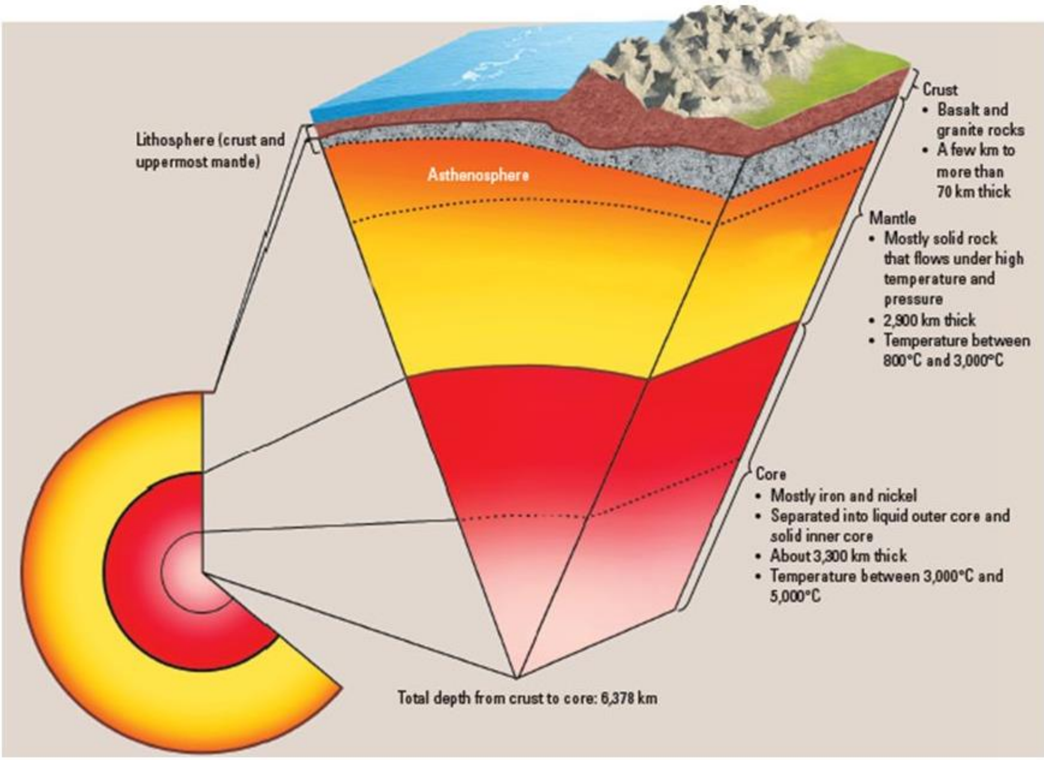
GEOLOGY

AS Level

Unit 2 Foundations of Geology

Topic 4: Earth Structure and Plate Tectonics

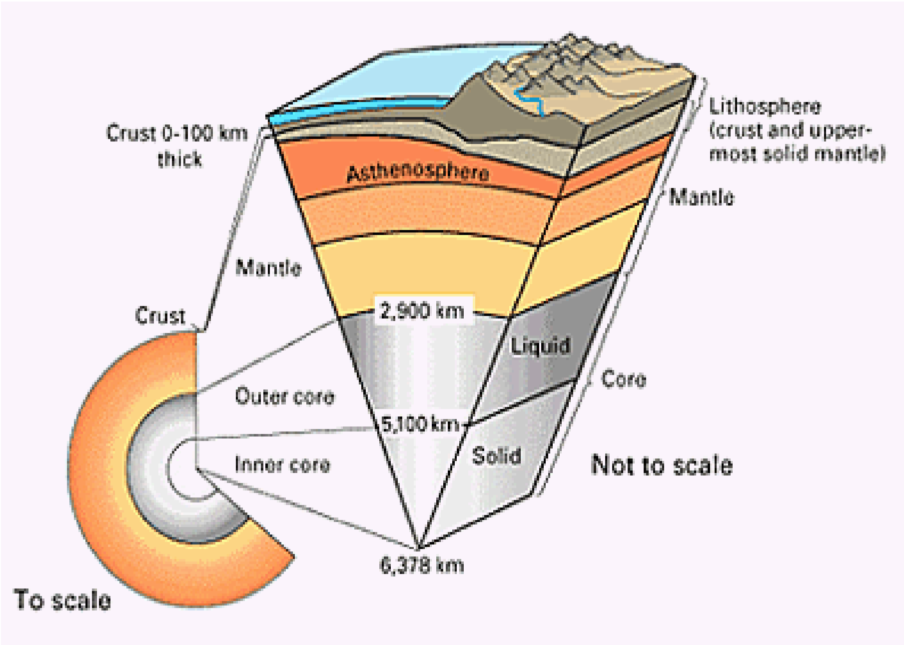


A. Prickett

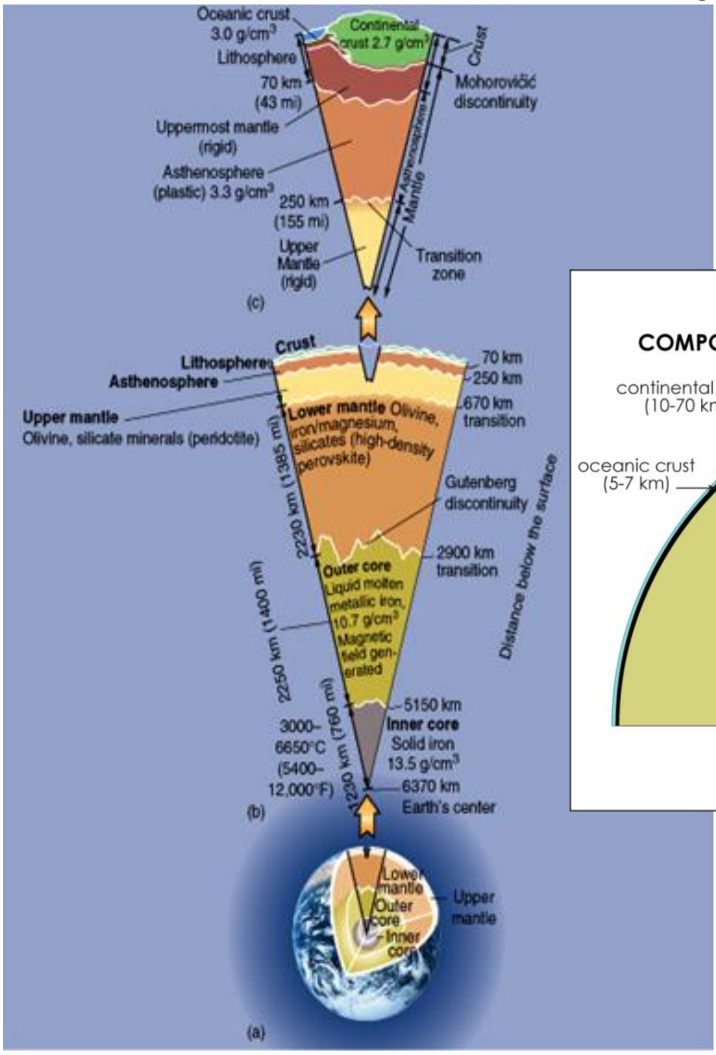
Whitmore High School

Topic 4: Earth Structure

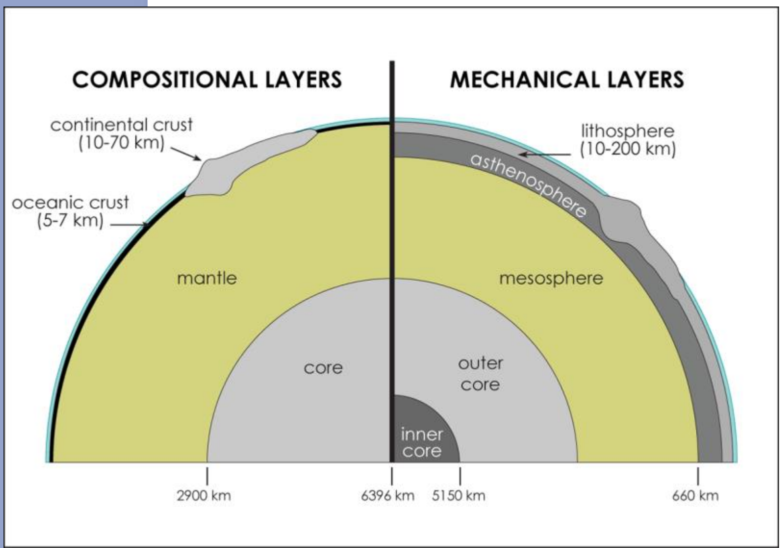
Key Idea 1: The Earth has a concentrically zoned structure and composition.

