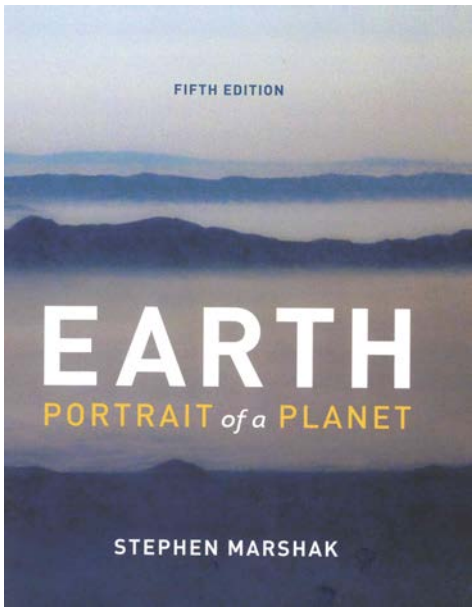
CEEES/SC 10110-20110

# Journey to the Center of the Earth




**Earth**

**Portrait of a Planet**
**Fifth Edition**

**Chapter 2**

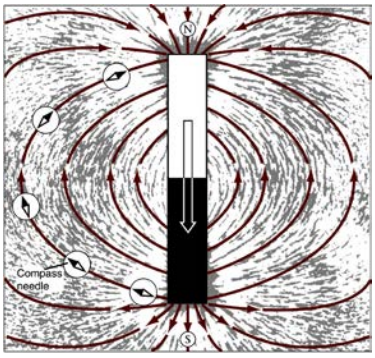
# Radiation Protection

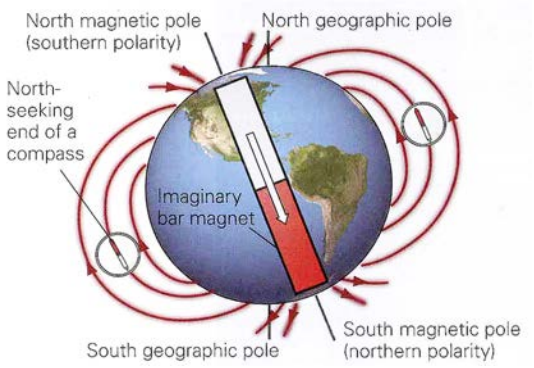
Sun emits protons and electrons = ***Solar Wind***.

Earth is protected by its magnetic field, which is a ***dipole magnet***.

Area inside the magnetic shield = ***magnetosphere***.

Even with the shield, particularly strong solar flares can cause disruption in telecommunications and electricity generation.

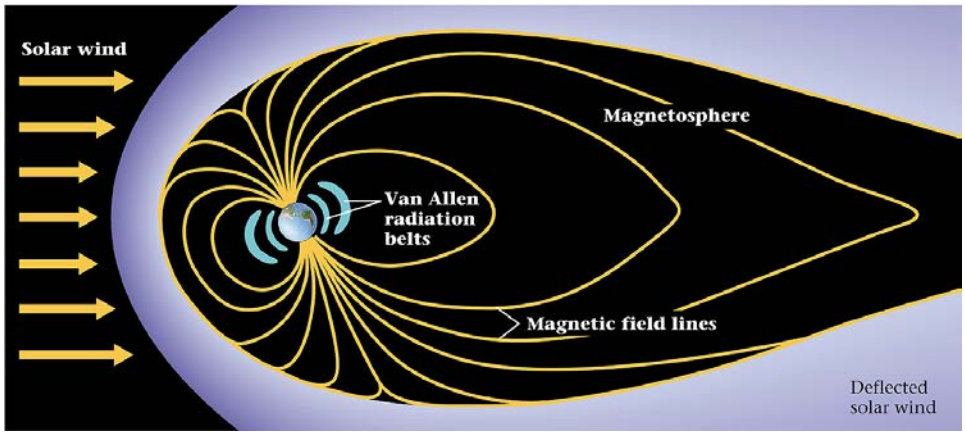


# Van Allen Radiation Belts

Occur at 3,000 km and 10,500 km out from Earth.

Made up of solar wind particles and cosmic rays (nuclei of atoms, which may have been emitted from supernovae.



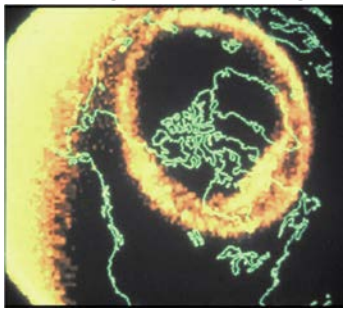

These particles move so fast that they penetrate the weaker outer part of the magnetic shield.

Van Allen belts protect Earth from dangerous radiation.



