EES 1000
Chapter 2

Earth’s Interior and Geophysical Properties

Introduction

- What do geologists know about earth's interior?
- How do they know it?

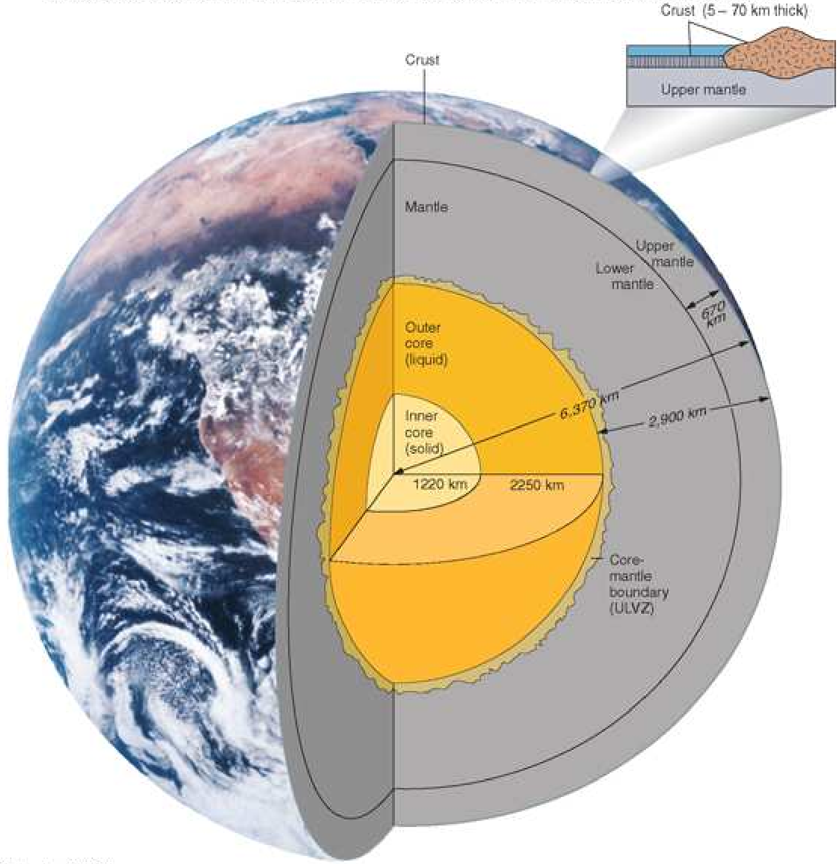


Photo by NASA

Introduction

- 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

Seismic Waves

- ***Seismic waves*** are generated when the earth shakes..

    - Earthquakes
    - Nuclear Explosions

Types of Seismic Waves

Energy released due to earthquake or nuclear explosion.

You can think of these waves by picturing the ripples created when a stone is thrown into a puddle or lake.

The first set of waves are called **P-waves** or primary waves. The second ones are called **S-waves** or secondary waves.

P- Waves

Primary waves (**P-waves**) travel the fastest, at an average speed of 4.5 km/sec.

They can move through solid rock and fluids, like water or the liquid core layers of the earth.

P-waves are the first waves to reach the Earth's surface after an earthquake.

S- Waves

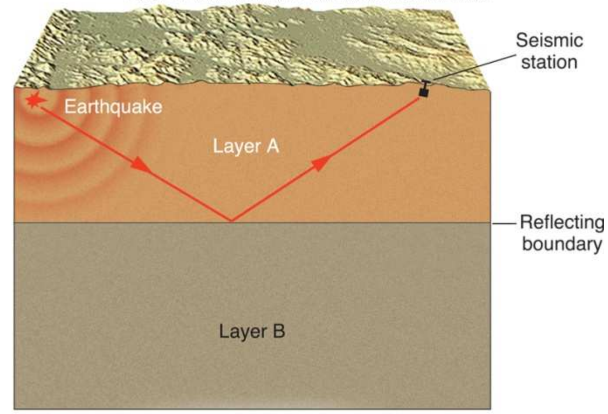
Secondary waves (**S-waves**) travel slower than primary waves.

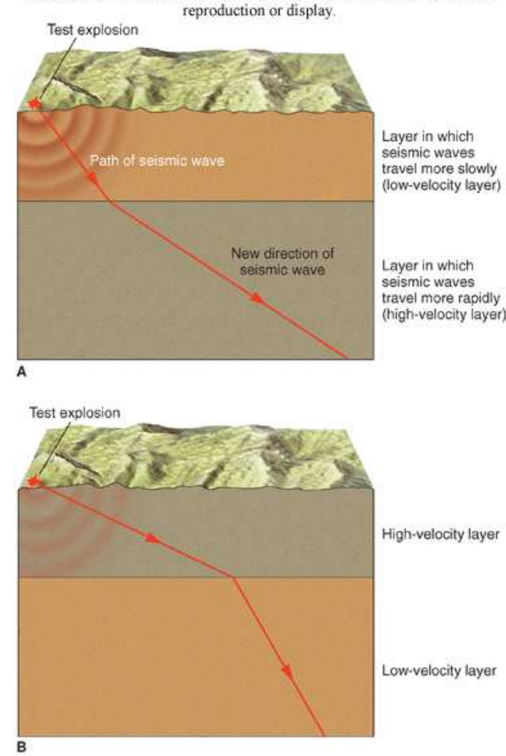
Their average speed is 2.4 km/sec.

Unlike the P-waves, S-waves cannot travel through water or the liquid rock of the Earth's core layer.

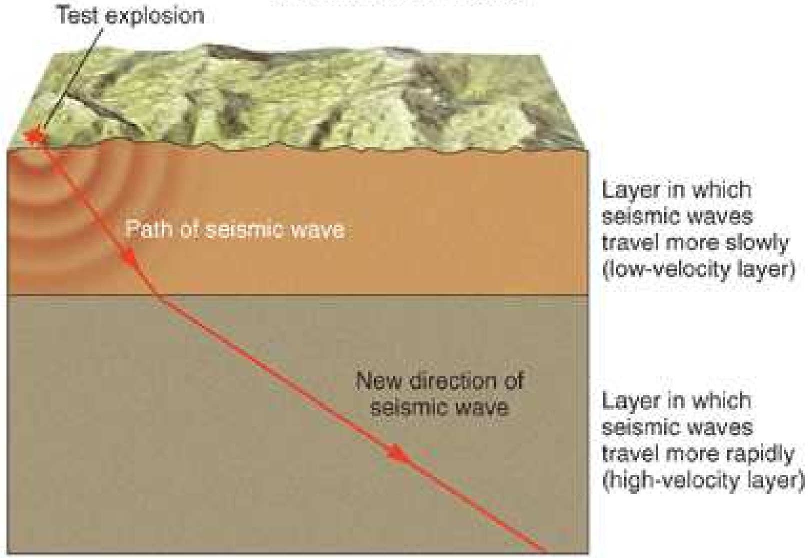
Evidence from Seismic Waves

- ***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





Evidence from Seismic Waves



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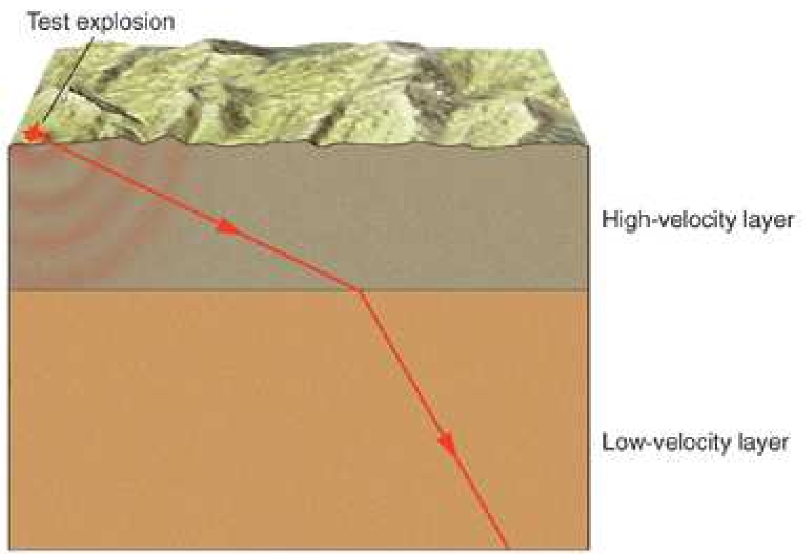