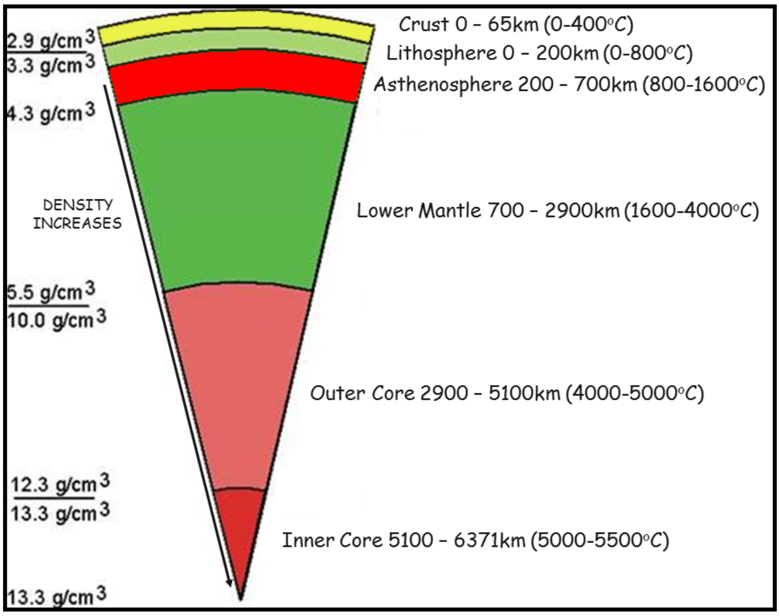


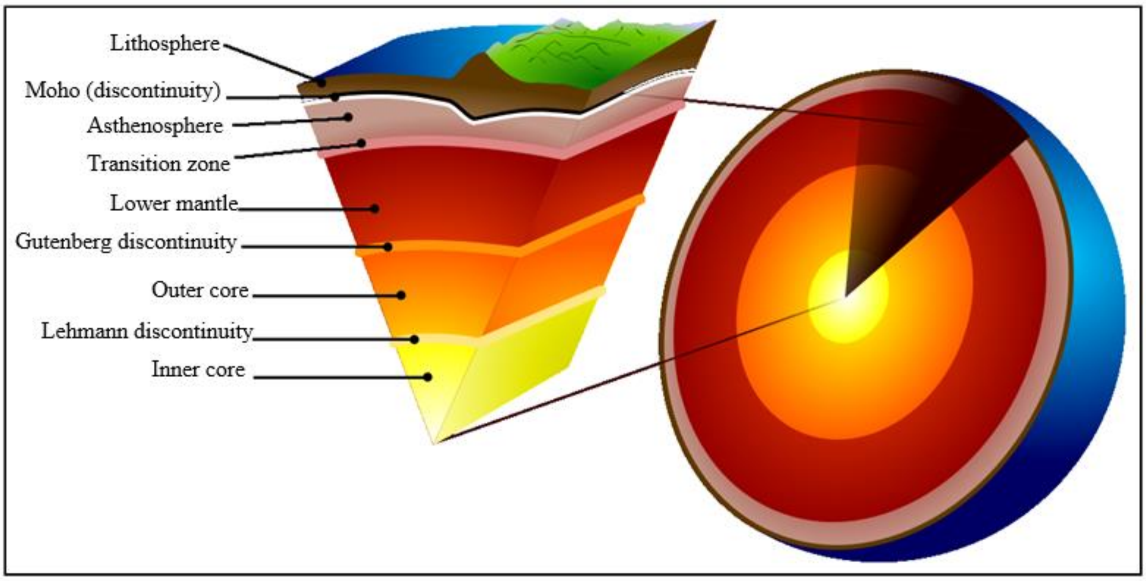
A cross-section through the Earth



KEY (for all diagrams)
Temperature given in °C
Depth given in km
Density given in g/cm^3







Evidence for this Internal Structure

1) Meteorites

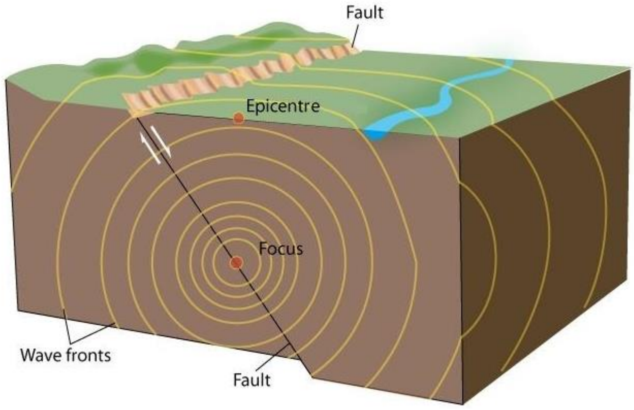
Meteorites are broken up pieces of planets, or material that didn't make it into a planet when they formed. There are two main types:

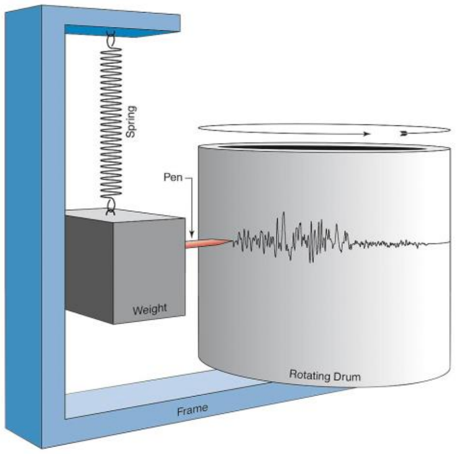
IRON: which represent the core, as they are thought to have a similar composition and density to our core (~13g/cm^3).

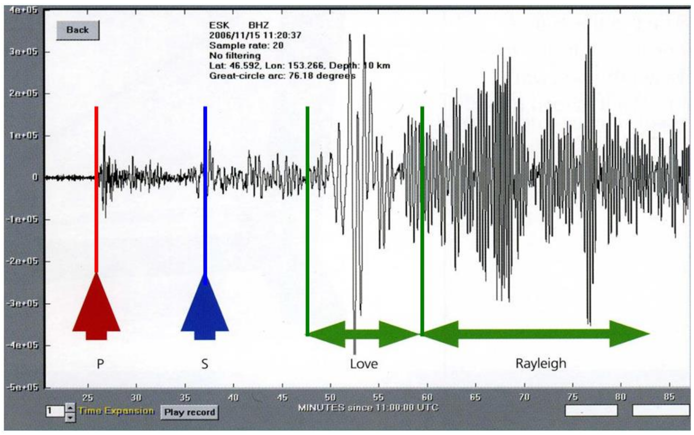
STONY: which represent the mantle/crust, as they have a similar density to our crustal rocks (~3g/cm^3).

2) Seismology

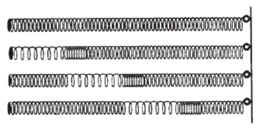
Earthquake (seismic) waves such as P, S (body) waves and Rayleigh and Love (surface) waves travel at different velocities through different rocks and layers of the Earth. They are all picked up by seismometers.



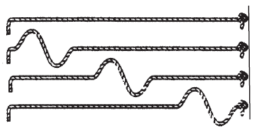




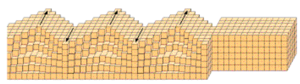
The main waves types:



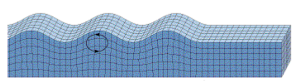
P waves – these squeeze and stretch the material and can pass through both liquids and solids. They travel at about 6-7 km/s.



S waves – these are vertical shear waves that can pass through solids and partial melts (slowly) but not liquids. They travel at about 4-5 km/s.



Love waves – these can only travel through the lithosphere and are sideways shear waves. They travel at about 2-3 km/s.

