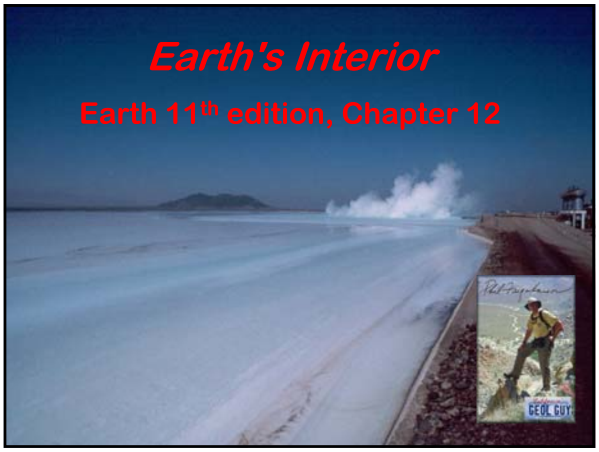
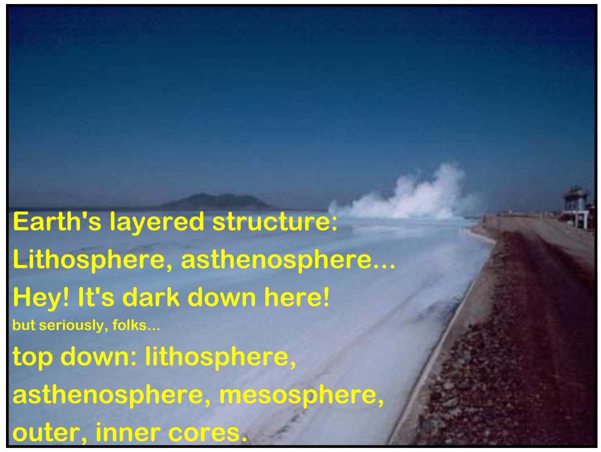
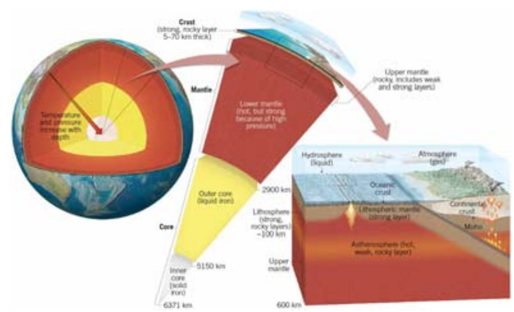




Earth's Internal Structure

- Earth's interior can be divided into three major layers defined by chemical composition
  - Crust, mantle, core
  - These layers are further divided into zones based on physical properties

Earth's Layered Structure



Earth's Internal Structure

- Gravity and Layered Planets
  - The densest material (iron) sinks to the center of the planet
  - The least dense material makes up the outer layers of the planets

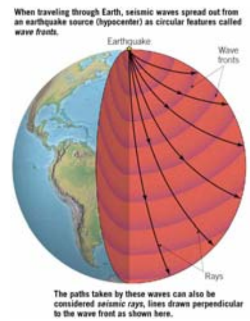
Earth's Internal Structure

- Mineral and Phase Changes
  - The density of rocks increases toward the center of the planet
    - Upper mantle rocks have a density of 3.3 grams per cubic centimeter
    - The same rocks in the lower mantle have a density of 5.6 grams per cubic centimeter
    - The lower mantle rocks undergo a mineral phase change as the minerals are compressed under higher pressures

Probing Earth's Interior

- "Seeing" Seismic Waves
  - Most of our knowledge of Earth's interior comes from the study of earthquake waves
  - Seismic velocities
    - Travel times of P (compressional) and S (shear) waves through Earth vary depending on the properties of the materials
      - Seismic waves travel fastest in stiff (rigid) rocks
      - Seismic wave velocities also vary based on composition of the rocks

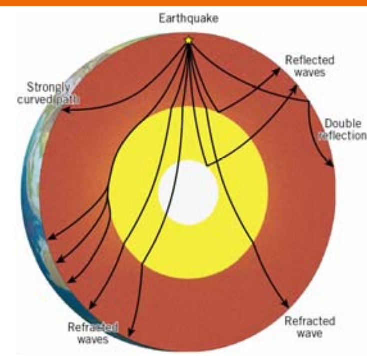
Seismic Waves Provide a Way to "See" into Our Planet



Probing Earth's Interior

- "Seeing" Seismic Waves
  - Interactions between seismic waves and Earth's layers
    - Seismic waves reflect and refract as they pass through the different layers of Earth