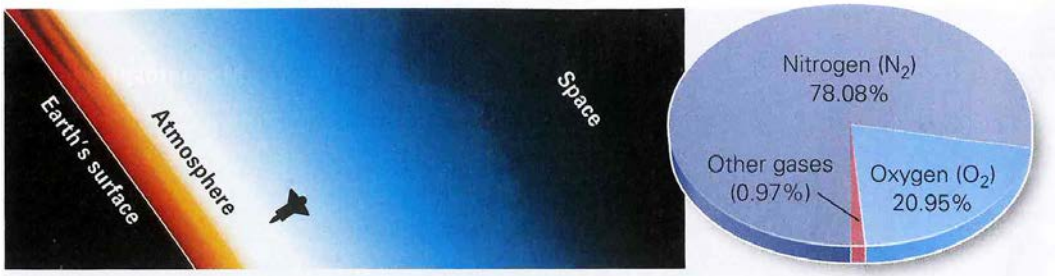
# Van Allen Radiation Belts

Particles that penetrate the Van Allen belts are channeled along the magnetic lines and interact with gas atoms of the upper atmosphere, which glow forming ***aurorae***.



# The Earth's Atmosphere

**Composition**: **78% $N_2$; 21% $O_2$; 0.93% Ar; 0.04% $CO_2$; 0.03% Ne, CO, $CH_4$, $O_3$, $SO_2$**

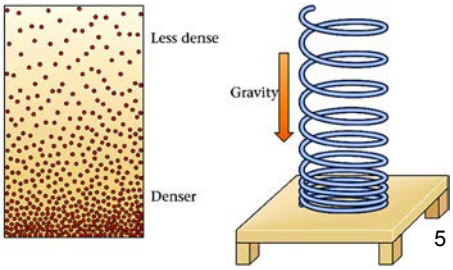



**(a)** An orbiting astronaut's photograph shows the haze of the atmosphere fading up into the blackness of space.

**(b)** Composition of atmosphere. Nitrogen and oxygen dominate.

Air pressure decreases with elevation.
Pressure given in "atm." or "bars".
1 atm. = 1.94 kg = 14.7 pounds/inch$^2$.
1 atm. = 1.01 bars.

Humans cannot survive above elevations of 4.5-5.5 km.

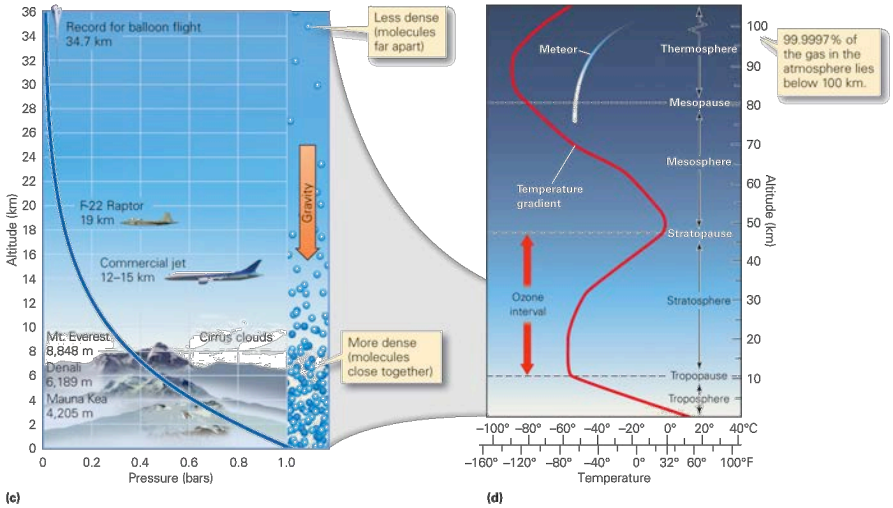





# The Earth's Atmosphere

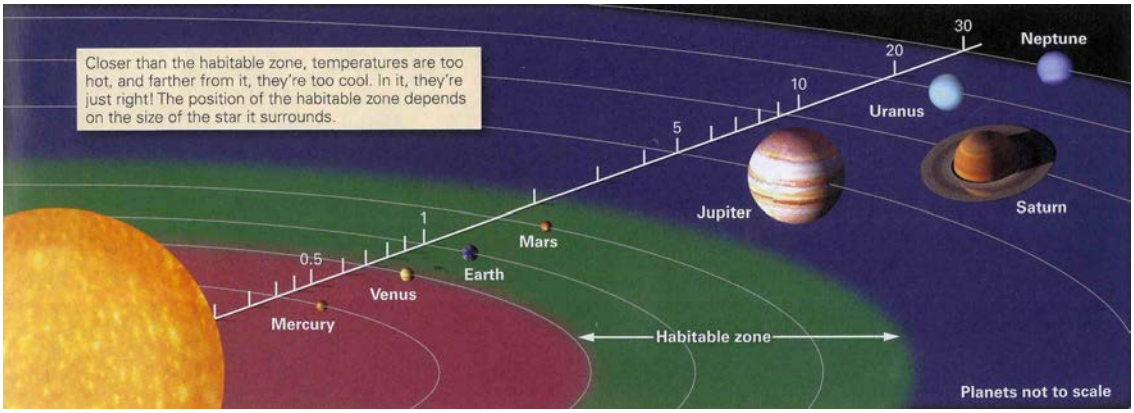
**Troposphere**: where our weather occurs. Atmosphere convects: sinking cold, dense air replaces warm, light air as it rises. This causes winds to blow.

Moisture in atmosphere from interaction with oceans.
Oceans, rivers, and lakes = surface water.
Surface water, groundwater = ***hydrosphere***.