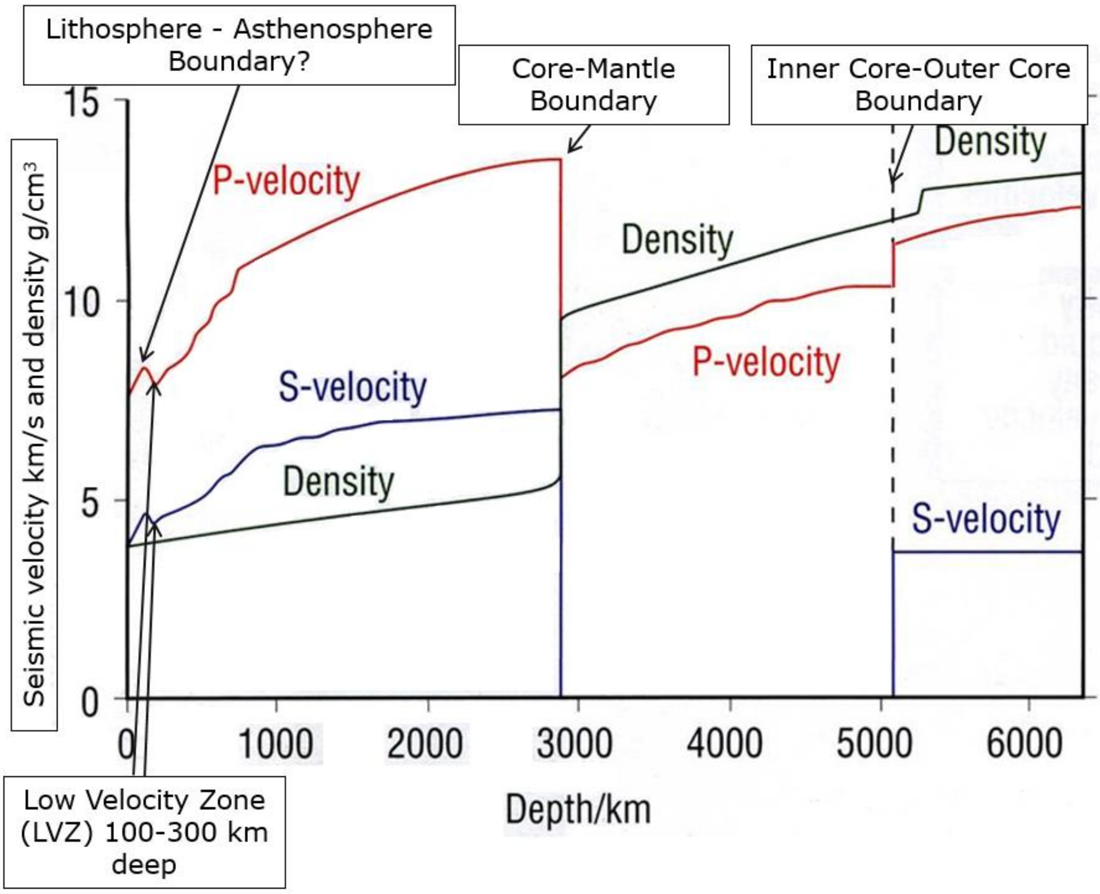


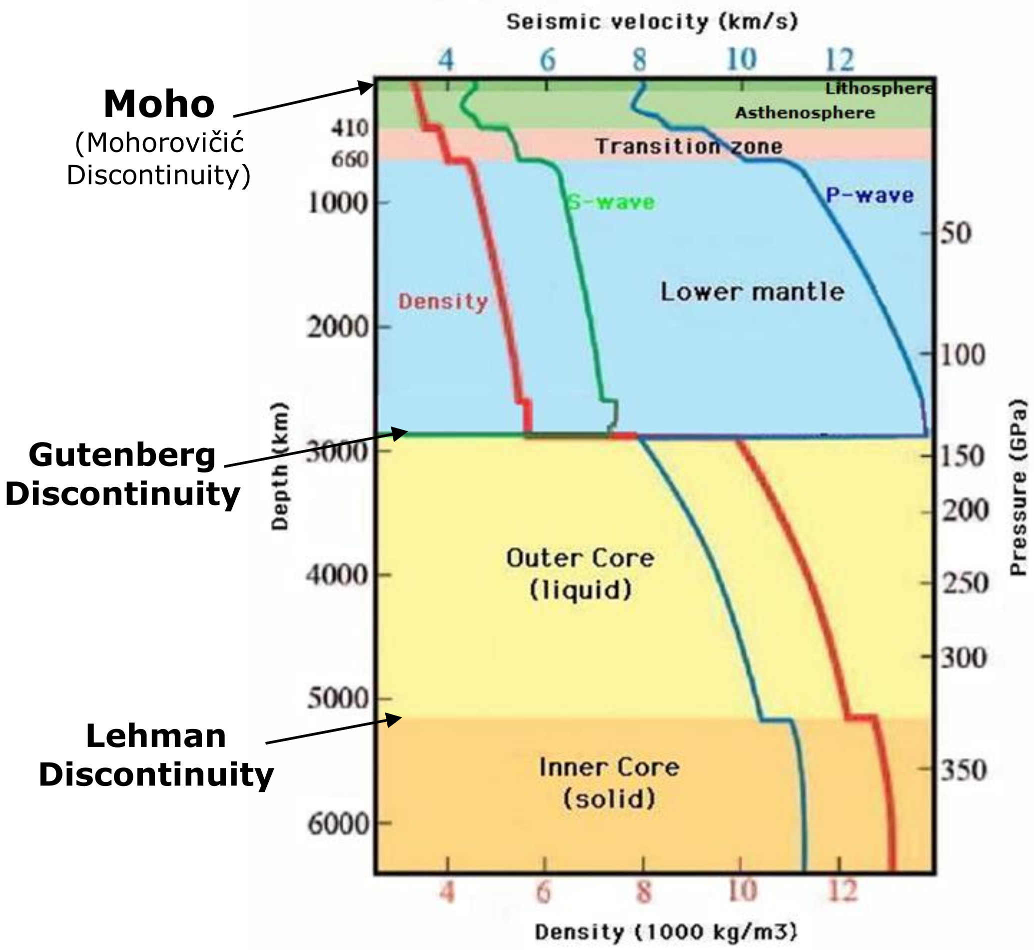
Rayleigh waves – these can only travel through the lithosphere and move like waves in water. They travel at about 2-3 km/s.

Factors affecting the speed of these seismic waves:

- Seismic waves **increase** in velocity as the **density** of the material they pass through increases.
- However, seismic waves will **slow down** as the material they pass through becomes more **incompressible**. This is why P waves travel more slowly in the Inner Core than the Lower Mantle.
- So velocity is a factor of both the density and incompressibility (bulk and shear modulus) of the medium.

Earthquake Waves and Density with Depth





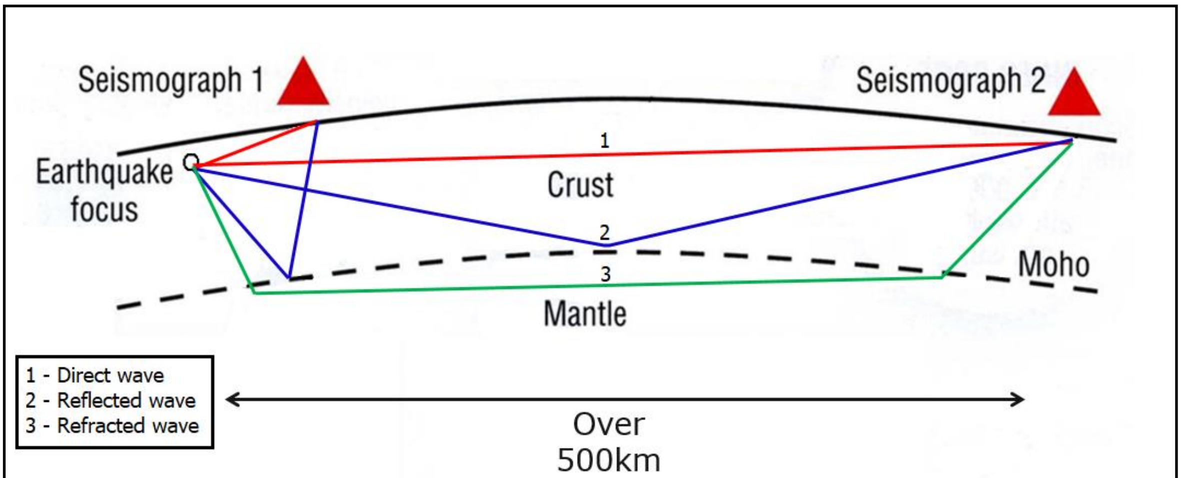
Earthquake Waves and the Lithosphere and Asthenosphere

The Moho

The boundary between the crust and the mantle is known as the Mohorovičić Discontinuity (Moho). It was discovered when it was noticed that seismographs over 500km from an earthquake focus received three sets of P waves.

Under 500km only two sets are seen – direct P waves and reflected P waves.