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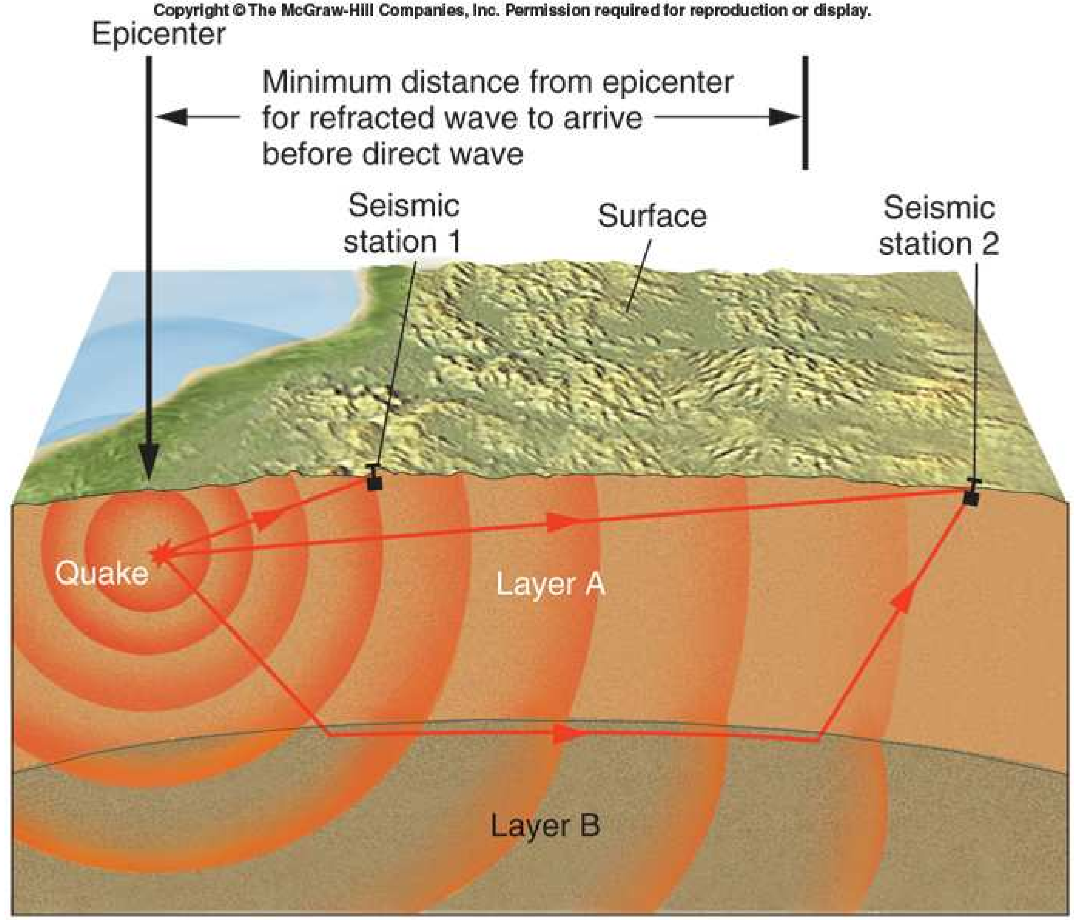


Earth's Internal Structure

- *Seismic waves* have been used to determine the three main zones within the Earth: the *crust*, *mantle* and *core*
- The ***crust*** is the outer layer of rock that forms a thin skin on Earth's surface
- The ***mantle*** is a thick shell of dense rock that separates the crust above from the core below
- The ***core*** is the metallic central zone of the Earth

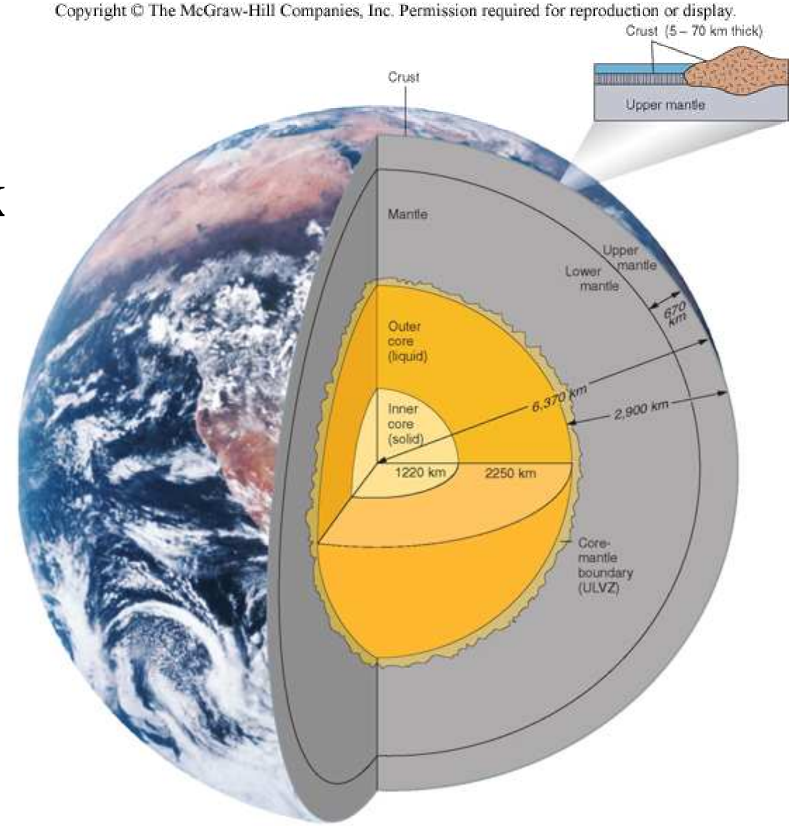
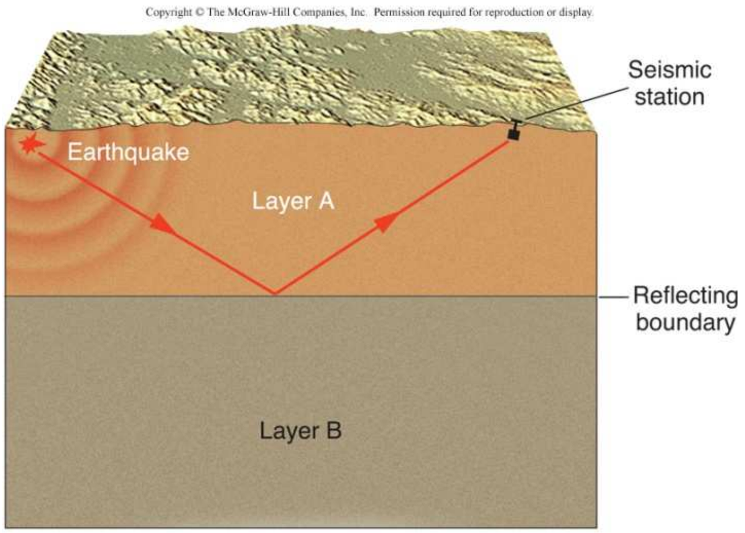
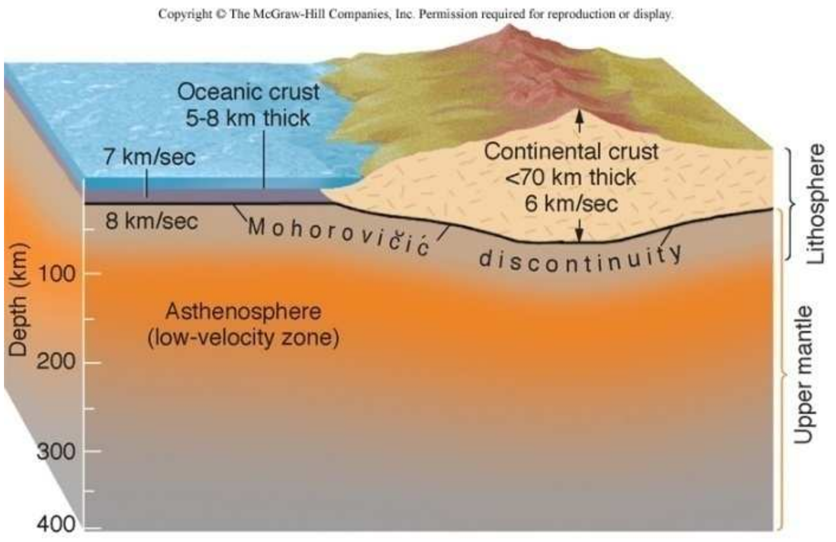


Photo by NASA

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*** *(rocks high in magnesium and iron)*, composed primarily of basalt and gabbro
- Continental crust is ***felsic*** *(rocks high in feldspar and silicon)*, , with an average composition similar to granite



