Earth’s Interior and Geophysical Properties

Chapter 13
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
Indirect Study of the Earth's Interior - Geophysics

- Seismic Waves
- Gravity
- Heat Flow
- Magnetic Field
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.
• **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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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.
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
• 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?
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

\[(\text{Mg,Fe})_2 \text{SiO}_4\]  
olivine  
perovskite
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**.
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 $\sim$10 g/cm$^3$
- What can seismic waves tell us?

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
• 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 electromagnetic 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)
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 rocks as they cool below their Curie Point
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
- Computer simulations from Los Alamos (Glatzmaier)
- Also predicted the inner core must be spinning faster than Earth
- These perturbations may initiate reversals
Song and Richards (Columbia U.) later confirmed the rotation rate of the inner core to be 1°/year faster than the Earth's rotation.