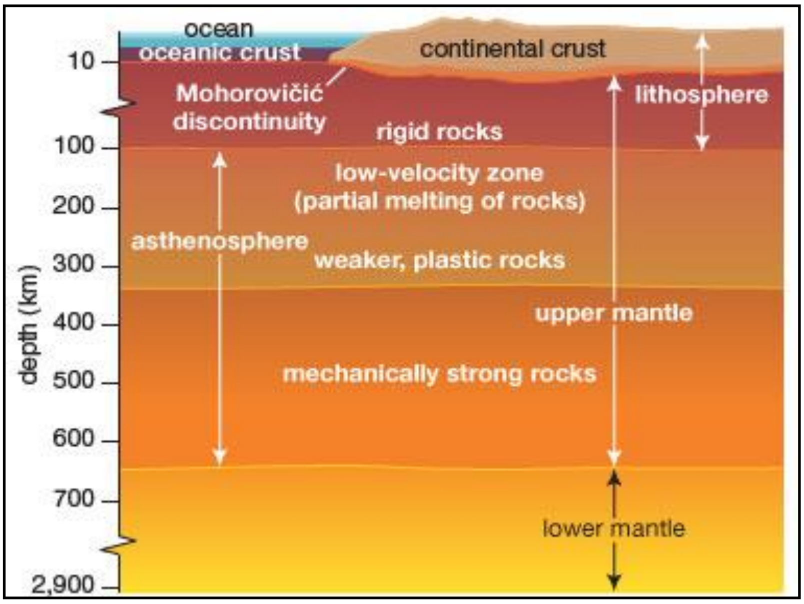
Over 500km three sets are seen – direct P waves, reflected P waves and P waves refracted through the upper mantle. It was also notice that these refracted waves arrived first so must travelling faster through something more dense (the upper mantle).



The refracted wave arrives first as it has travelled through the mantle.

The Asthenosphere

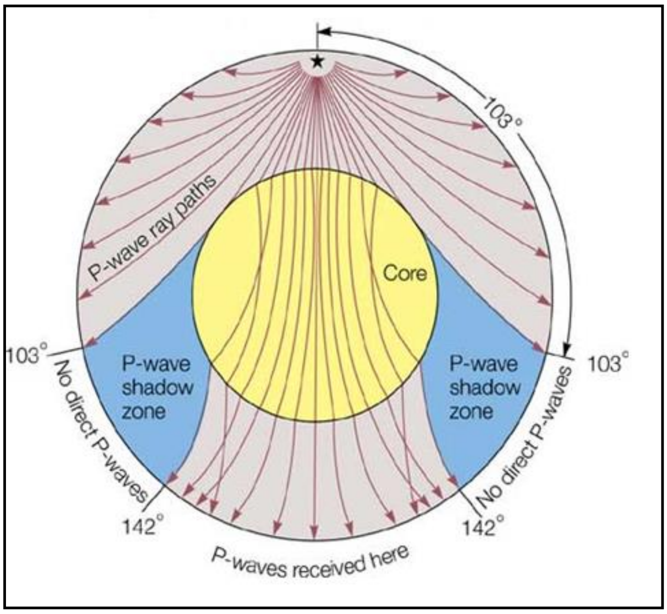
Both P and S waves slow down in the Asthenosphere (low velocity zone - LVZ) as the 1% to 5% partial melting reduces the density slightly and increases the incompressibility of the material. This is due to changes in the rheology (nature and behaviour of the material) of the layers.



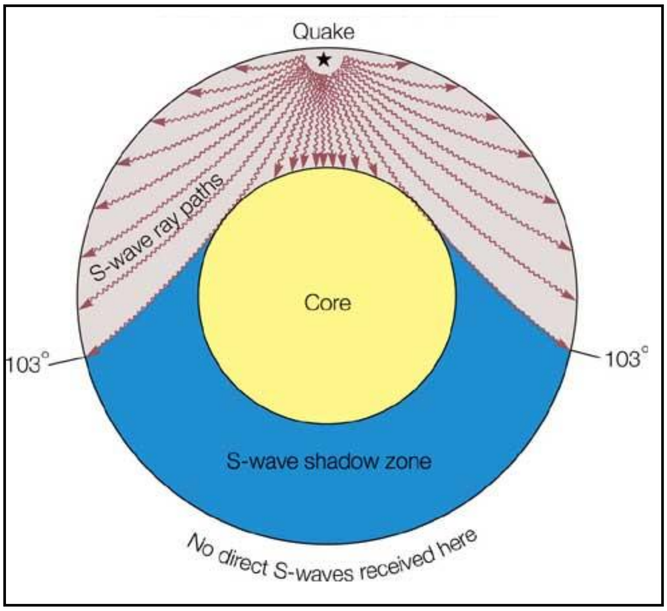
Earthquake Waves further inside the Earth

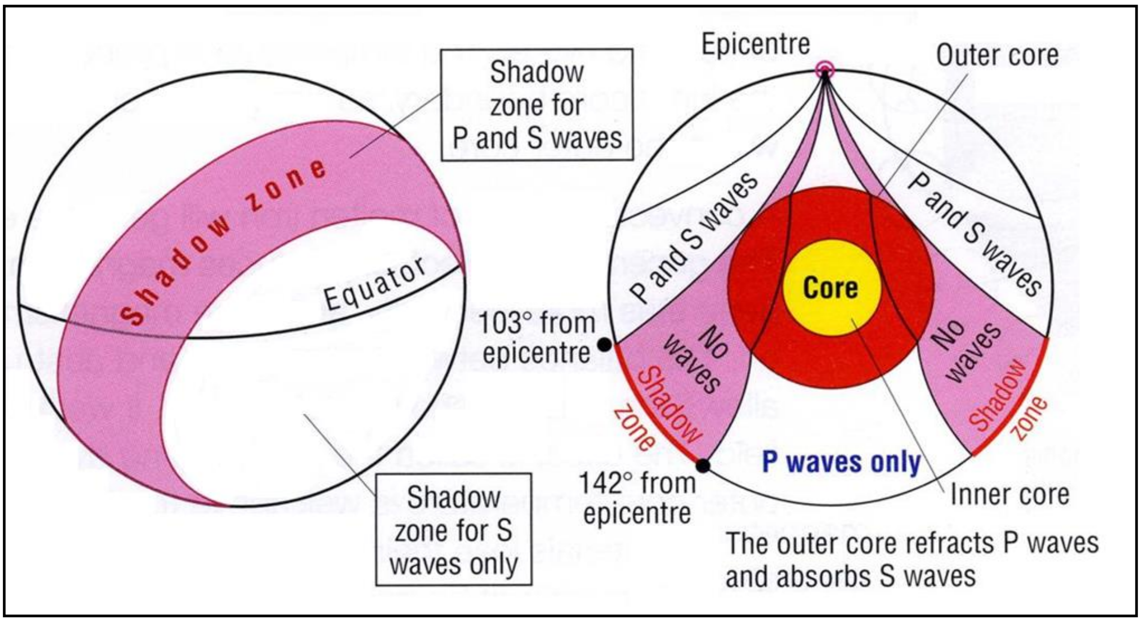
<u>Shadow zones</u>

P wave shadow zone:
P waves are affected by the liquid outer core. They are refracted (bent) as they speed up or slow down on entering or leaving it. Because of this there is a zone that no direct P waves reach. This is known as the P wave shadow zone.



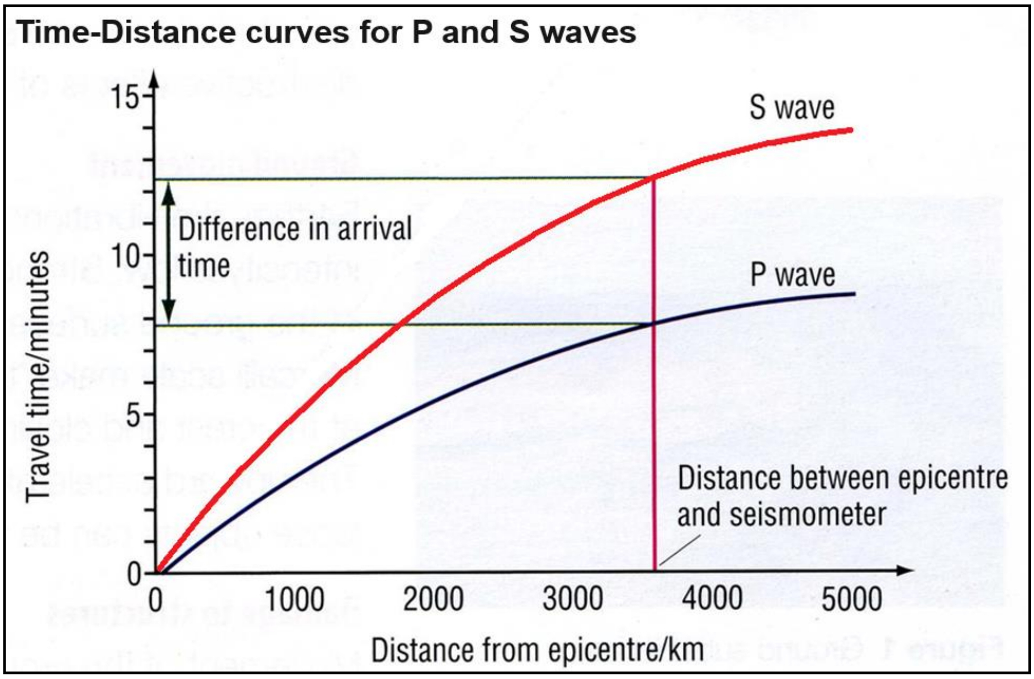
S wave shadow zone:
As the outer core is entirely liquid S waves cannot travel through it and so are stopped or reflected. Therefore, no direct S waves are found on the far side of the Earth from the earthquake focus. This is known as the S wave shadow zone.