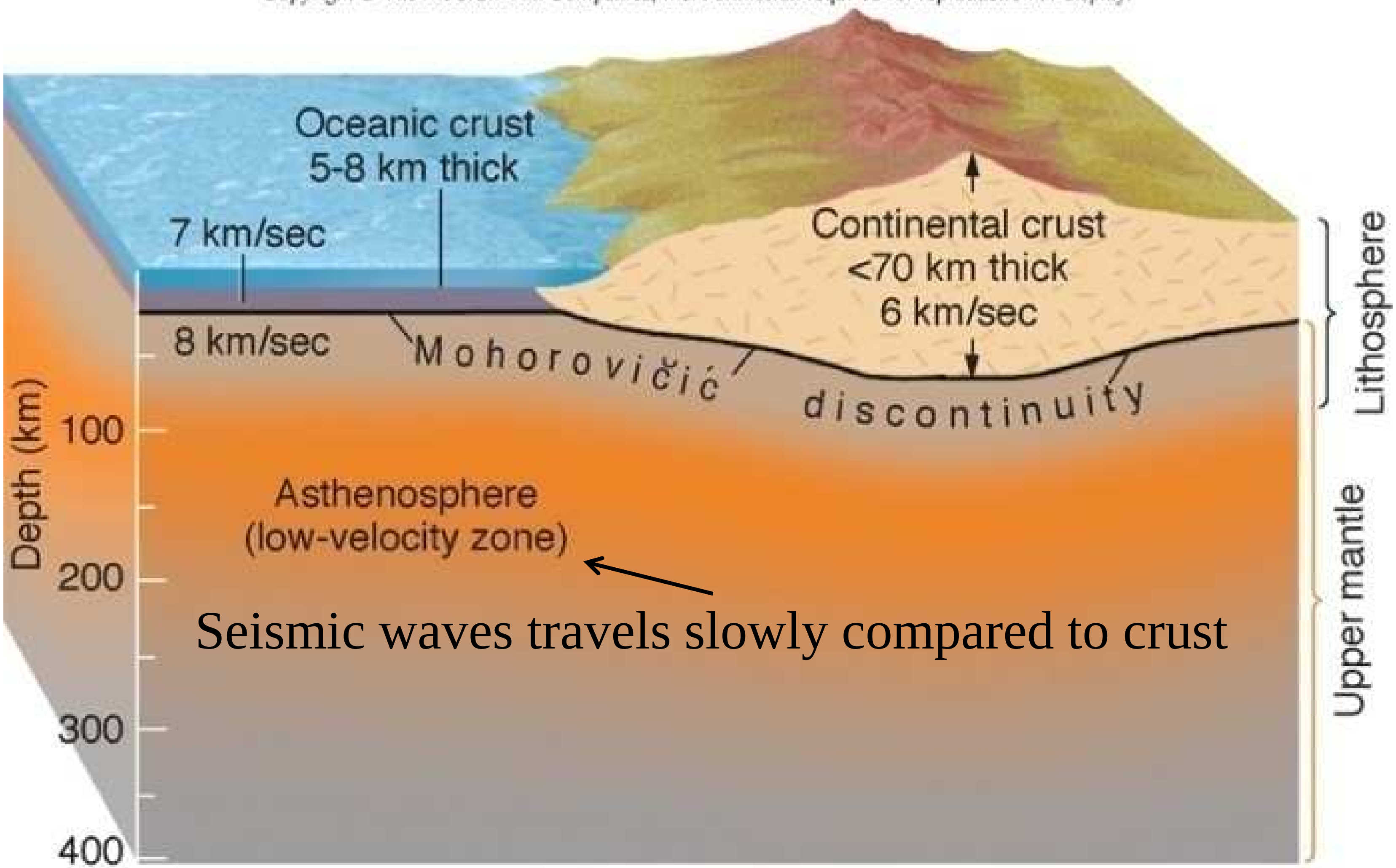


The Crust

TABLE 2.1 Characteristics of Oceanic Crust and Continental Crust

	Oceanic Crust	Continental Crust
Average thickness	7 km	20 to 70 km (thickest under mountains)
Seismic P-wave velocity	7 km/second	6 km/second (higher in lower crust)
Density	3.0 gm/cm^3	2.7 gm/cm^3
Probable composition	Basalt underlain by gabbro	Granite, other plutonic rocks, schist, gneiss (with sedimentary rock cover)

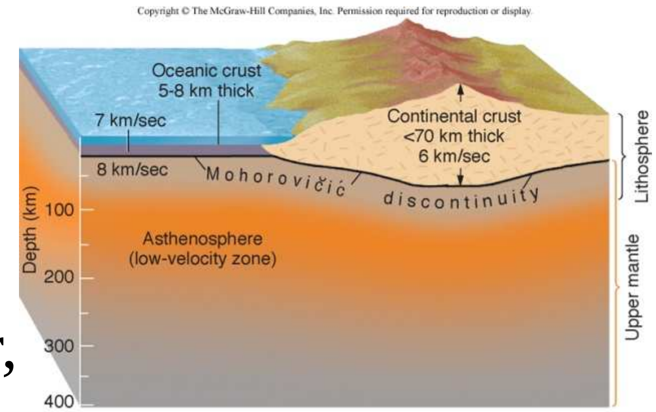
The "MOHO"

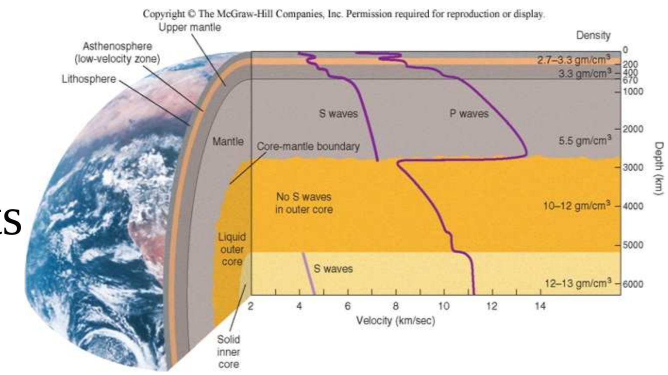


Seismic waves travels slowly compared to crust

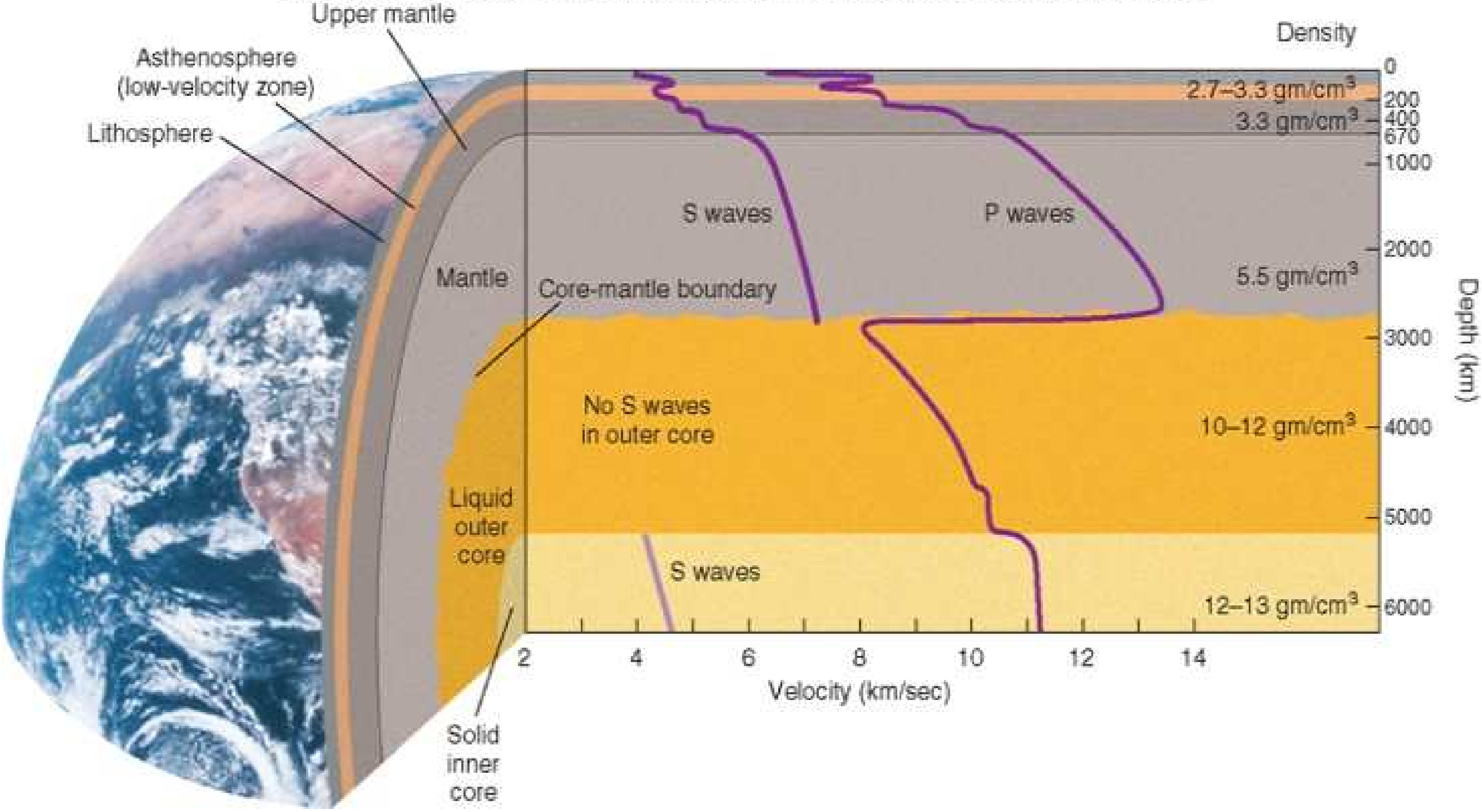
The Mantle

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



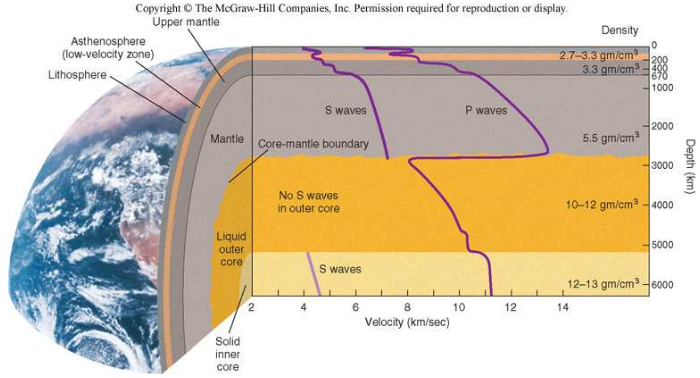


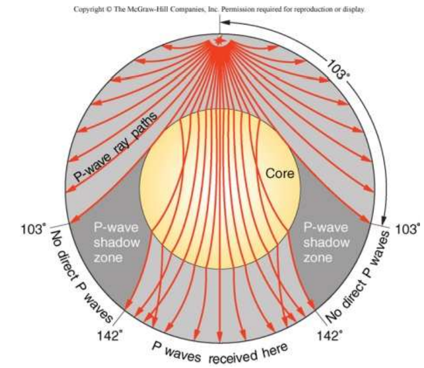
The Mantle

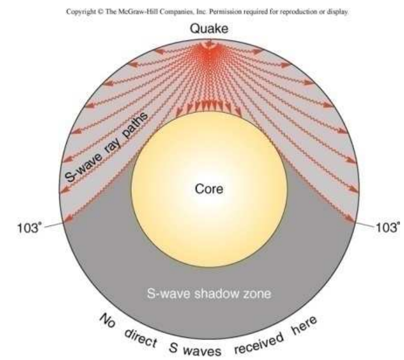

Upper mantle
Asthenosphere
(low-velocity zone)
Lithosphere
Mantle
Core-mantle boundary
Liquid
outer
core
Solid
inner
core
S waves
P waves
No S waves
in outer core
S waves
Density
2.7–3.3 gm/cm³
3.3 gm/cm³
5.5 gm/cm³
10–12 gm/cm³
12–13 gm/cm³
0
200
400
670
1000
2000
3000
4000
5000
6000
Depth (km)
2
4
6
8
10
12
14
Velocity (km/sec)

