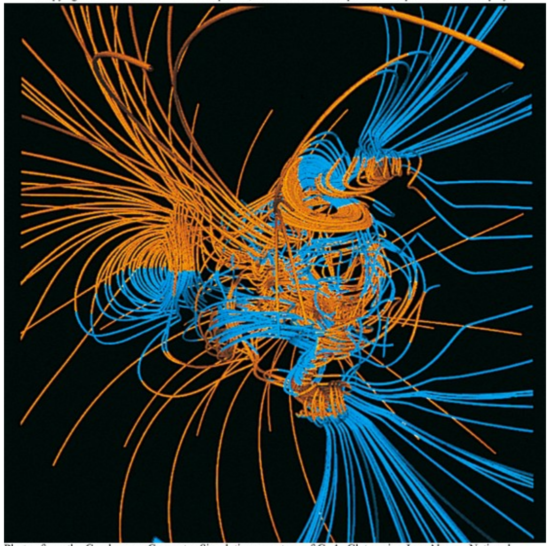

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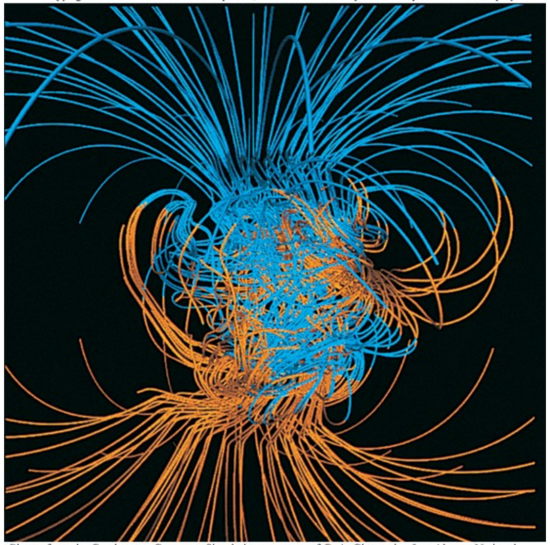

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- Computer simulations from Los Alamos (Glatzmaier)
- Also predicted the inner core must be spinning faster than Earth
- These perturbations may initiate reversals

What is the magnetic field reversal?

A geomagnetic **reversal** is a change in a planet's **magnetic field** such that the positions of **magnetic** north and **magnetic** south are interchanged, while geographic north and geographic south remain the same. ... During this change the strength of the **magnetic field** weakened to 5% of its present strength.

What happens when there is a magnetic reversal?

These **magnetic reversals**, in which the direction of the field is flipped, are believed to occur when small, complex fluctuations of **magnetic** fields in the Earth's outer liquid core interfere with the Earth's main dipolar **magnetic** field to the point where they overwhelm it, causing it to reverse.

What is the cause of magnetic reversal?

"The Earth's magnetic field is thought to be generated by fluid motions in the liquid, outer part of the Earth's core, which is mainly composed of iron. ... The reversal process is not literally 'periodic' as it is on the sun, whose magnetic field reversesevery 11 years