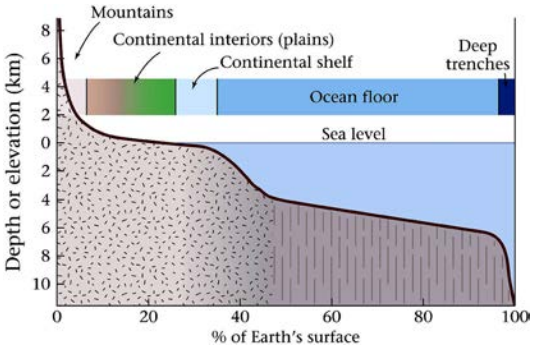
# The Habitable Zone

Distance from the Sun where water is liquid as long as atmospheric pressure is high enough to stabilize it.

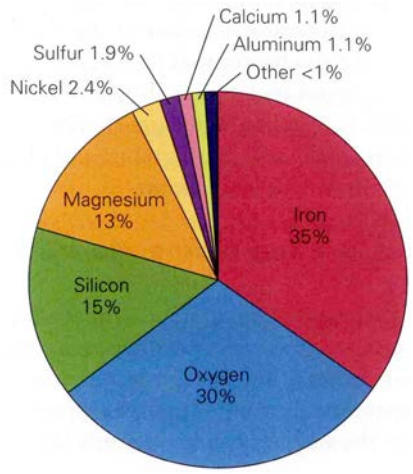



# Topography

Interaction of hydrosphere and atmosphere with the lithosphere (rocks and sediment) causes weathering and erosion, which lowers high peaks and smooths out sharp land features.



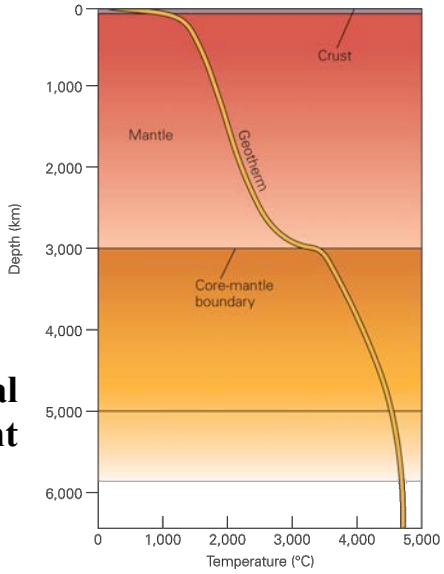

# Composition of the Earth




| | |
|---|---|
| Iron | 35% |
| Oxygen | 30% |
| Silicon | 15% |
| Magnesium | 13% |
| Other | 7% |

Initial formation of Earth meant most of the volatiles were "blown" to the outer Solar System.

**Geothermal Gradient**




# Geothermal Gradient

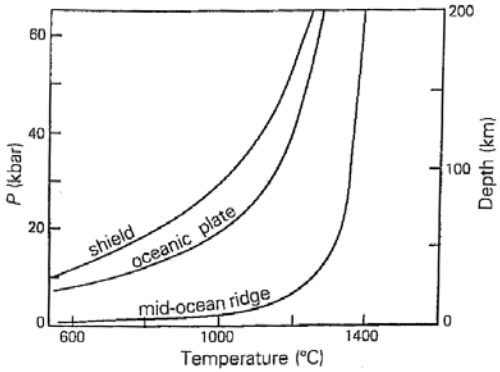
Change of pressure and temperature with depth.

Mass of overlying rock increases with depth in the Earth - pressure increases. So does temperature.

Varies between 15˚C and 50˚C per km in the upper part of the crust and decreases to ~10˚C per km at greater depths.

Core temperature estimated to be ~4,700˚C - this is ~800˚C cooler than the surface of the Sun!

Heat from kinetic energy (accretion) and radioactive decay.




Shield = Continental Interior

**Solidus Temperature**: above which the rock starts to melt;

**Liquidus Temperature**: above which the rock is completely molten.

# Composition of the Earth

## Categories of Earth Materials

**Organic Chemicals**: C-bearing compounds that occur in living organisms or have characteristics that resemble those in living organisms (e.g., oils, proteins, fats).

**Minerals**: solid substance in which the atoms are arranged in an orderly manner. Grow by cooling/freezing a liquid or by precipitation from water. A "crystal" has smooth flat faces; irregular shaped sample, or crystal fragment, is a "grain".

**Glasses**: solid in which the atoms are arranged randomly. Formed from a freezing liquid.

**Rocks**: aggregates of minerals crystals and/or grains. 3 types - Igneous (cooled from magma); Sedimentary (from the weathered and eroded fragments of preexisting rocks or precipitate from water); Metamorphic (created from preexisting rocks undergoing solid state transformations due to changes in temperature and/or pressure).



# Composition of the Earth

## Categories of Earth Materials

**Metals**: solids composed of metals atoms (i.e., those that allow electrons to flow freely) - e.g., Tin, Copper, etc. Alloy = mixture of two or more metals (e.g., bronze = copper + tin).

**Melts**: molten material. Molten rock from Earth's interior = 2 types: Magma = liquid rock + dissolved gases; Lava = liquid rock that has lost some of the dissolved gas.

**Volatiles**: materials that easily transform into gases at the relatively low temperatures (and pressures) at the Earth's surface.