The Core

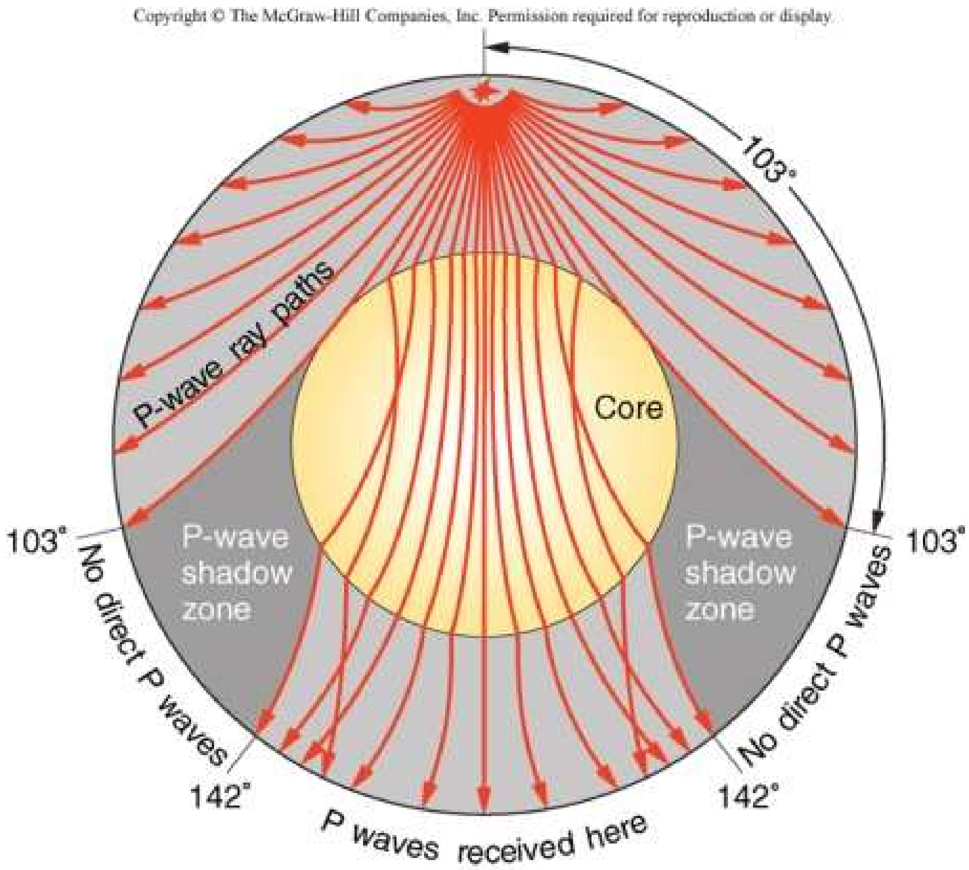
- *Seismic wave* studies have provided primary evidence for existence and nature of Earth's core
- Specific areas on the opposite side of the Earth from large earthquakes do not receive seismic waves, resulting in *seismic shadow zones*
- *P-wave shadow zone* (103°-142° from epicenter) explained by refraction of waves encountering core-mantle boundary
- *S-wave shadow zone* (≥103° from epicenter) suggests outer core is a liquid
- Careful observations of *P-wave* refraction patterns indicate inner core is solid







The Core



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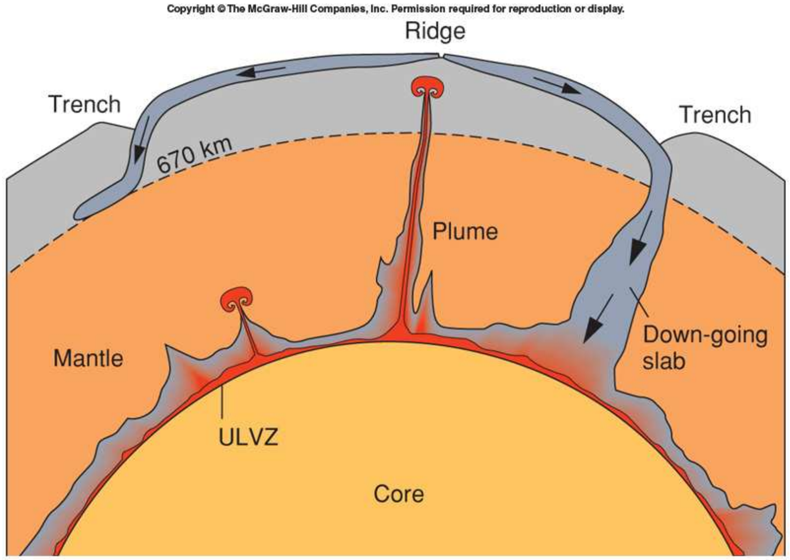
103°
P-wave ray paths
Core
P-wave shadow zone
P-wave shadow zone
103°
103°
No direct P waves
No direct P waves
142°
142°
P waves received here



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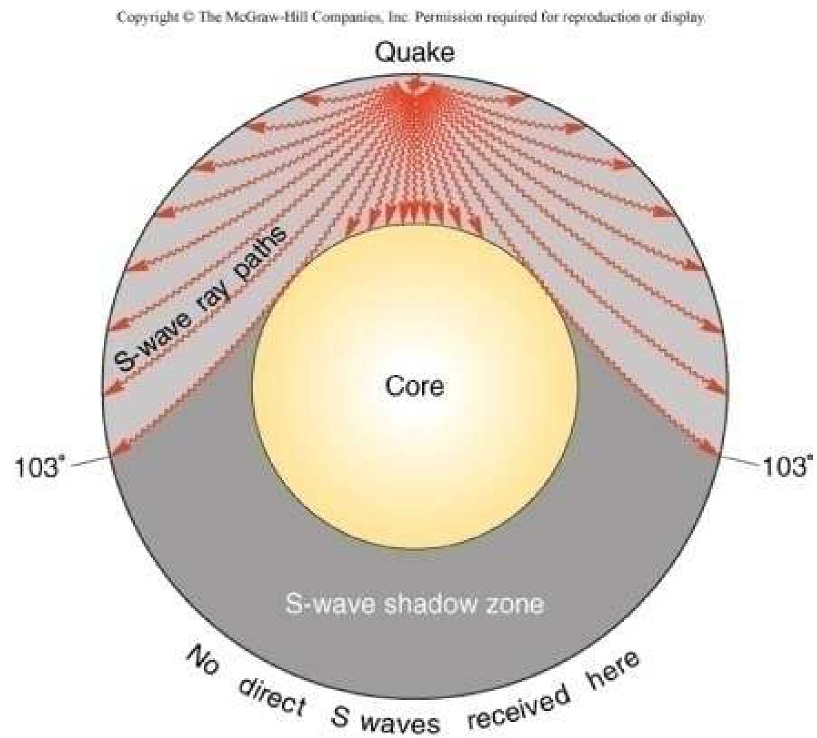
Ridge
Trench
Trench
670 km
Plume
Mantle
Down-going slab
ULVZ
Core



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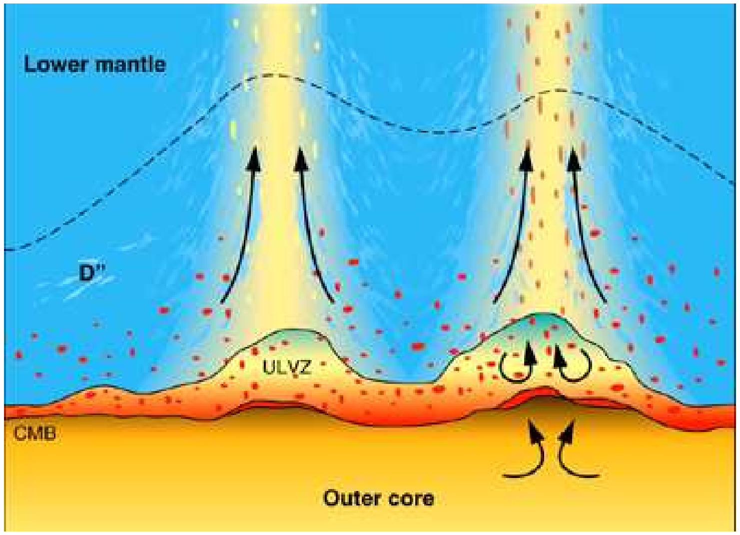
Quake
S-wave ray paths
Core
103°
103°
S-wave shadow zone
No direct S waves received here

Shadow Zone Animation

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 in this seismic wave *ultra-low-velocity zone (ULVZ)*