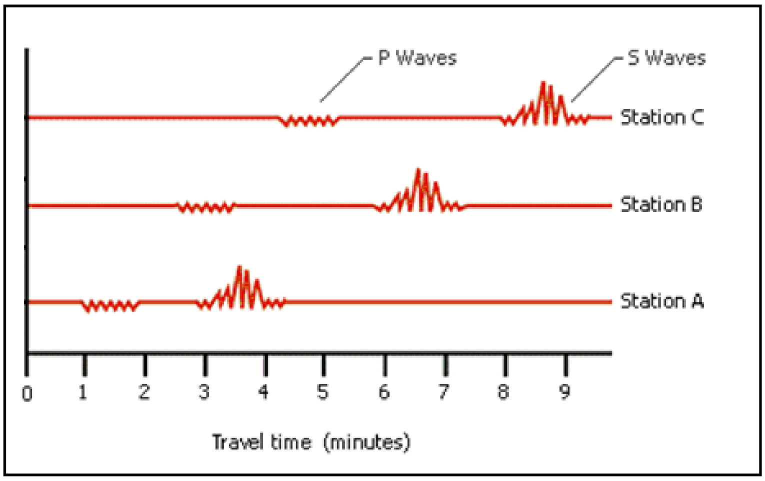


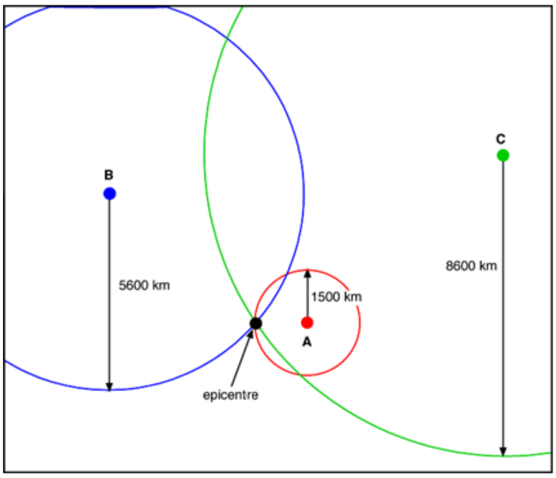
Earthquake wave travel speeds

As P waves travel faster than S waves, the time interval between their arrivals at a seismometer increases with distance.



As a result of the time intervals it is possible to locate precisely the epicentre of an earthquake using data from just three seismometers.





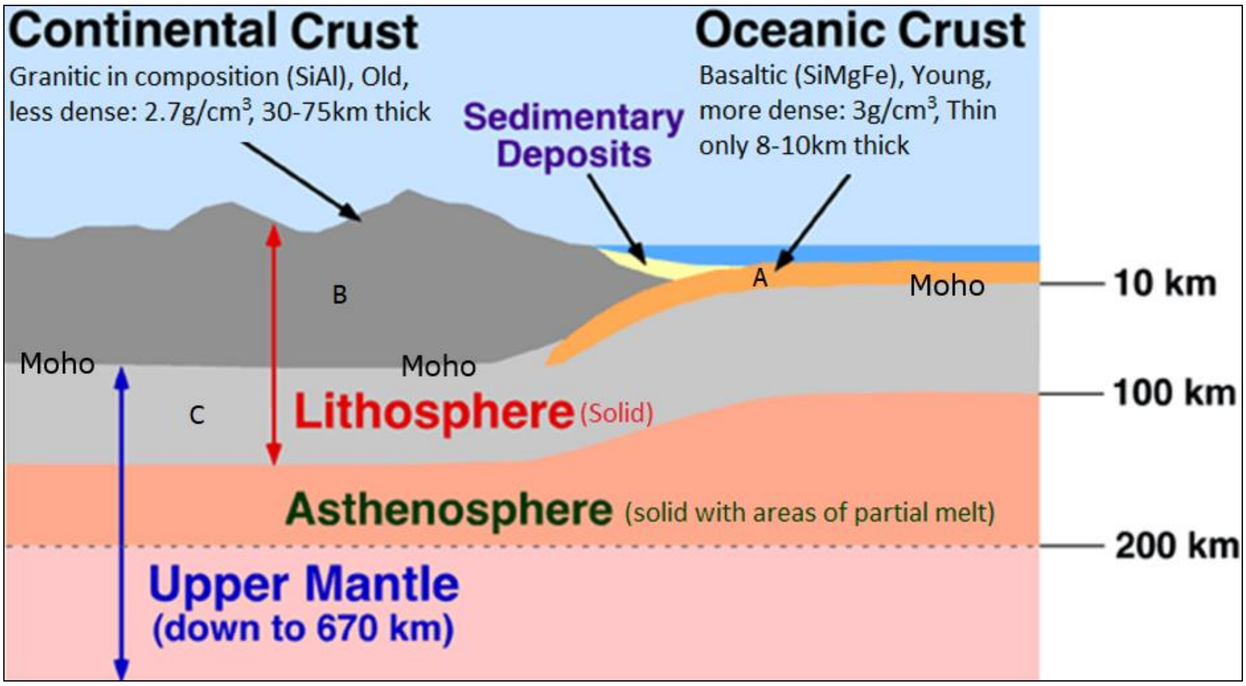
3) Direct evidence

The crust is a solid layer of the Earth, moving together with the top layer of the mantle. Together they form the Lithosphere. It is divided into three layers:

A) OCEANIC CRUST–beneath the oceans, basaltic, thinner 8 – 10km, almost all igneous, layered structure (see page 15), young up to 200mya, density 3g/cm^3

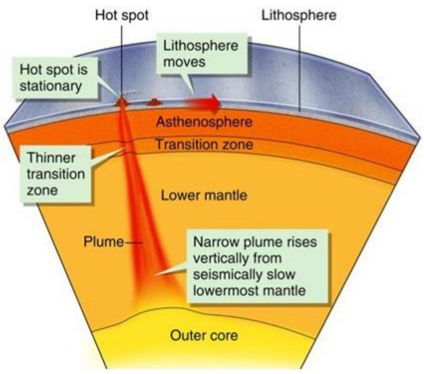
B) CONTINENTAL CRUST – forming the continents, granitic, thicker 30 – 75km, random structure, consists of all rock groups, older up to 3800mya, density lower 2.7g/cm^3

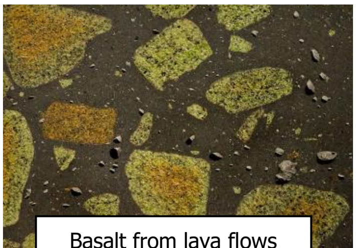
C) SOLID UPPER MANTLE - Iron and magnesium rich layer that with the crust forms the Lithosphere.



Other direct evidence

Volcanic eruptions can bring with them solid portions of the lower Lithosphere, Asthenosphere and lower mantle, particularly at mantle hotspots. These fragments of material from deeper in the Earth have a peridotite composition (rich in Fe, Mg). This tells geologists what the composition of these layers is.