Most common minerals contain silicon + oxygen = silicate minerals. Igneous rocks are subdivided into 4 broad groups in terms of the ratio of Si to Fe+Mg - in decreasing order: Felsic (or ***Silicic***), Intermediate, Mafic, Ultramafic.

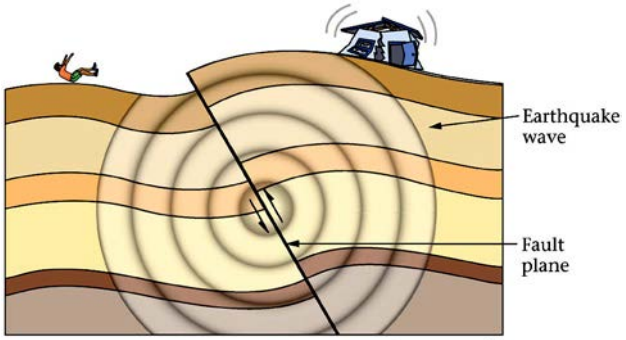
Introduction - Granite (felsic, coarse grained); Basalt (mafic, fine grained); Gabbro (mafic, coarse grained); Peridotite (ultramafic, coarse grained.

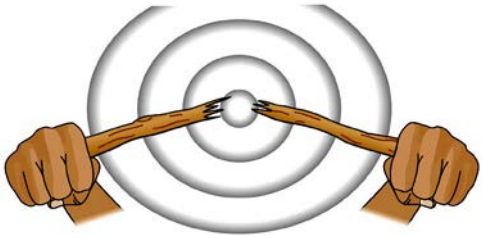
# Interior of the Earth

Bulk density of the Earth (>5 gm/cm$^3$) exceeds the density of surface rocks (2.2 - 2.5 gm/cm$^3$). Different "layer(s)" beneath.

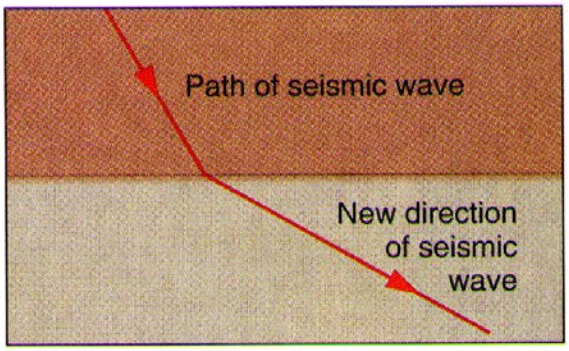
Seismic waves generated by earthquakes travel through the Earth. Occur when there is brittle slip along a fault in the Earth's crust.

Arrival times at various stations around the globe show that earth is made up of different layers of different density.