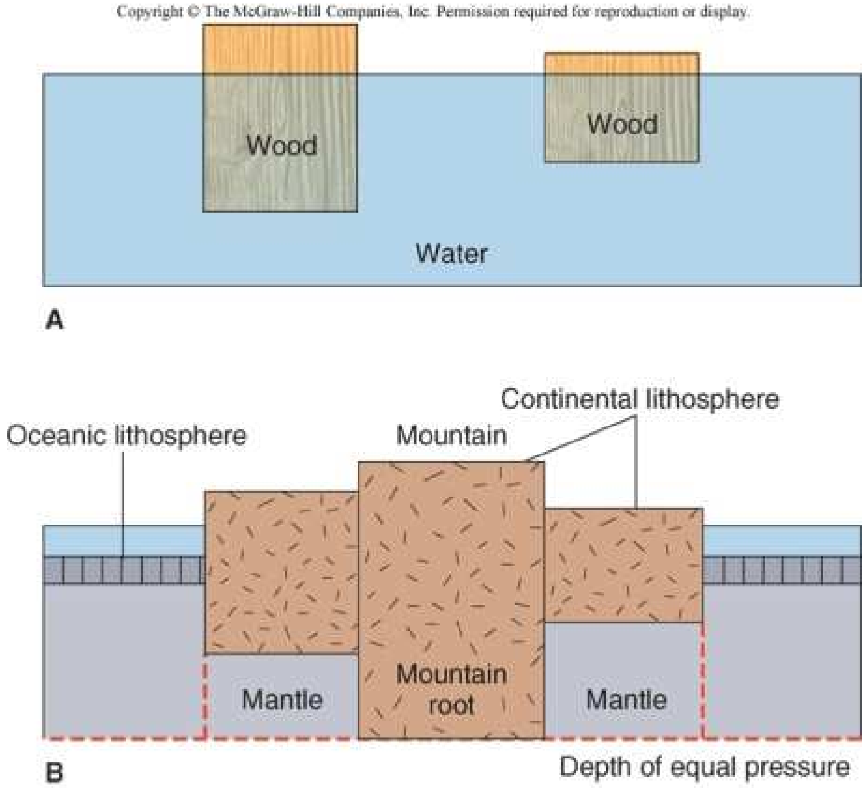
Seismic Waves and Earth's Interior

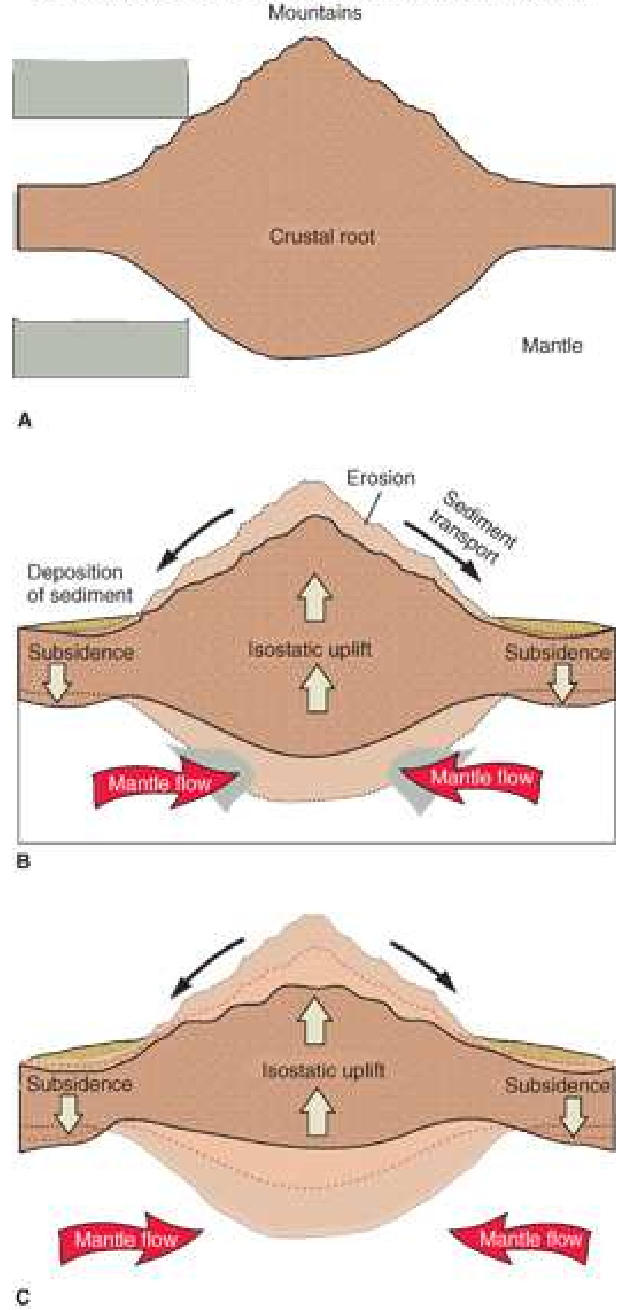
Depth	Density	Layer	P wave Velocity	S wave Velocity
0-100km	2.7-3.0 gm/cm3	Lithosphere	7-9km/sec	4-5km/sec
100-200km	2.7-3.3 gm/cm3	Asthenosphere	6km/sec	4km/sec
200-670km	3.3gm/cm3	Upper Mantle	11km/sec	7km/sec
670-2800km	5.5gm/cm3	Mantle	14km/sec	7.5km/sec
2800-5200km	10-12 gm/cm3	Outer Core	10km/sec	-
5200-6200km	12-13gm/cm3	Inner Core	11km/sec	4.5km/sec

Isostasy

Isostasy **-** equilibrium of adjacent blocks of brittle crust “floating” on upper mantle

– Thicker blocks of lower density crust have deeper *“roots”* and float higher (as mountains)

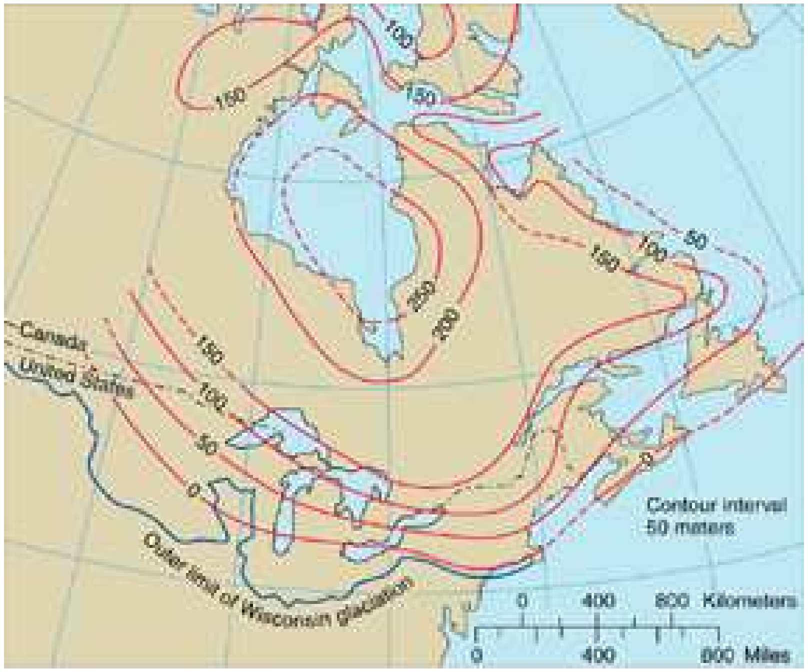


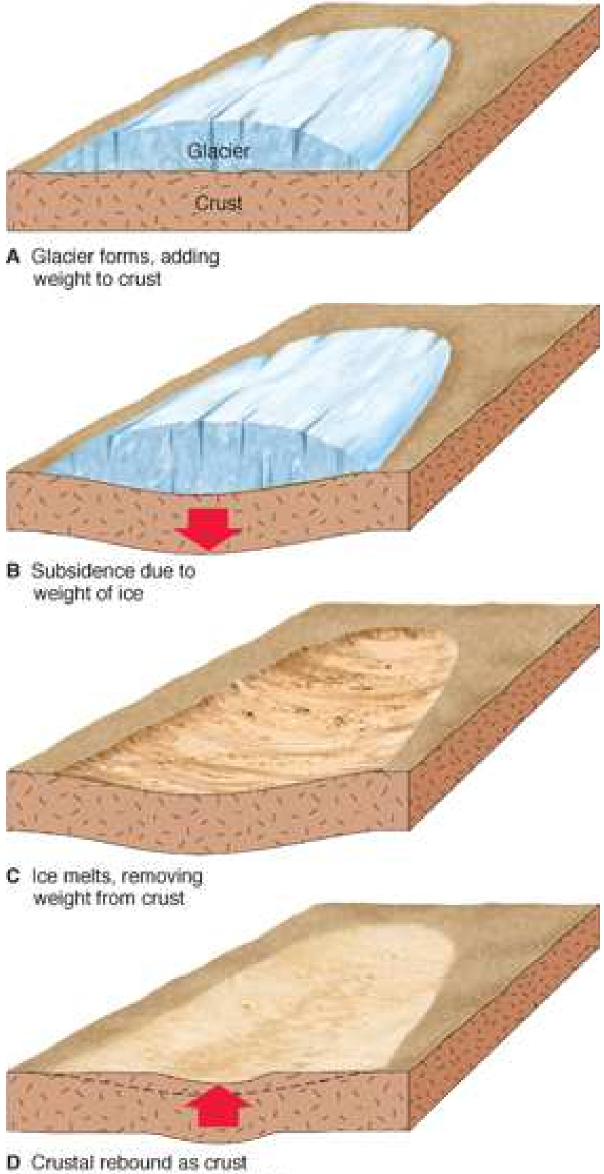


Isostasy

Isostatic adjustment - rising or sinking of crustal blocks to achieve isostatic balance

- Crust will rise when large mass is rapidly removed from the surface, as at end of ice ages
- Rise of crust after ice sheet removal is called ***crustal rebound***
  - Rebound still occurring in northern Canada and northern Europe





A Glacier forms, adding weight to crust

B Subsidence due to weight of ice

C Ice melts, removing weight from crust

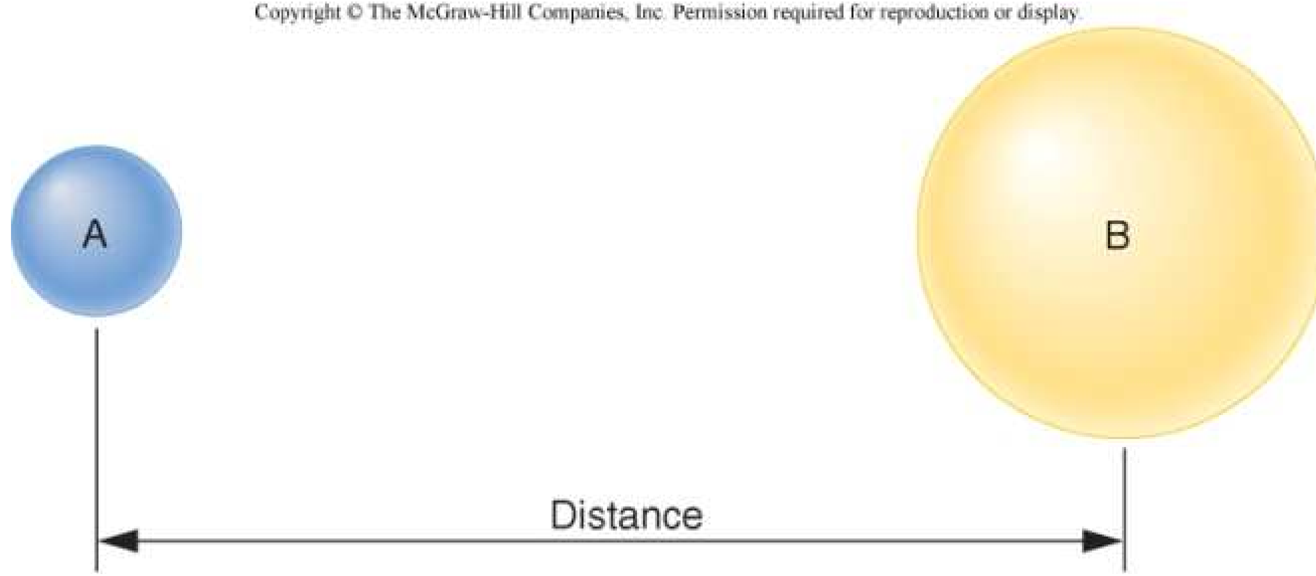
D Crustal rebound as crust rises toward original position