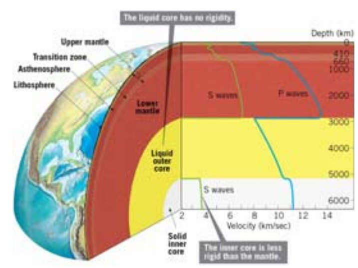
Possible Paths That Seismic Rays Follow Through Earth



Earth's Layers

- Studying seismic-wave velocities gives seismologists a layer-by-layer understanding of Earth's composition

Average Velocities of P and S Waves at Each Depth



Earth's Layers

- Earth's Crust
  - Oceanic crust
    - Forms at mid-ocean ridges
    - Averages 7 kilometers thick
    - Composed of basalt and gabbro
    - Average density of 3.0 g/cm^3

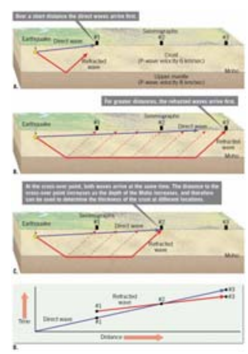
Earth's Layers

- Earth's Crust
  - Continental crust
    - Heterogeneous structure and composition
    - Averages 40 kilometers thick
      - Thickest (70 kilometers) at mountains like the Himalayas
      - Thinnest (20 kilometers) in the Basin and Range region
    - Average density of 2.7 g/cm^3

Earth's Layers

- Earth's Crust
  - Discovering the boundaries: The Moho
    - The Moho is the boundary between the crust and the mantle
    - P wave velocities abruptly increase at the Moho
      - Seismic waves refract as they cross the Moho

Determining the Depth of the Moho



Earth's Layers

- Earth's Mantle
  - Over 82 percent of Earth's volume is in the mantle, which is the layer between the crust and the core
  - Based on observations of seismic waves, the mantle is a solid rocky layer

Earth's Layers

- Earth's Mantle
  - The upper mantle extends from the Moho to 660 kilometers deep
    - Composed of peridotite, an iron and magnesium rich rock composed of olivine and pyroxene
    - The lithospheric mantle is the uppermost part of the mantle and extends down to 200 kilometers
      - This layer plus the crust make up the rigid lithosphere
    - The asthenosphere is a weak layer beneath the lithospheric mantle

Earth's Layers

- Earth's Mantle
  - The upper mantle extends from the Moho to 660 kilometers deep
    - The lowest portion of the upper mantle is the transition zone, between 410 and 660 kilometers
      - Due to pressure increase, olivine converts to spinel
      - Capable of holding large amounts of water

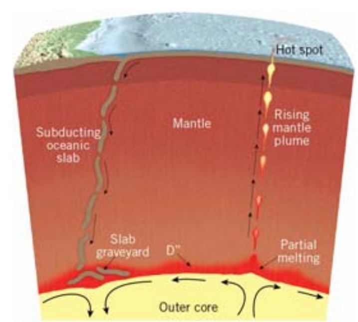
Earth's Layers

- Earth's Mantle
  - The lower mantle extends from the transition zone to the liquid core (2900 kilometers deep)
    - Earth's largest layer, occupying 56 percent of Earth's volume
    - Olivine and pyroxene are converted into perovskite

Earth's Layers

- Earth's Mantle
  - The D" layer is the boundary between the rocky lower mantle and the liquid outer core
    - Cool regions are thought to be the remnants of subducted lithospheric plates
    - Hot regions are though to be the start of deep mantle plumes

The Variable and Unusual D Layer Lies at the Base of the Mantle



Earth's Layers

- Earth's Mantle
  - Discovering boundaries: The core-mantle boundary
    - Beyond 100 degrees from an epicenter, P and S waves are absent or weak
      - S waves cannot travel through liquid
      - P waves are considerably refracted through liquid

Earth's Layers

- Earth's Core
  - The outer core is liquid, based on the absence of S waves traveling through the core
    - The outer core has a density of 9.9 g/cm^3
    - Composed mostly of iron with some nickel
    - 15 percent of the outer core consists of lighter elements
    - The core (outer core and inner core) accounts for 1/6 of Earth's volume but 1/3 of its mass because it is so dense