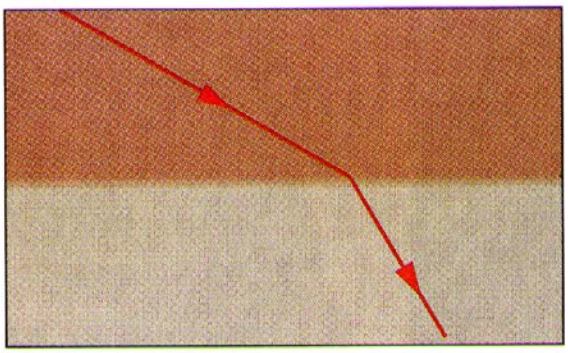




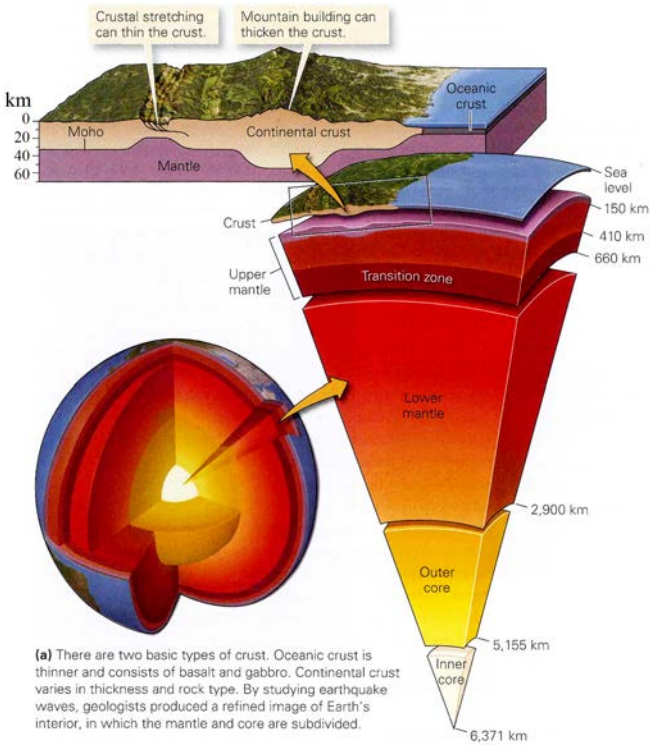



**A** Two types of seismic wave pass through the interior – P & S waves. S waves don't pass through liquid




**B** **Seismic Refraction**: bending of seismic waves due to density changes.

# Earth's Interior

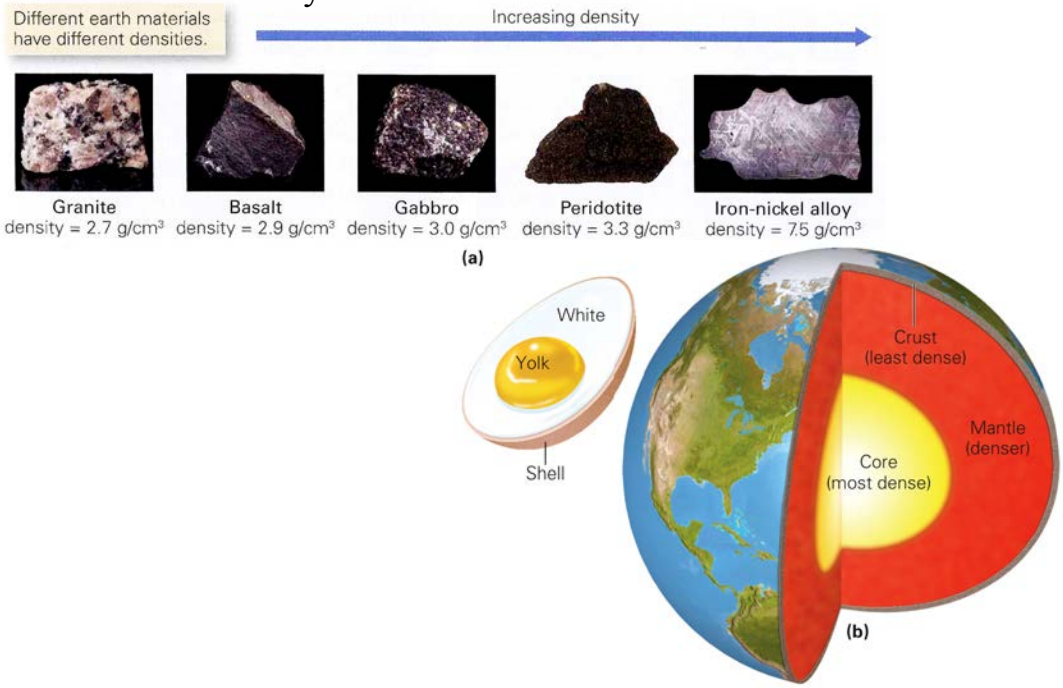



(a) There are two basic types of crust. Oceanic crust is thinner and consists of basalt and gabbro. Continental crust varies in thickness and rock type. By studying earthquake waves, geologists produced a refined image of Earth's interior, in which the mantle and core are subdivided.

Density increases downwards from the surface.

# Earth's Interior

Density increases downwards from the surface.



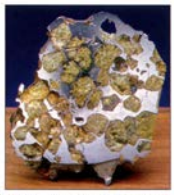
# Earth's Interior

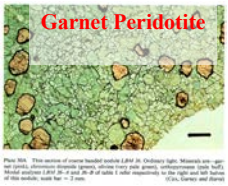
If the interior of the Earth is denser than crustal material, what's it made of?

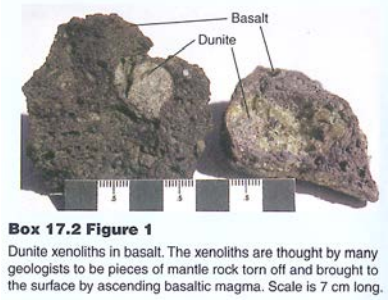
Geologists have addressed this question in a number of ways:

Laboratory experiments to see what kind of material could serve as a source region for magma;

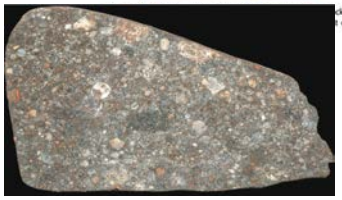
Studied "chunks" (xenoliths) of mantle material included in magma erupted at the surface;






**Box 17.2 Figure 1**
Dunite xenoliths in basalt. The xenoliths are thought by many geologists to be pieces of mantle rock torn off and brought to the surface by ascending basaltic magma. Scale is 7 cm long.



Measured densities of known rock types;

Estimated the composition of the interior assuming Earth formed initially from meteoritic material.



# The Crust

Oxygen is the most abundant element in the crust.

Two main types of crust:

**Continental** & **Oceanic**; each have distinct compositions from each other and from the underlying mantle.

| Element | Symbol | % by weight | % by volume | % by atoms |
|---|---|---|---|---|
| Oxygen | O | 46.3 | 93.8 | 60.5 |
| Silicon | Si | 28.0 | 0.9 | 20.5 |
| Aluminum | Al | 8.1 | 0.8 | 6.2 |
| Iron | Fe | 5.5 | 0.5 | 1.9 |
| Calcium | Ca | 3.4 | 1.0 | 1.9 |
| Magnesium | Mg | 2.8 | 0.3 | 1.4 |
| Sodium | Na | 2.4 | 1.2 | 2.5 |
| Potassium | K | 2.3 | 1.5 | 1.8 |
| All others | — | 1.2 | >0.1 | 3.3 |

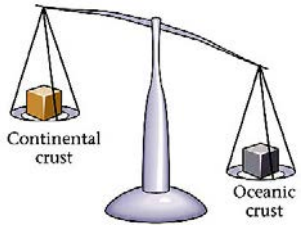
Seismic waves abruptly change velocity between 7-70 km depth - indicates a major change in density and, therefore, composition.