Isostasy and Rebound Animation

Gravity Measurements

Newton's Law of Gravitation:

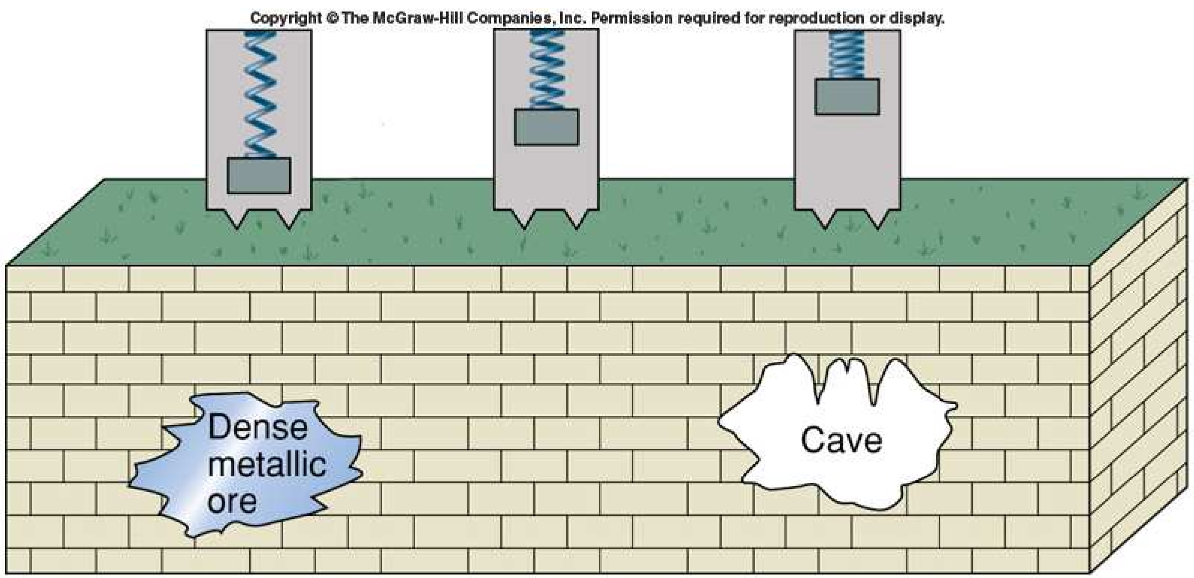
Gravitational force between two objects determined by their *masses* and the *distance* between them



$$\text{Force} = \text{Constant}\left(\frac{\text{mass}_A \times \text{mass}_B}{\text{distance}^2}\right)$$

Gravity Measurements

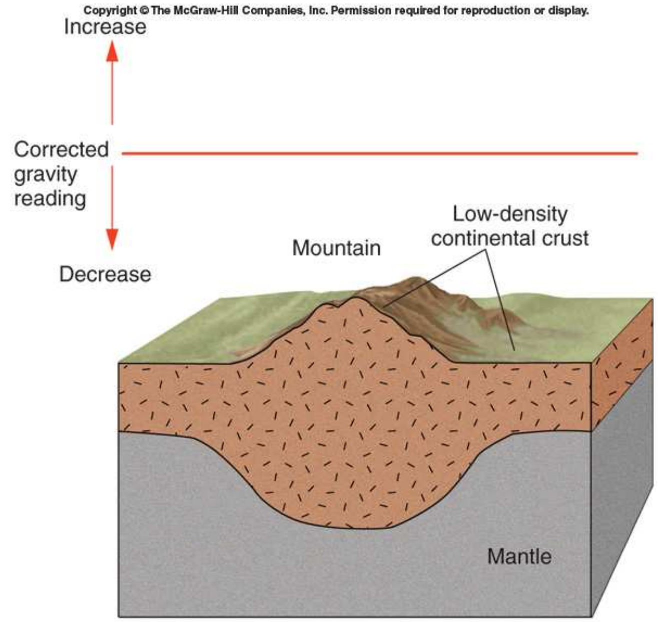
- ***Gravity meters*** **-** detect tiny changes in gravity at Earth's surface related to total mass beneath any given point
  - ***one use*** of the gravity meter is to explore for local variations in rock density (density = mass/volume).



Dense rock such as metal ores and ultramafic rock pull strongly on the mass inside the meter

Gravity Measurements

- ***Another use of a gravity meter is to discover whether regions are in isostatic equilibrium.***
  - A gravity reading higher than normal regional gravity (***positive gravity anomaly***) and lower than normal regional gravity (***negative gravity anomaly***)



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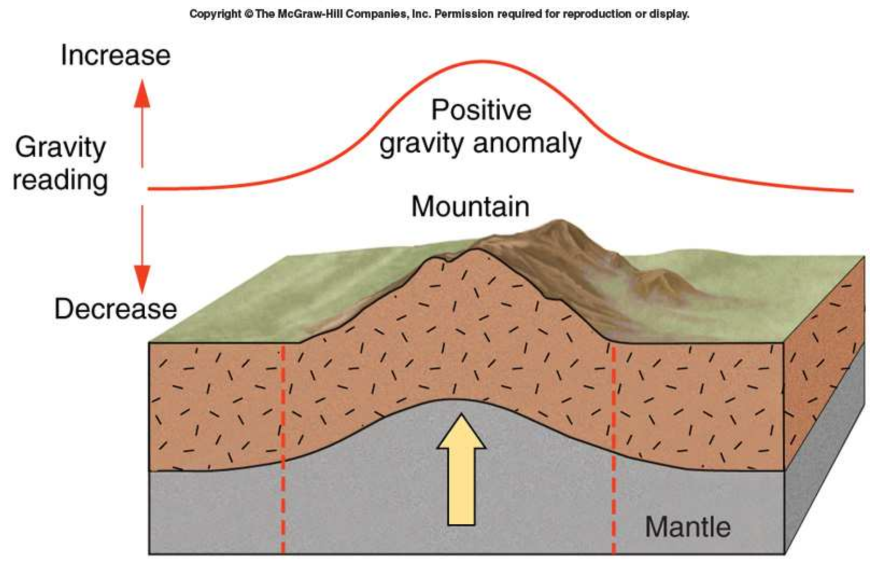

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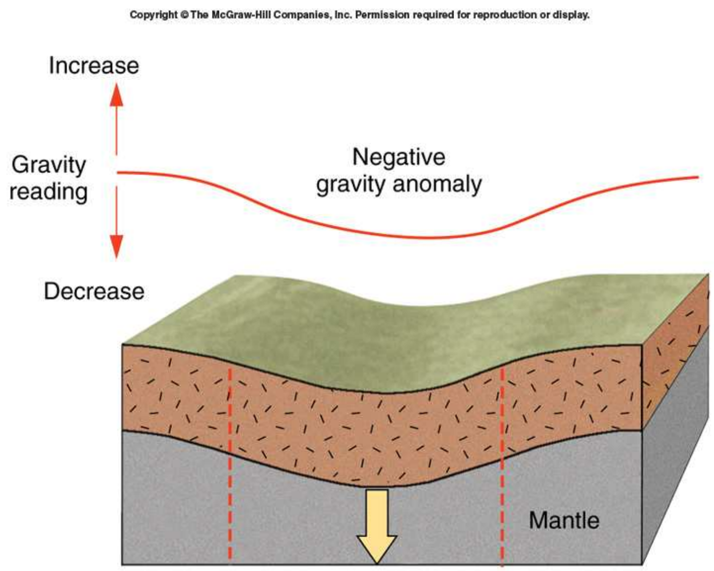
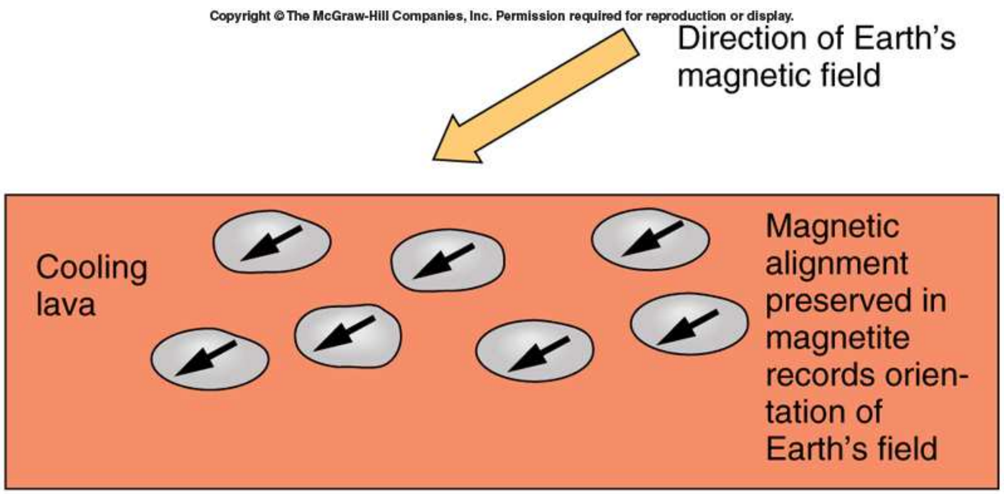