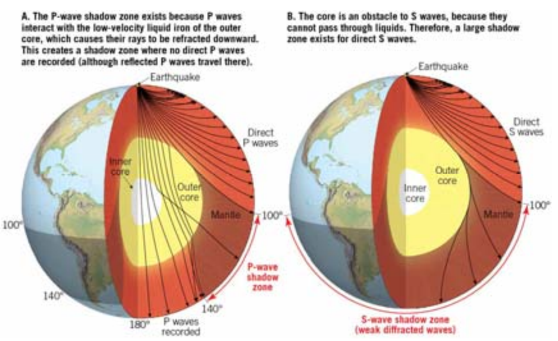
Earth's Layers

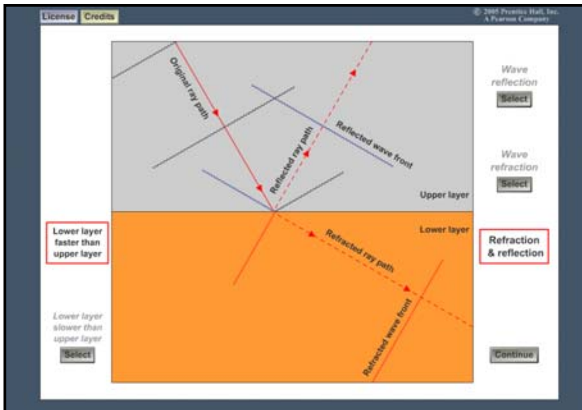
- Earth's Core
  - The inner core is a solid, dense sphere
    - Has a density of 13 g/cm^3
    - Is growing as Earth cools at the expense of the outer core
    - Rotates faster than the crust and mantle

Earth's Layers

- Earth's Core
  - Discovering boundaries: The inner core-outer core boundary
    - Some P waves are strongly refracted by a sudden increase in velocity at a boundary within Earth's core

P and S wave Shadow Zones





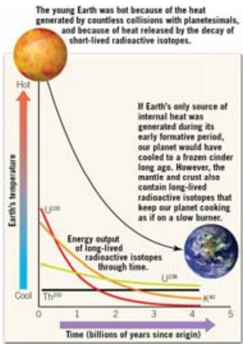
Earth's Temperature

- Heat flow from hotter regions to colder regions
  - Earth's core is 5500º C
  - Earth's surface is 0º C
  - Heat flows from the core to the surface

Earth's Temperature

- How Did Earth Get So Hot?
  - Earth has experienced two thermal stages
    - First stage lasted 50 million years when temperatures increased rapidly, caused by
      - Collision of planetesimals
      - Decay of radioactive isotopes
      - Asteroid collision that created the Moon
      - Temperatures increased
    - Second stage involves the slow cooling over the next 4.5 billion years
      - Some heat is still generated through radioactive decay in the mantle and crust

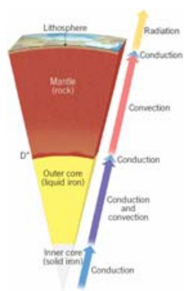
Earth's Thermal History Through Time



Earth's Temperature

- Heat Flow
  - Heat travel through Earth by conduction, convection, and radiation
    - Conduction and convection occur within Earth's interior
    - Radiation transports heat away from Earth's surface to space

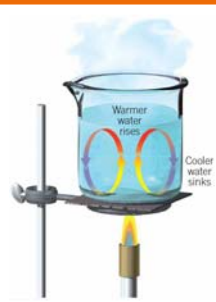
Dominant Types of Heat Transfer at Various Depths



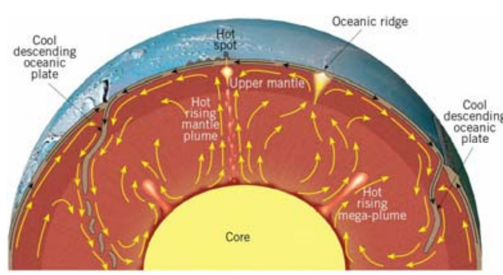
Earth's Temperature

- Heat Flow
  - Convection is the transfer of heat where hot materials replace cold material (or vice-versa)
    - Primary means of heat transfer within Earth
    - Convection cycles occur within the mantle and outer crust
      - Mantle plumes are the upward flowing arm of the cycle
    - Similar to a pot of boiling water
    - Material must flow in a convection cycle
      - Viscosity is a material's resistance to flow

Convection: Heat Transfer That Involves the Movement of a Substance



Whole-Mantle Convection



Earth’s Temperature

- Heat Flow
  - Conduction is the transfer of heat through a material
    - Through the collision of atoms or through the flow of electrons
    - Materials conduct heat at different rates
      - Metals are better than rocks at conducting heat
      - Diamonds are better than air at conducting heat
    - Conduction is not an efficient way to move heat through most of Earth
      - Most rocks are poor conductors of heat