This is the "Moho" - it is shallower under oceanic crust.

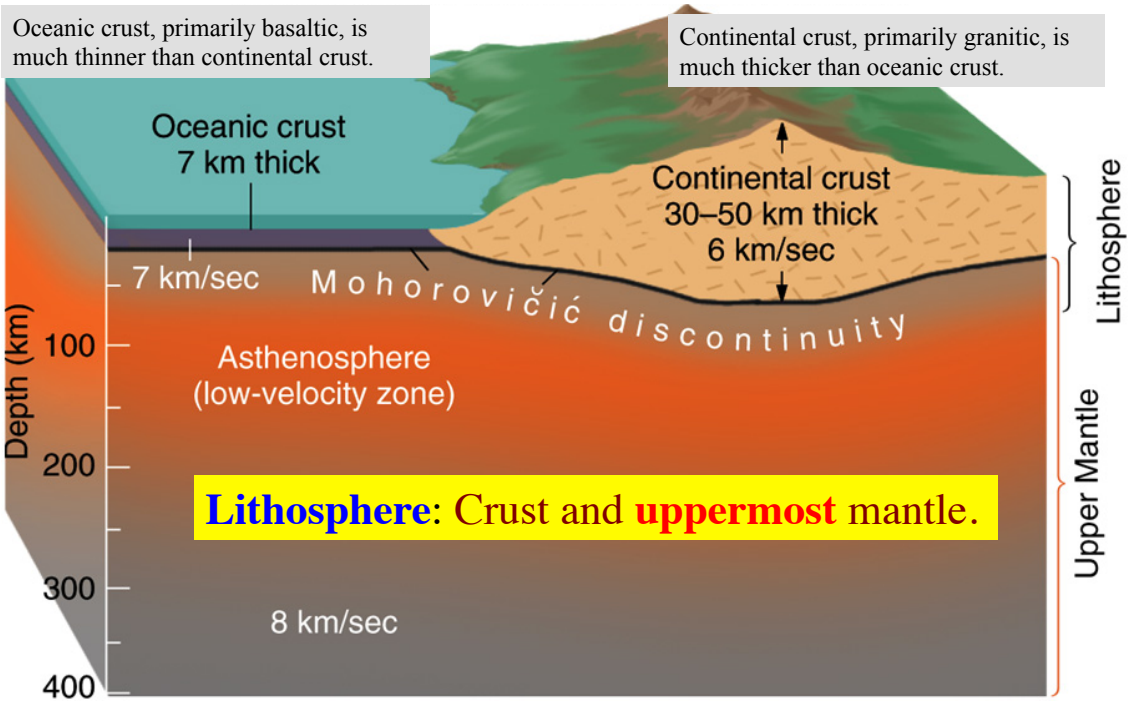
**Oceanic crust**: *5-8 km thick (avg. = 7 km)*. Layer of sediment is underlain by basalt and then gabbro.