C

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



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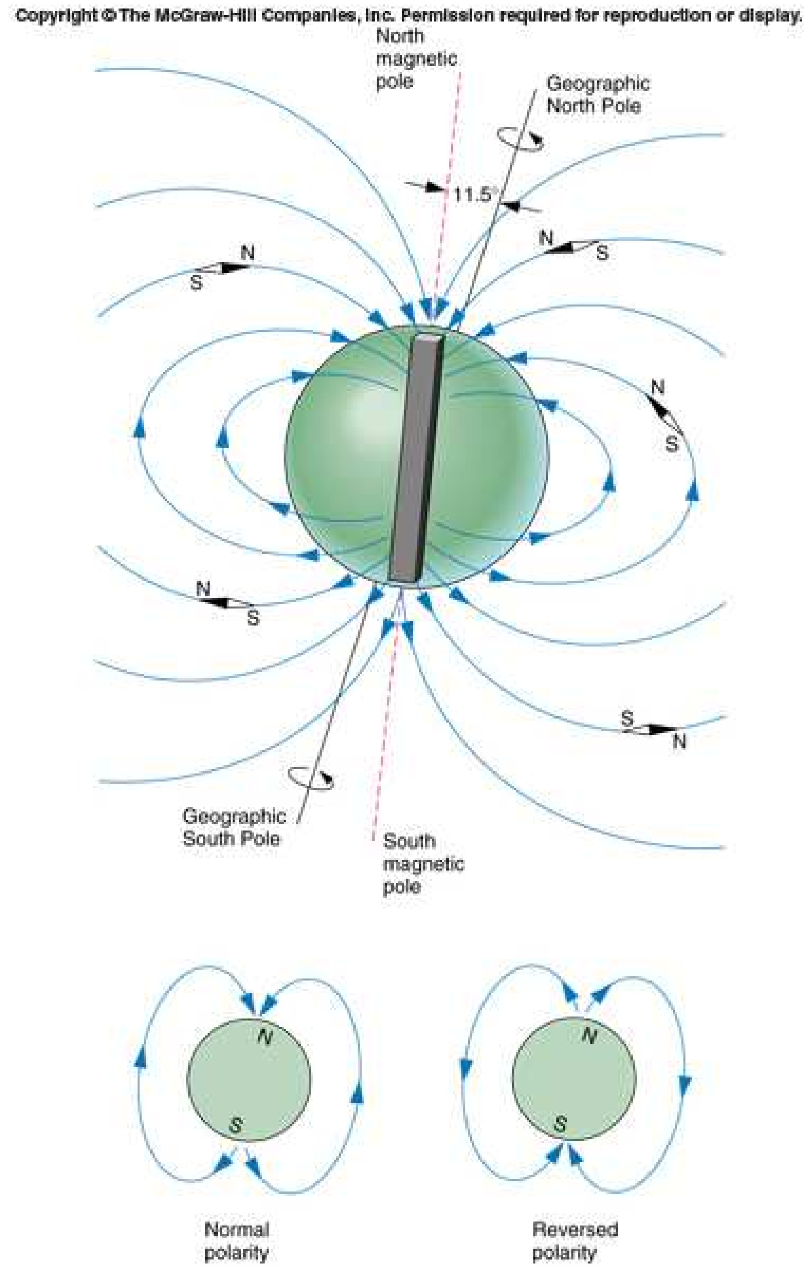
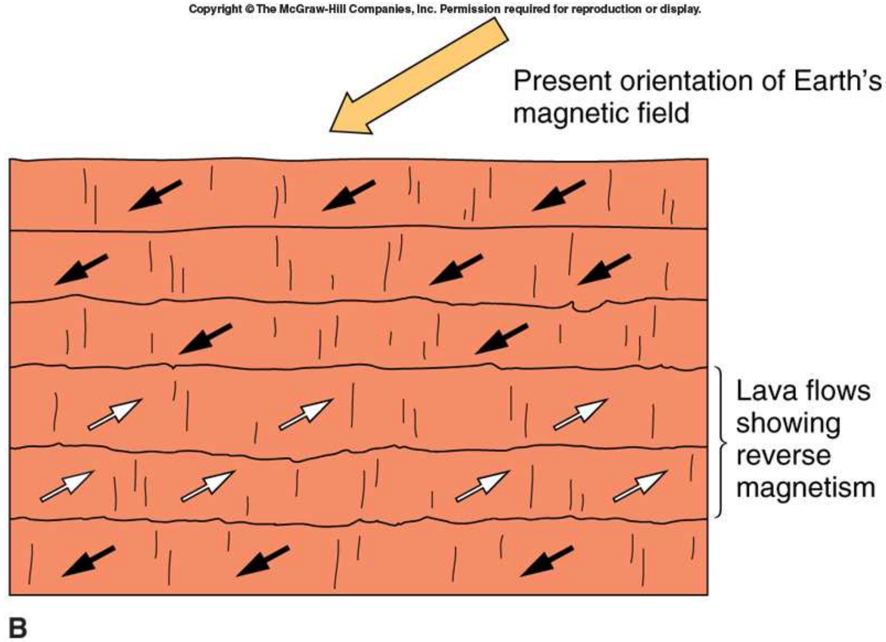
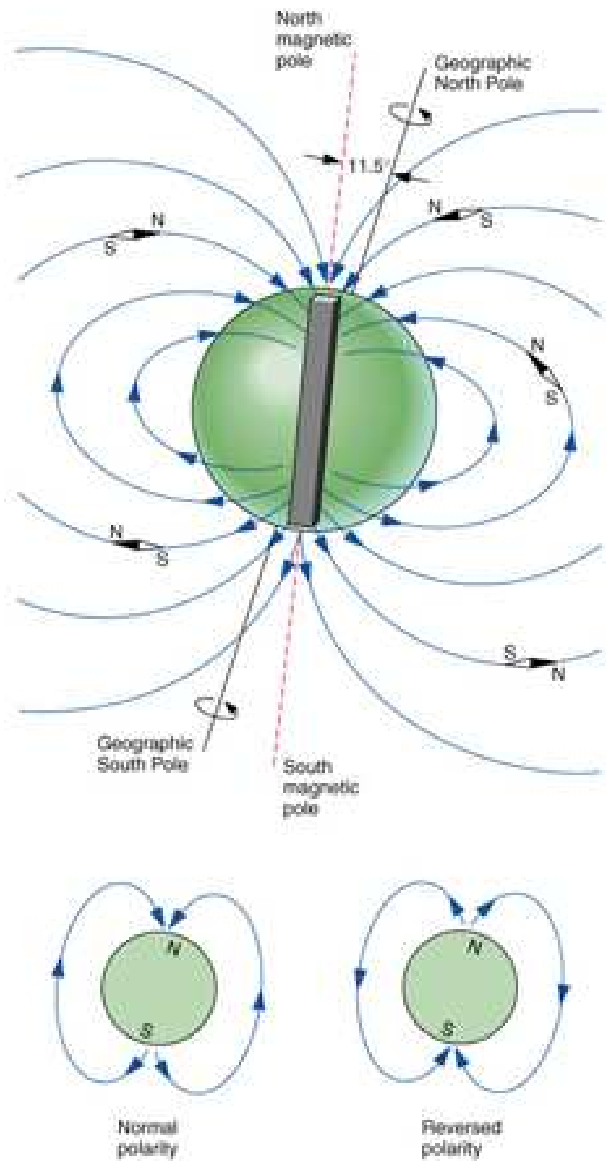


Earth's Magnetic Field

- ***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



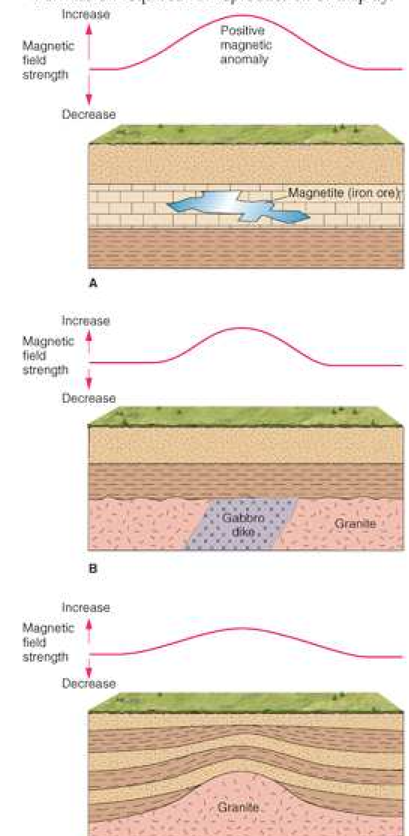


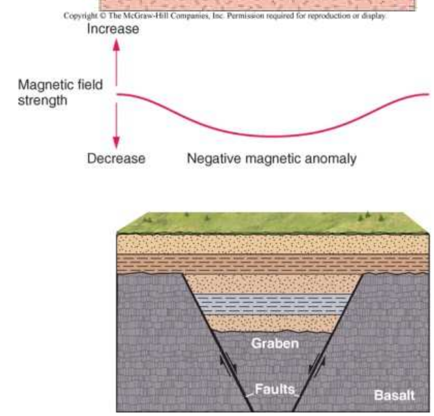
Magnetic Reversals

- Occur approximately every 700,000 years
- Not at constant time intervals
- Last reversal to “normal polarity” occurred 780,000 years ago
- Fast geologically but slow on human scale

Magnetic Anomalies

- Local increases or decreases in the Earth's magnetic field strength are known as ***magnetic anomalies***
  - Positive and negative magnetic anomalies represent larger and smaller than average local magnetic field strengths, respectively
- ***Magnetometers*** are used to measure local magnetic field strength
  - Used as metal detectors in airports
  - Can detect metallic ore deposits, igneous rocks (positive anomalies), and thick layers of non-magnetic sediments (negative anomalies) beneath Earth's surface