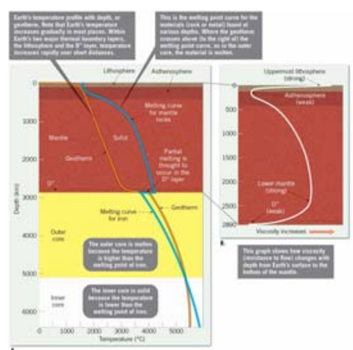
Earth’s Temperature

- Heat Flow
  - Heat flow in Earth’s interior
    - Conduction is important in the inner core
    - Convection is important in the outer core
      - Top-down, thermally driven convection
      - Crystallization of iron drives chemical convection
      - Radioactive isotopes provide additional heat to drive convection

Earth’s Temperature

- Earth’s Temperature Profile
  - The profile of Earth’s temperature at each depth is called the geothermal gradient
    - Varies within Earth’s interior
      - Crust is 30º C per kilometer of depth
      - Mantle is 0.3º C per kilometer
        - » Exception is the D” layer

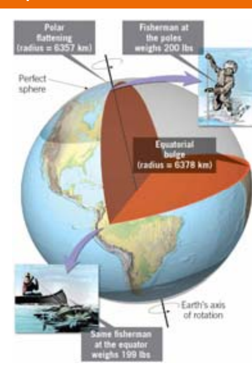
Geothermal Gradient



Earth’s Three-Dimensional Structure

- Earth’s Gravity
  - Changes at the surface are due to Earth’s rotation
    - Rotation causes a centrifugal force that is proportional to the distance from the axis of rotation
    - Earth’s shape is an oblate ellipsoid (bulges at the equator), resulting in weaker gravity at the equator

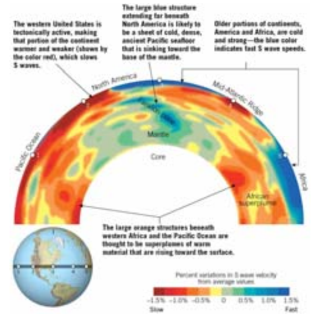
Earth: Not a Sphere but an Oblate Spheroid



Earth's Three-Dimensional Structure

- Seismic Tomography
  - Seismic tomography involves collecting data at many different seismic stations to "see" parts of Earth's interior
    - Variations in P and S wave velocities allow scientists to image subducting plates and mantle plumes

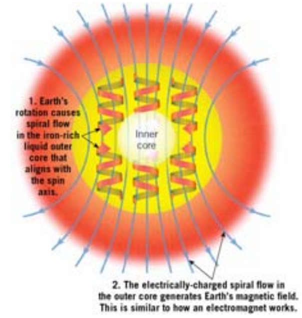
A Seismic Tomographic Slice Showing the Structure of the Mantle



Earth's Three-Dimensional Structure

- Earth's Magnetic Field
  - Produced by convection of liquid iron in the outer core
  - A geodynamo is the magnetic field caused by spiraling columns of rising fluid in the outer core
    - It is primarily dipolar
    - Patterns of convection change rapidly enough so that the magnetic field varies noticeably over our lifetimes

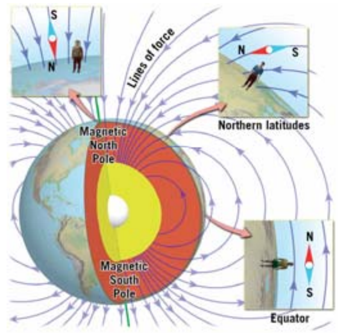
How Earth's Magnetic Field Is Generates in the Liquid, Iron-Rich Outer Core



Earth's Three-Dimensional Structure

- Earth's Magnetic Field
  - Measuring Earth's magnetic field and its changes
    - The magnetic field is measured by declination and inclination
      - Declination measures the direction of magnetic north pole with respect to the geographic north pole
      - Inclination measures the downward tilt of the magnetic lines

Inclination (or Dip) of the Magnetic Field at Different Locations



Earth's Three-Dimensional Structure

- Magnetic Field
  - Magnetic reversals
    - The magnetic field randomly reverses and north and south poles swap direction
    - Reversal takes only a few thousand years, but during that time, the magnetic field, which protects Earth from solar wind, significantly decreases

Earth's Three-Dimensional Structure

- Magnetic Field
  - Global dynamic connections
    - Example: The breakup of Pangaea
      - Breakup of Pangaea led to an increase in subduction of seafloor, leading to an increase in cold, suducted slabs at the core-mantle boundary
      - Cold slabs displaced hot rocks at the core-mantle boundary causing an increase in mantle plume activity
      - Cold slabs disrupted outer core convection and magnetic reversal activity

End of Chapter 12