



1 2  **Chapter 12 – Earth's Interior**3  **Earth's Internal Structure**

- Earth's three major interior layers can be further subdivided into zones
 - Gravity and chemical segregation established the three basic divisions
 - The densest material (iron) sinks to the center
 - The least dense material makes up the outer layers of the planets
 - In addition, the layers have small horizontal variations in mineral composition and temperature with depth
 - These differences indicate that the Earth's interior is very dynamic

4  **Earth's Layered Structure**5  **Earth's Internal Structure**



- Mineral and Phase Changes
 - The density of rocks increases toward the center of the planet due to gravity
 - Upper mantle rocks have a density of 3.3 g/cm^3
 - The same rocks in the lower mantle have a density of 5.6 g/cm^3
 - The lower mantle rocks undergo a mineral phase change as the minerals are compressed under higher pressures

6  **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











7  **Seismic Waves Provide a Way to "See" into our Planet**8  **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
 - Allow us to "see" inside the Earth
 - P and S waves travel at different velocities which also depend on the properties of the materials that transmit them
 - Faster through more rigid materials
 - S-waves cannot travel through liquids

9  **Possible Paths That Seismic Rays Follow Through Earth**10  **Possible Paths That Seismic Rays Follow Through Earth**11  **Possible Paths That Seismic Rays Follow Through Earth**12  **Earth's Layers**

- Studying seismic-wave velocities gives seismologists a layer-by-layer understanding of Earth's composition
 - When a seismic wave hits a boundary between different Earth materials some of the waves are reflected and some are refracted
 - Velocity of seismic waves increases with depth
 - By examining the behavior of a variety of rocks at the pressures corresponding to various depths, geologists have learned about the compositions of Earth's crust, mantle, and core

- 13  **Average Velocities of P and S Waves at Each Depth**
- 14  **Earth's Layers**
- Earth's Crust
 - Oceanic crust
 - Forms at mid-ocean ridges
 - Averages 7 km thick
 - Composed of basalt and gabbro
 - Average density of 3.0 g/cm^3
 - Continental crust
 - Heterogeneous structure and composition
 - Averages 40 km thick
 - Thickest (70 km) at mountains like the Himalayas
 - Thinnest (20 km) in the Basin and Range region
 - Average density of 2.7 g/cm^3
- 15  **Earth's Layers**
- Discovering the boundaries: The Moho
 - The Moho is the boundary between the crust and the mantle
 - Discovered in 1909 through jump in velocity of P waves below the base of the continents
 - P wave velocities abruptly increase at the Moho
 - Seismic waves refract as they cross the Moho
- 16  **Determining the Depth of the Moho**
- 17  **Earth's Layers**
- Earth's Mantle
 - Over 82% of Earth's volume is in the mantle, which is the layer between the crust and the core
 - Nearly 2900 km thick
 - Extends from Moho to the liquid outer core
 - Solid rocky layer composed of silicate minerals rich in iron and magnesium
 - Determined based on observations of seismic waves
- 18  **Earth's Layers**
- Earth's Mantle
 - The upper mantle extends from the Moho to 660 km 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 ranges in thickness from a few km to 200 km
 - This layer plus the crust make up the rigid lithosphere
 - The asthenosphere is a weak layer beneath the lithospheric mantle
 - The lower portion of the upper mantle ranges between 410 and 660 km depth, called the transition zone
 - Due to pressure increase, olivine converts to spinel
 - Pyroxene converts to a garnet-like structure
- 19  **Earth's Layers**
- Earth's Mantle
 - The lower mantle extends from the transition zone to the liquid core (2900 km deep)
 - Earth's largest layer, occupying 56 percent of Earth's volume
 - Olivine and pyroxene are converted into perovskite
 - 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 thought to be the start of deep mantle plumes

- 20  **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
 - Called a shadow zone
 - S waves cannot travel through liquid
 - P waves are considerably refracted through liquid
- 21  **P and S wave Shadow Zones**
- 22  **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 one-sixth of Earth's volume but one-third of its mass because it is so dense
 - Outer core is 2270 km thick
- 23  **Earth's Layers**
- Earth's Core
 - The inner core is a solid, dense sphere (all other layers are *shells*)
 - Has a density of 13 g/cm^3
 - Is growing as Earth cools at the expense of the outer core
 - Rotates faster, and moves independently of, the crust and mantle
 - Has a radius of 1216 km
 - *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
- 24  **Earth's Core**
- 25  **Earth's Temperature**
- Heat flow from hotter regions to colder regions
 - Earth's core is 5500°C
 - Earth's surface is 15°C
 - Heat flows from the core to the surface
 - Rate at which Earth is cooling can be estimated by determining the rate at which heat escapes Earth's surface
 - Heat flow is highest near mid ocean ridges
 - Heat flow is lowest the deep abyssal plains
- 26  **Earth's Temperature**
- 27  **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
- 28  **Earth's Thermal History Through Time**
- 29  **Earth's Temperature**
- Heat Flow
 - Heat travel through Earth by conduction, convection, and radiation

- Convection and conduction occur within Earth's interior
- Radiation transports heat away from Earth's surface to space

30 **Dominant Types of Heat Transfer at Various Depths**

31 **Earth's Temperature**

- 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

32 **Whole-Mantle Convection**

33 **Earth's Temperature**

- 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

34 **Earth's Temperature**

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

35 **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 30°C per kilometer of depth
 - Mantle is 0.3°C per kilometer
 - » Exception is the D" layer
 - Base of the lithosphere is roughly 1400°
 - Base of the mantle is roughly 2500°
 - Temperature at Earth's center is estimated to be 5500°

36 **Geothermal Gradient**

37 **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
 - Other variations cannot be explained by Earth's rotation:
 - » Bodies of unusually dense rock
 - » Metals, metal ores

38 **Earth: Not a Sphere but an Oblate Spheroid**

39 **Gravity Anomalies**

40 **Earth's Three-Dimensional Structure**

- Seismic Tomography
 - Seismic tomography involves collecting data at many different seismic stations to “see” parts of Earth’s interior in three dimensions
 - Three-dimensional changes in composition and density are detected with gravity measurements and can be viewed using seismology
 - Identifies regions where P and S waves travel faster or slower than average
 - Variations in P and S wave velocities allow scientists to image subducting plates and mantle plumes

41  **A Seismic Tomographic Slice Showing the Structure of the Mantle**

42  **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 electrically charged fluid in the outer core
 - It is primarily dipolar but considerably more complex
 - Patterns of convection change rapidly enough so that the magnetic field varies noticeably over our lifetimes

43  **How Earth’s Magnetic Field Is Generated in the Liquid, Iron-Rich Outer Core**

44  **How Earth’s Magnetic Field Is Generated in the Liquid, Iron-Rich Outer Core**

45  **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
 - The locations of magnetic poles change significantly over time

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

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

48  **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—to about 10% of normal
 - Evidence that convection patterns in the outer core change over relatively short time spans
 - The discovery of reversals has been extremely important to the foundation of the theory of plate tectonics

49  **Earth’s Three-Dimensional Structure**

- Magnetic Field
 - Global dynamic connections: Earth’s layers are connected by their thermally driven motions
 - Example: The break-up of Pangaea
 - Break-up of Pangaea led to an increase in subduction of sea-floor, leading to an increase in cold, subducted 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

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End of Chapter 12