**Continental crust**: *30-50 km thick (up to 70 km)*. Variety of rock types - usually deformed.

**Important**: Oceanic crust is denser than Continental crust.



**Crust**: outer layer or "scum that floats".



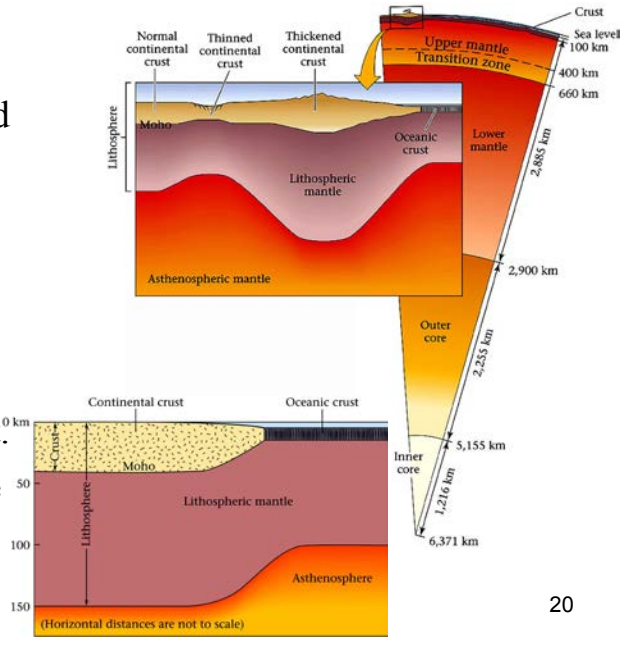



# The Mantle

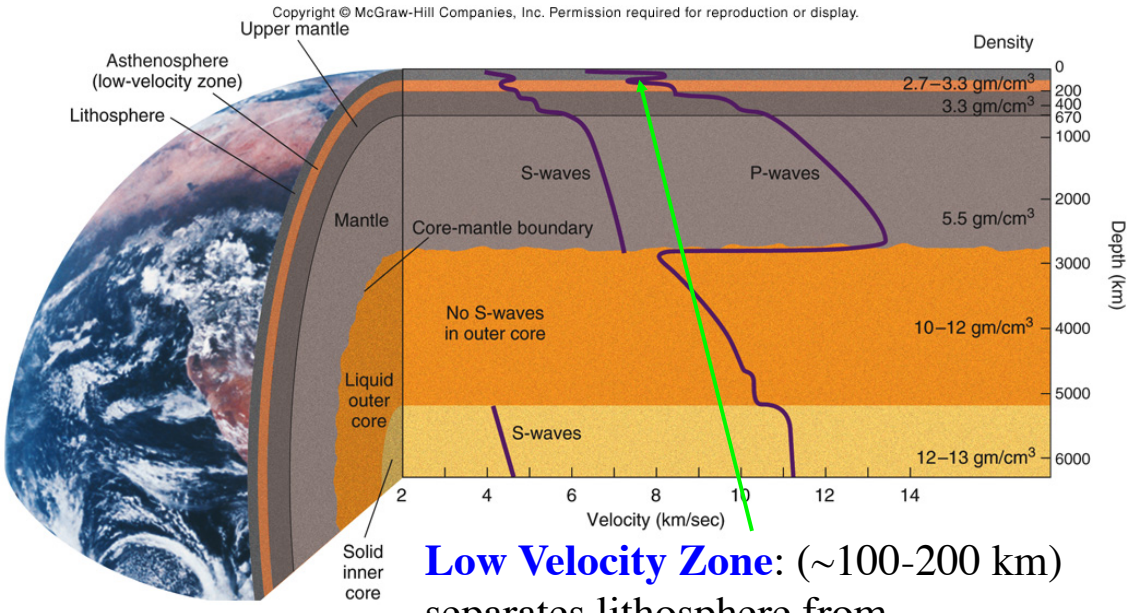
2,885 km-thick layer surrounding the core.
Made up of ultramafic rock - peridotite (higher density than basalt).
The mantle is layered (from seismic wave velocities).

While the mantle is comprised of rock, the heat makes it plastic or "soft", which allows it to flow **slowly**.
At about 100-200 km beneath the oceans, a "low velocity zone" suggests a few percent of partial melt may be present.

Changes in temperature in the mantle produce changes in density - mantle can convect.



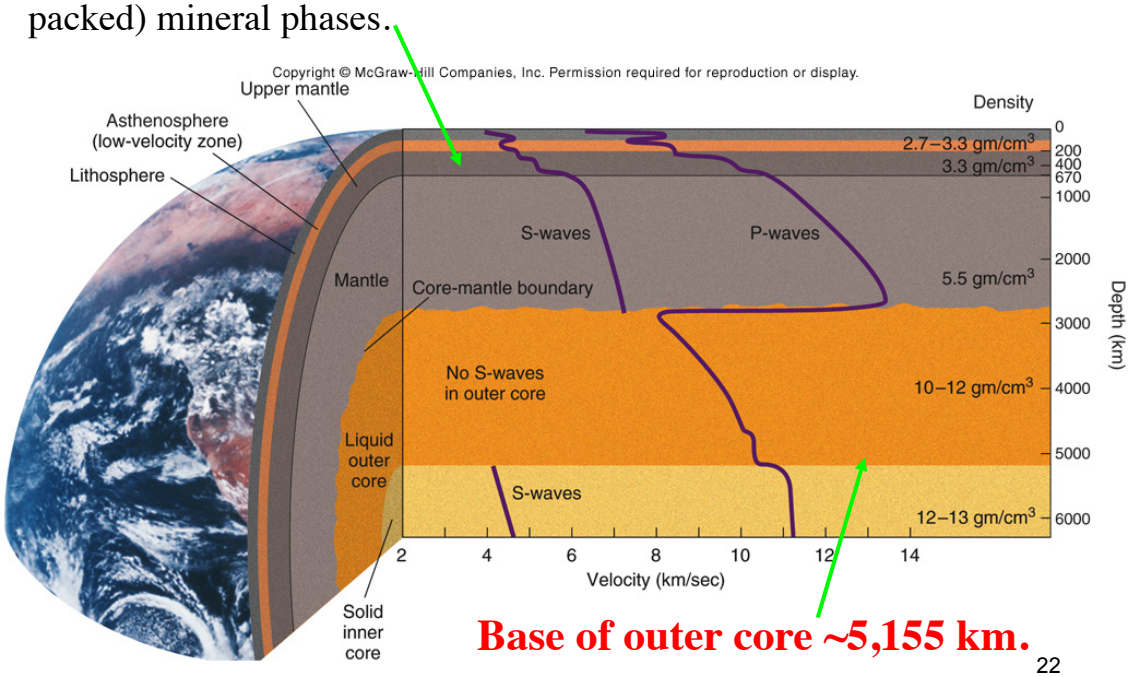
# **MANTLE**: ~2,885 km thick.