Inner Core Rotation

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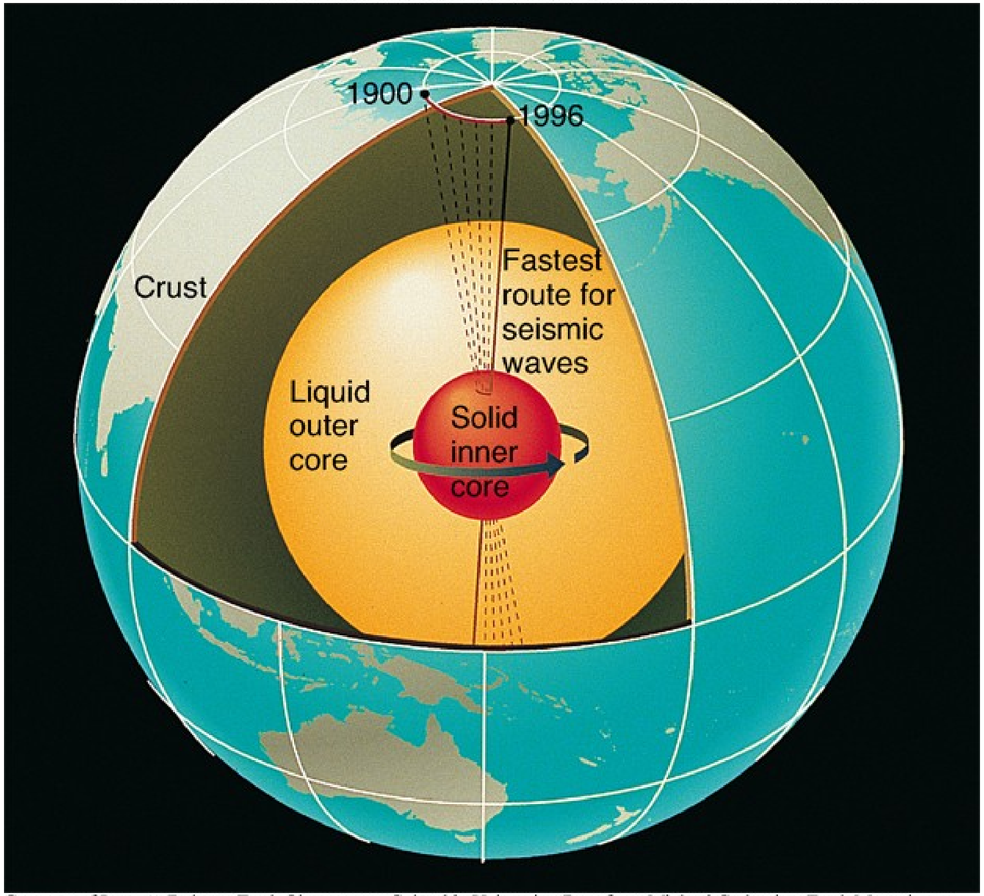

Courtesy of Lamont-Doherty Earth Observatory, Columbia University. Data from Michael Carlowicz, Earth Magazine, p.

Song and Richards (Columbia U.) later confirmed the rotation rate of the inner core to be 1°/year faster than the Earth's rotation.

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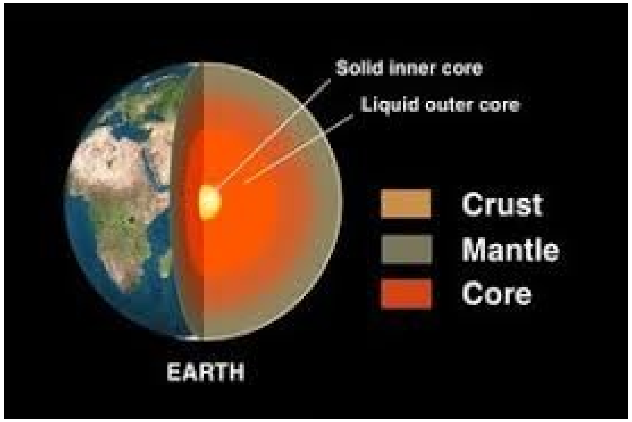
Earth has multiple layers: the crust, the mantle, the liquid**outer core** and the solid **inner core**. The Earth's magnetic field controls the direction and speed at which Earth's **inner**and **outer** cores spin, even though they move in opposite directions, new research suggests.Sep 19, 2013



What causes the Earth's inner core to spin?

"The magnetic field pushes eastwards on the **inner core**, causing it to **spin** faster than the **Earth**, but it also pushes in the opposite direction in the liquid **outer core**, which **creates** a westward motion." The solid iron **inner core** is about the size of the Moon.Sep 16, 2013

How does the inner core of the earth move?

The **core** consists of a solid **inner core** and a fluid outer **core**. The fluid contains iron, which, as it **moves**, generates the Earth's magnetic field. The crust and upper mantle form the lithosphere, which is broken up into several plates that float on top of the hot molten mantle below.Aug 25, 2005

How do the inner core and outer core of the earth compare to each other?

The **outer core** of the **Earth** is a fluid layer about 2,400 km (1,500 mi) thick and composed of mostly iron and nickel that lies above **Earth's** solid **inner core** and below its mantle. Its **outer** boundary lies 2,890 km (1,800 mi) beneath **Earth's**surface. ... Unlike the **inner core**, the **outer core** is liquid