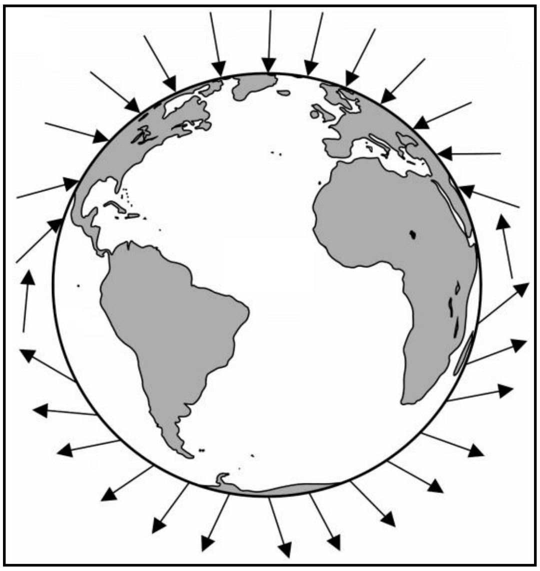


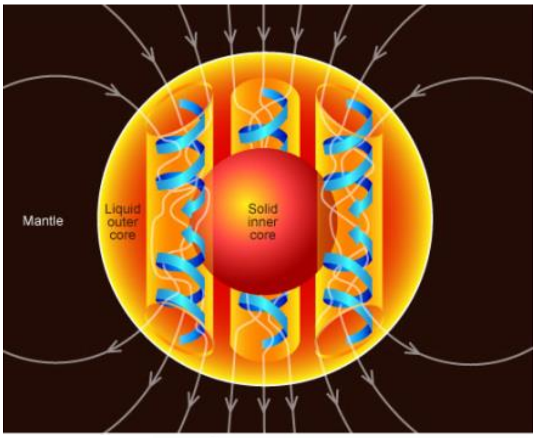


Basalt from lava flows containing olivine rich, peridotite fragments from the mantle

4) Geomagnetic evidence

The Earth has a dipole magnetic field (North and South). This can be explained by some form of liquid in the core which generates the field. The outer core must therefore be a fast flowing liquid. This would allow it to act as a SELF PERPETUATING DYNAMO with spiralling convection currents generating an electromagnetic field. This liquid outer core must be composed of metals capable of generating magnetism e.g. Iron, Nickel and Cobalt (most likely **NiFe** – from meteorite evidence)

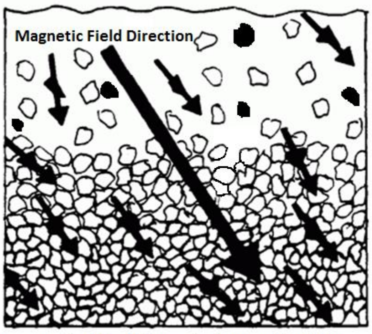




What can this tell us?

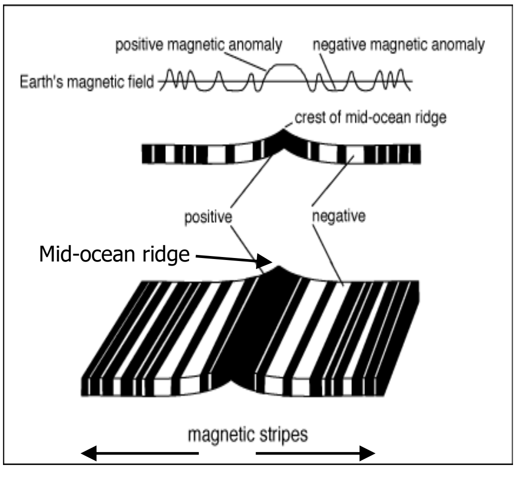
Within lava, magnetite and haematite (Fe rich) crystals become permanently magnetised in the direction of the Earth's magnetic field when they cool and harden into rock.

Thus, as lava flows and sets, it 'records' the relative direction of the magnetic field at the time and location that it solidified. This is known as **remnant magnetism**. It is said to be 'frozen' into the rock. This all happens when the lava cools below the Curie point for iron of ~570^{o}C.
Magnetite and Haematite crystals form as the lava cools. They settle to the bottom and line up in the direction of the magnetic field at the time.



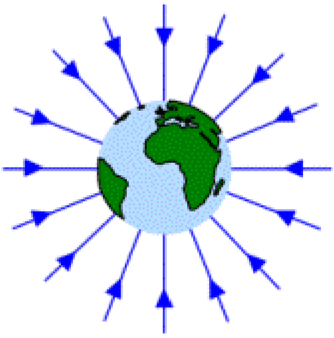
Iron particles (black) line up in the direction of the magnetic field at the time that the lava/magma cooled

Magnetic anomalies



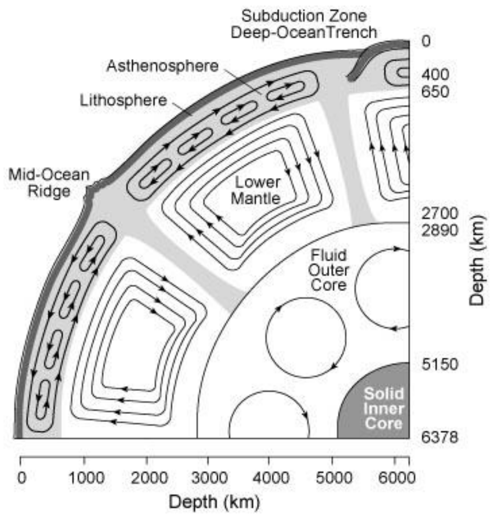
Another consequence of the magnetic field being 'frozen' into lave flows is that periodic reversals of the magnetic field are preserved within these rocks. At mid-ocean ridges where new ocean crust is made these reversals are preserved as 'magnetic stripes' in the ocean crust. These are symmetrical either side of the ocean ridge where the lava cooled at the same time.

5) Gravitational evidence



The Earth has a fairly uniform gravitational field with very small differences between places on the surface. This can only be explained by some form of dense material (Ni Fe) at the centre that generates a fairly uniform field. Thus indicating a solid, spherical, dense core.

6) Plate Tectonic evidence



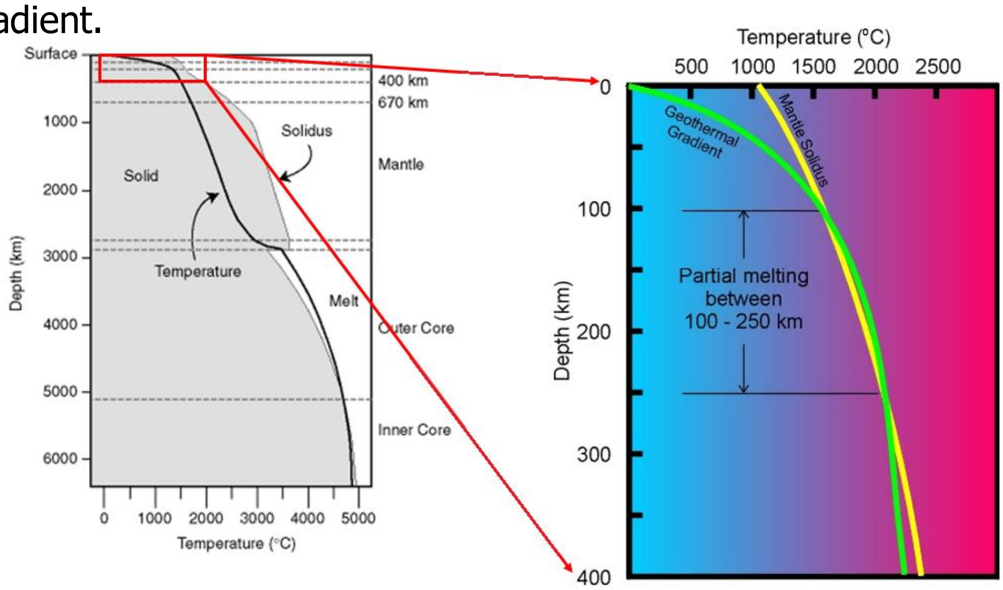
The Earth's tectonic plates (lithosphere) are moving. What could be causing movement? The best theory that ties up with all of the other evidence is that within the partially molten layers of the planet convection currents exist. These bring heat from the radioactive decay of elements in the core upwards and cause the surface plates to move. As the diagram (right) shows, there are various theories about where the convection currents are, and how they move.