**Low Velocity Zone**: (~100-200 km) separates lithosphere from **Asthenosphere** (100-250 km thick).

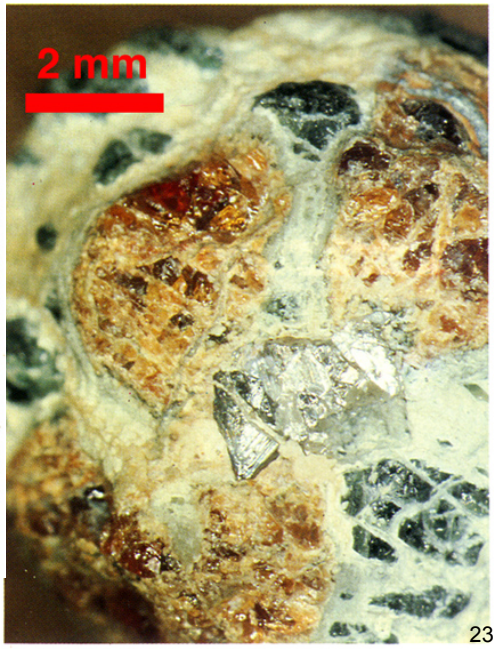


**Mesosphere**: solid, below **asthenosphere**. Higher velocities due to higher pressure, which produces higher pressure (more closely packed) mineral phases.




**Base of outer core ~5,155 km.**


## Mantle Minerals




**Diamond - recycling?**



# The Core

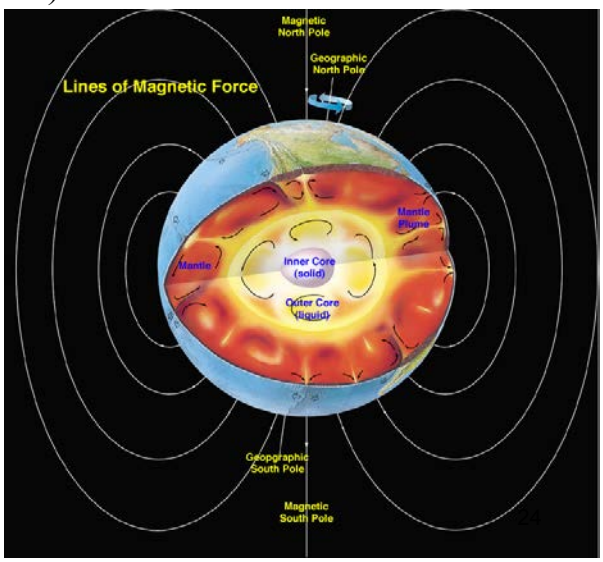
Primarily Fe, Ni (minor Si, O, S and others).

Liquid outer core (2,885 - 5,155 km);

Solid inner core (5,155 - 7,371 km).

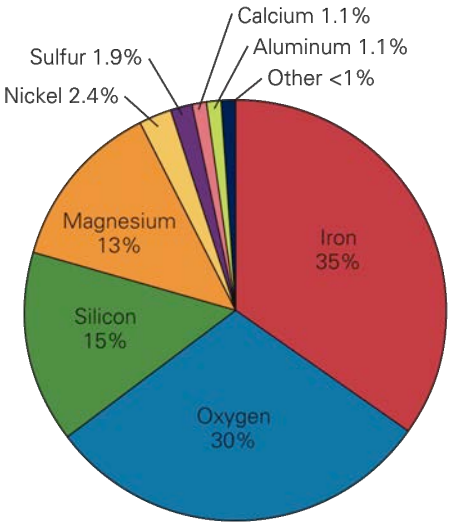
Inner core is hotter than the outer core, but intense pressure prevents melting.

Convection in the liquid outer core produces Earth's magnetic field.

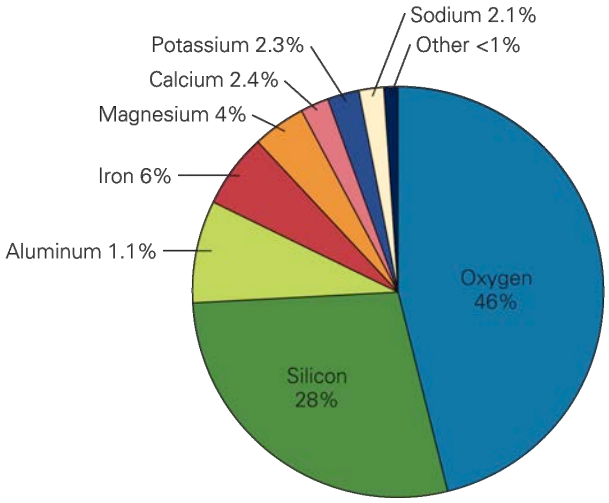


# Compositions

**Entire Earth**




**Earth's Crust**






# Summary

**Radiation Protection**: Magnetic Field.

**Van Allen Radiation Belts**.

**Atmospheres**: Mercury, Venus, Mars, Earth.

**Earth's Atmosphere**: Composition, pressure, layering.

**Topography**: weathering and erosion.

**Earth Materials**: Organics, Minerals, Glasses, Rocks, Metals, Melts, Volatiles. Compositions

**Igneous Rocks**: Felsic, Intermediate, Mafic, Ultramafic.

**Earth's Interior**: seismic wave velocity variations, Seismic Refraction.

**Geothermal Gradients**: Heat sources.

**What's the Interior Made Of?**

**Crust**: Continental, Oceanic, Moho.

**Mantle**: Peridotite, Upper, Lower, Transition Zone, Asthensophere, Lithosphere, Low Velocity Zone.

**Core**: Fe-Ni metal, Inner, Outer, Magnetic Field generation.