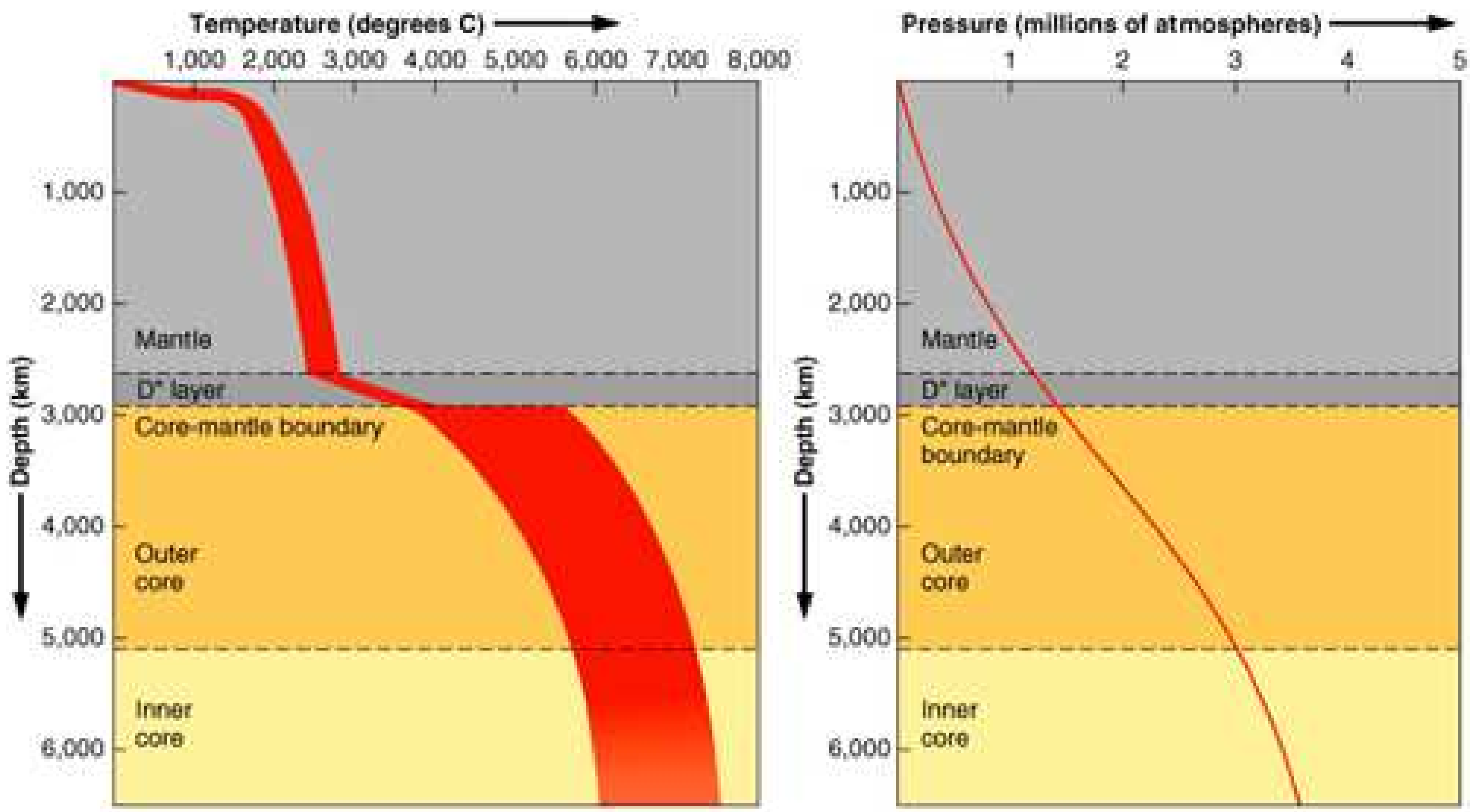




Heat Within the Earth

Geothermal gradient **-** temperature increase with depth into the Earth

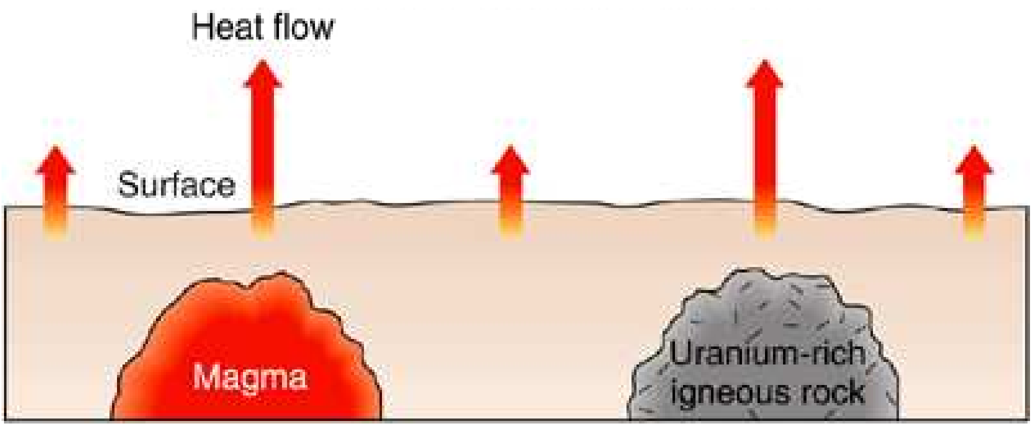
- Tapers off sharply beneath lithosphere
- Due to steady pressure increase with depth, increased temperatures produce little melt (mostly within asthenosphere) except in the outer core

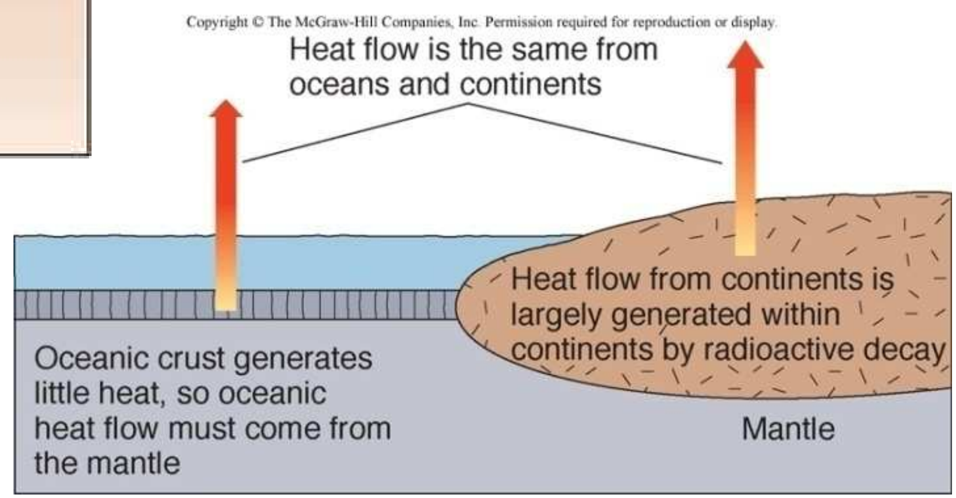


Heat Within the Earth

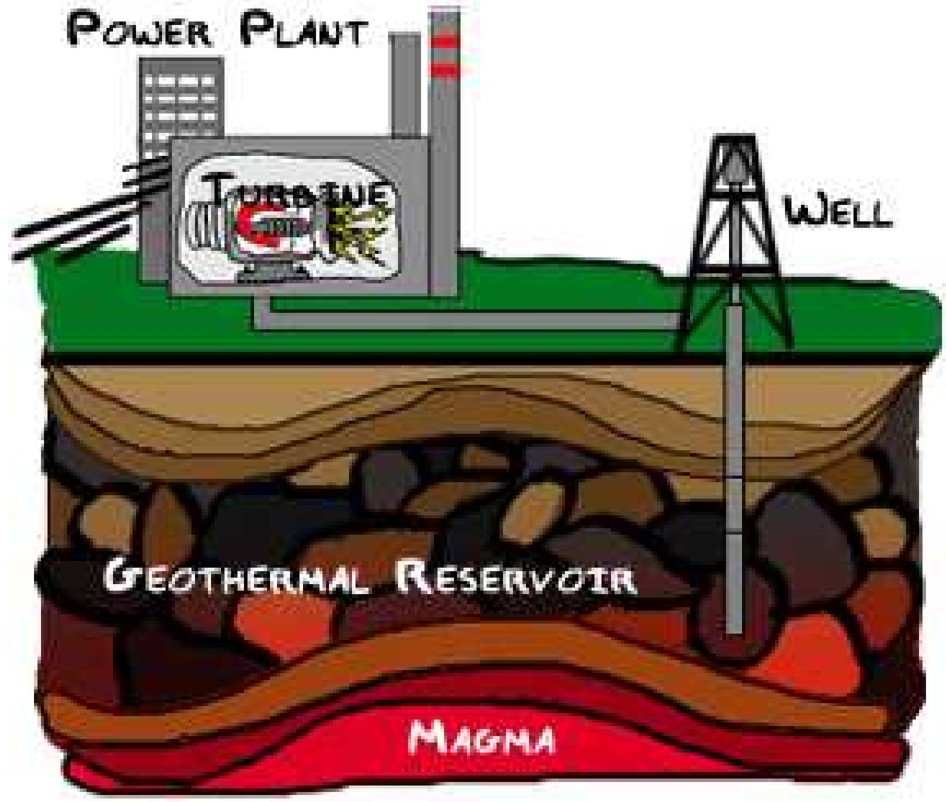
Heat flow **-** the gradual loss of heat through Earth's surface

- Major heat sources include original heat (from accretion and compression as Earth formed) and radioactive decay
- Locally higher where magma is near surface
- Same magnitude, but with different sources, in the oceanic (from mantle) and continental crust (radioactive decay within the crust)





Geothermal Energy



Alternative Energy!

- Next Class - Chapter 3: The Sea Floor