7) Conductivity evidence

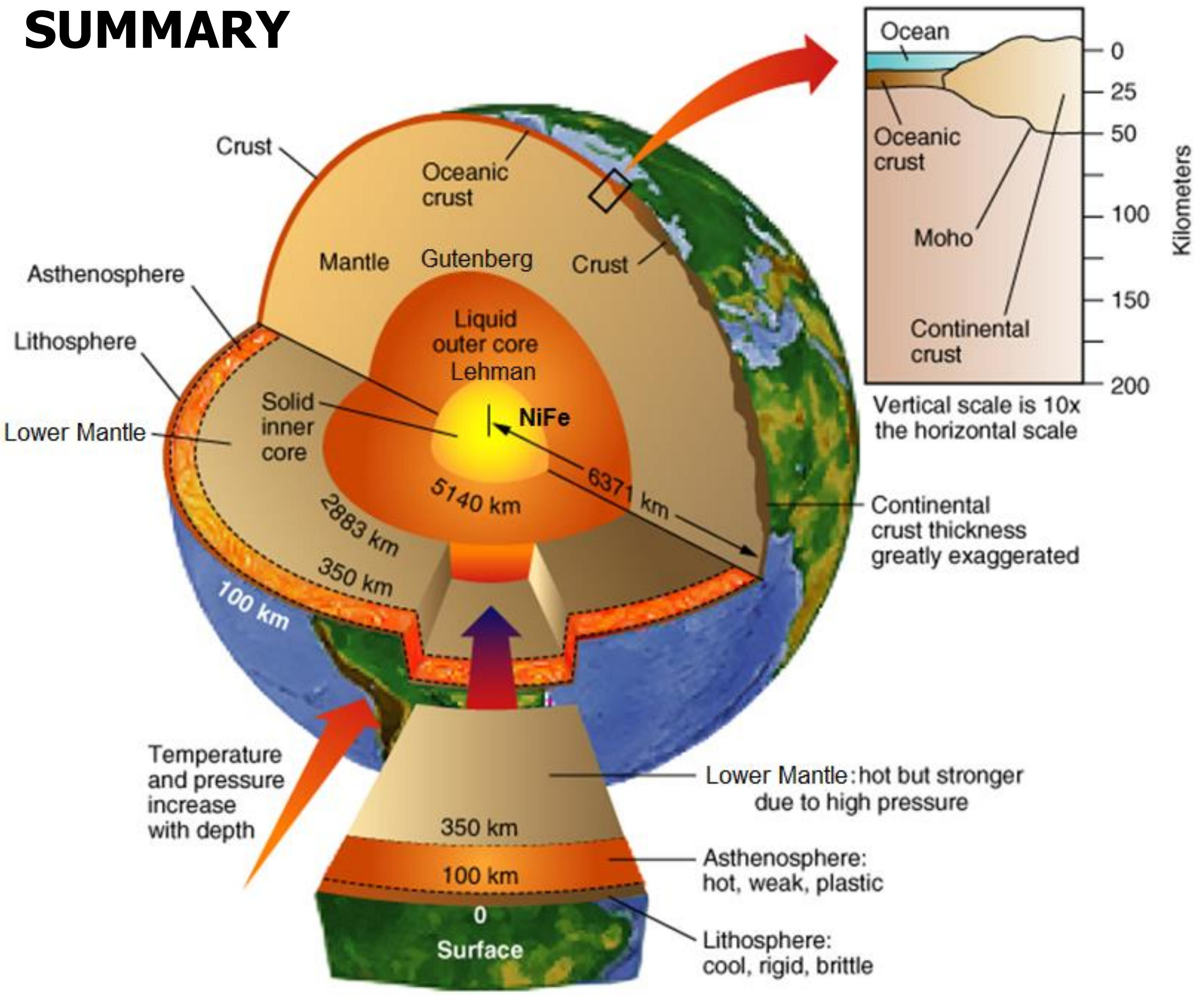
The ability of materials to conduct electricity or heat generally increase with density and therefore depth inside the earth. Field surveys of conductivity can be compared to lab experiments and used to determine the types and densities of materials found inside the earth.

Based on all the evidence we can calculate the Geotherm

The change in temperature with depth is known as the Geotherm or geothermal gradient.



SUMMARY

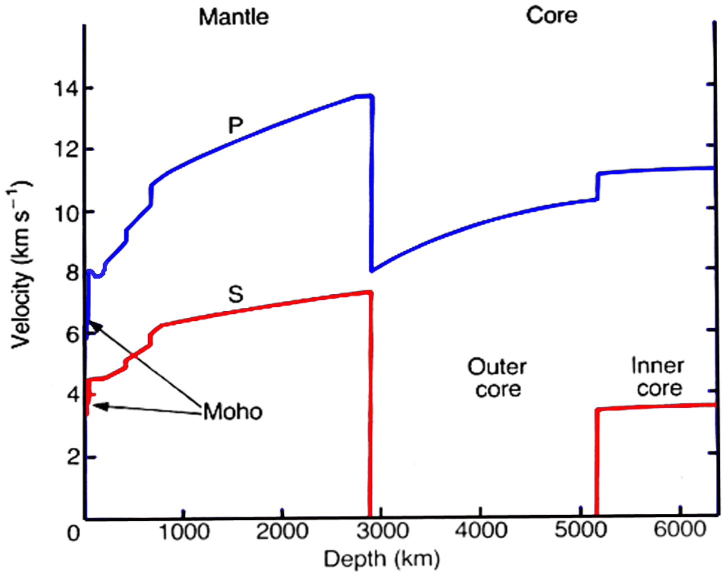

Ocean
0
25
50
100
150
200
Kilometers
Oceanic crust
Moho
Continental crust
Vertical scale is 10x the horizontal scale
Crust
Oceanic crust
Mantle
Gutenberg
Crust
Asthenosphere
Lithosphere
Lower Mantle
Liquid outer core
Lehman
Solid inner core
NiFe
6371 km
5140 km
2883 km
350 km
100 km
Continental crust thickness greatly exaggerated
Temperature and pressure increase with depth
Lower Mantle: hot but stronger due to high pressure
350 km
Asthenosphere: hot, weak, plastic
100 km
0
Surface
Lithosphere: cool, rigid, brittle

Key Idea 2: The Earth's internal heat is the underlying cause of lithospheric plate motions that control global geological processes

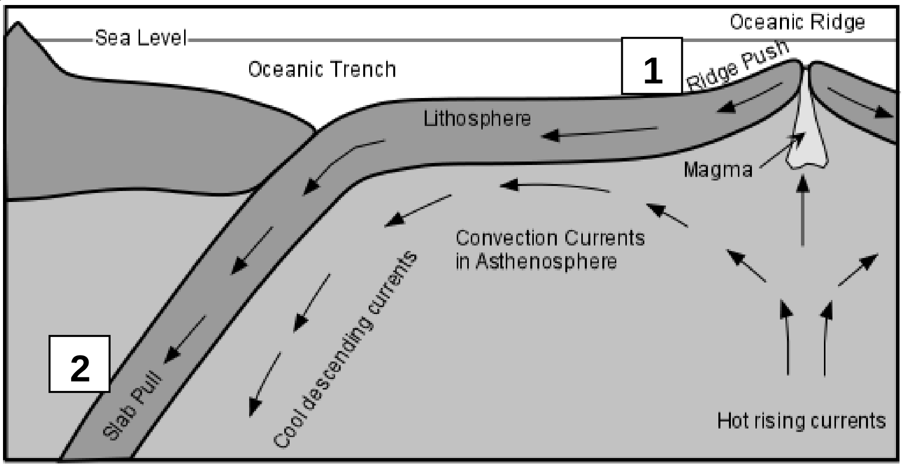
Plate Tectonics

The lithosphere of the Earth is underlain by a weaker zone in the mantle called the asthenosphere. This is a seismological low-velocity zone (see below). The lithospheric plates forming the surface of the Earth are in motion. This motion is controlled by convection currents in the asthenosphere and lower mantle, which both have areas of partial melt.

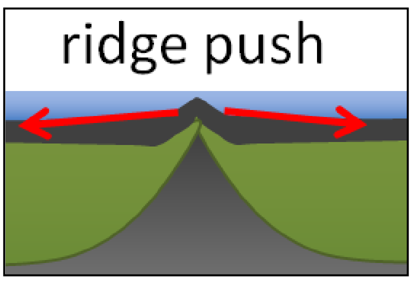
The areas at depths of 50 to 600 km have many low velocity zones where the waves are slowed this is due to partial melting. Earthquake waves are slowed on moving into a new material particularly partially molten ones. These partially molten areas allow convection currents to be set up. These help to drive the plates in a conveyor belt of tectonic movement.



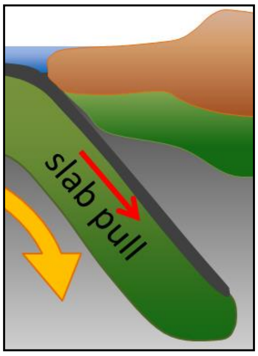
There are two main theories as to how these convection currents actually move the plates. These are illustrated below:



1) **Ridge push** – this is the theory suggesting that the main mechanism driving the plates occurs at divergent (constructive) plate margins. As magma rises it forces the crust to rise at the ridge. As the crust rises gravity then forces it away from the margin, thus driving the crust.

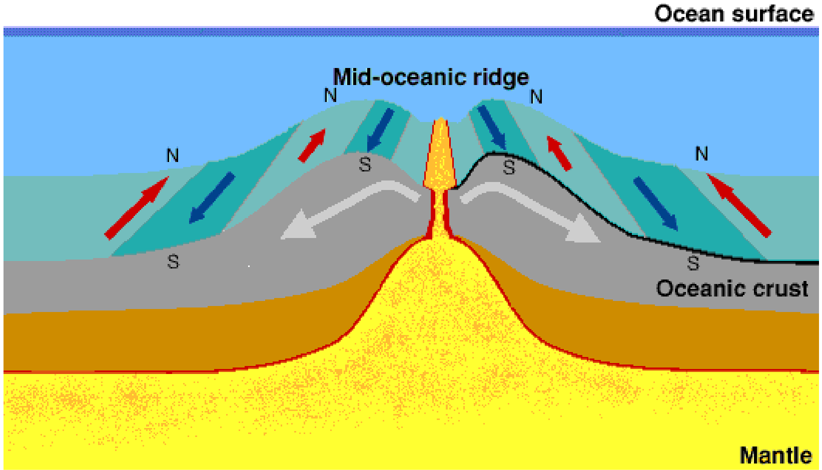


2) **Slab pull** – this however suggest that the main driving force is the subduction of the colder, denser oceanic crust into the mantle. This effectively pulls the oceanic crust along behind it. Many scientists today believe that this is the main driving force behind plate movement, far more so than ridge push.



This constant driving of the surface plates creates our tectonic conveyor belt. This is where plates are formed, driven along and then eventually subducted and returned to the mantle. This creates three main types of plate boundary:

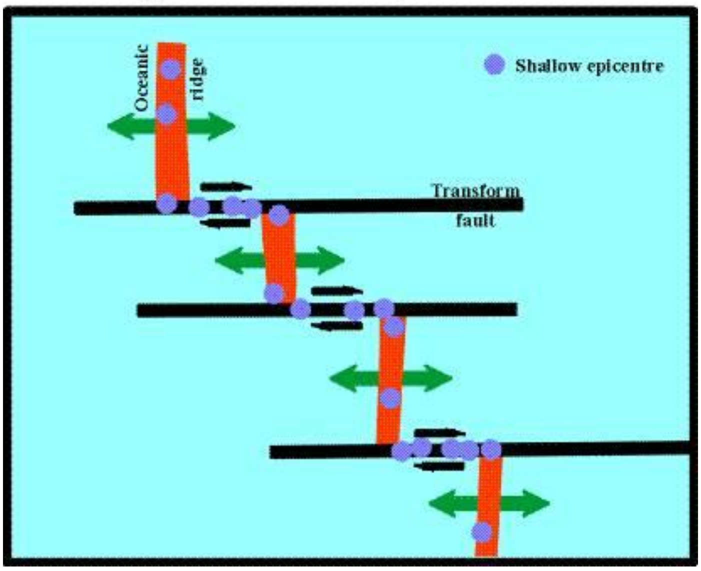
Divergent (constructive) plate boundaries



Sea floor spreading at the mid-oceanic ridge

Where plates move apart or diverge there is never a continuous rate of movement so the boundary is split along transform faults (see below).

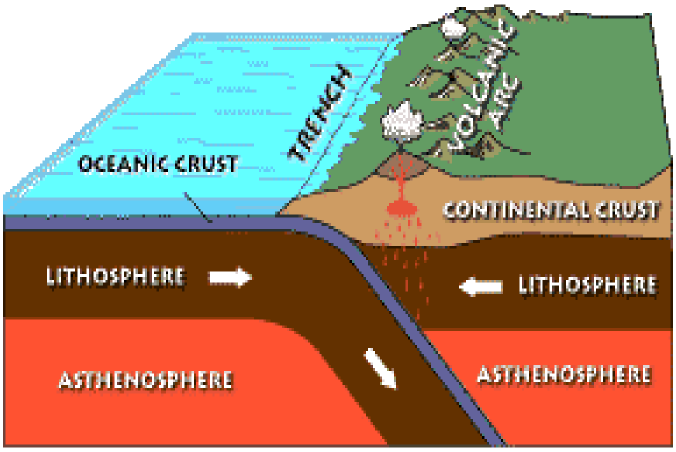
Earthquakes along
divergent and transform plate boundaries



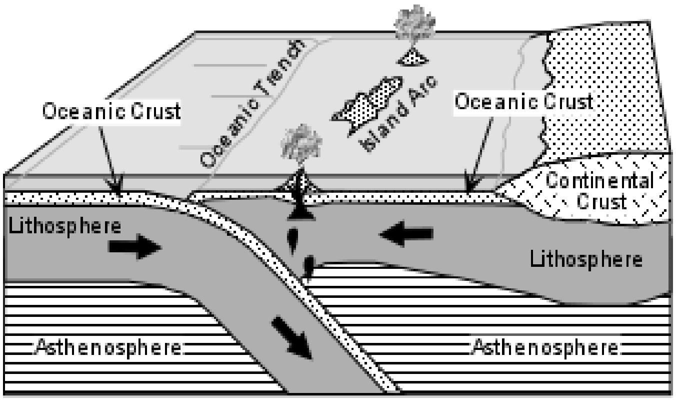
Convergent (destructive) plate boundaries

These are where plates converge or come together. They can be:

a) Continental and Oceanic:

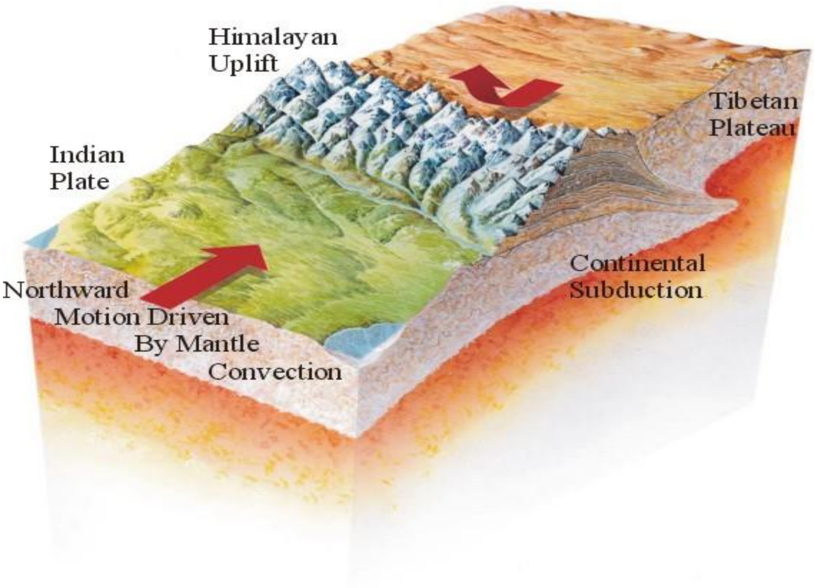


b) Oceanic and Oceanic:



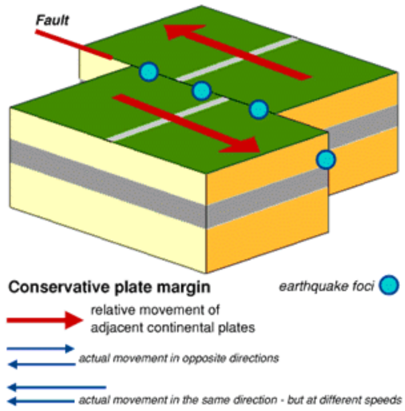
Ocean - Ocean Convergence

c) Continental and Continental:



Conservative (sliding) plate boundaries

These are found where plates are driven alongside each other neither converging nor diverging.



In conclusion all elements of the rock cycle (see next topic) can be linked to the internal structure of the earth and the plate tectonic processes that this creates:

- Igneous rocks – these are formed by the generation of magma at plate boundaries due to partial melting of the upper mantle. This magma then rises and either cools within the crust or erupts as lava onto the surface.
- Sedimentary rocks – erosional processes and depositional environments are influenced by tectonic movements e.g. the uplift of fold mountains.
- Metamorphic rocks are often formed due to large-scale intrusions of magma from the partially melted upper mantle. These heat and change the surrounding material. Regional metamorphism is due to subduction of plates at convergent plate boundaries or occurs in deeply buried rocks in fold mountain zones.