

EARTH'S INTERIOR

Information on Earth's interior:

- 1) seismic waves - earthquakes and nuclear explosions.
 seismic waves
 pass through the earth
 generate information on rocks they travel through
 Similar to x-ray - indirect sampling.

Direct sampling:

- 1) wells - not deep enough for direct information.
 Deepest well - the Russian Kola well - 13 kilometers deep.
- 2) Volcanic activity - may sample top 200 kms.

Earth's Interior

Information from:

- 1) P (compressional) and S (shear) waves
 penetrate the earth and emerge at some distant point.
 measuring time seismic waves travel from earthquake or nuclear explosion
 to a seismograph station.
 travel time depends upon rock materials encountered.
 seismologists study variations in travel times that cannot be
 accounted for simply by distances traveled.
 These variations correspond to changes in rock properties.

Need to know exact location and time of seismic event.

- Nuclear test explosions more exact than earthquakes.
- Post 1960 - extensive nuclear testing.

The Nature of Seismic Waves

To examine earth's composition and structure, we need to understand basic properties of wave propagation.

Seismic waves travel out from their source in all directions as a wave.

Significant characteristics of seismic waves include the following:

- 1) Velocity of the waves depends on the density and elasticity of the intervening material.
 Travel more rapidly in rigid material.
 e.g. Crystalline rocks transmit seismic waves more rapidly than
 unconsolidated sediments.

2) Within a given layer the speed of seismic waves increases with depth because the rock is a more compact (dense) material.

3) Compressional waves (P waves) which oscillate back and forth in the same direction as their direction of motion travel through solids as well as liquids.

Shear waves (S waves) oscillate at right angles to the direction of their motion, cannot travel through liquids - they have no shear strength.

4) In all materials, P waves travel faster than S waves.

5) When seismic waves pass across the boundaries of two materials of different densities, the path of the wave is bent (refracted).

Some of the energy is also reflected at surfaces of two dissimilar materials.

Depending on the nature of the layers through which the seismic waves pass, they are either speed up or slowed down, refracted or reflected, or cannot pass.

These changes allow seismologist's to probe the earth's interior.

If Earth were a perfectly homogeneous body, seismic waves would spread through Earth in all directions in a straight line at a constant speed.

However, with the earth, there is an increase in speed with depth as a consequence of increased pressure which enhances the elastic properties of deeply buried rock.

As a result, the paths of seismic rays through the earth are refracted (bent)

Abrupt changes were mapped at particular depths.

These worldwide discontinuities showed that the earth was composed of distinct layers or shells of varying composition or structure.

Compositional layering - believed to have resulted from density sorting which took place during an early molten period in the earth's history. At this time, heavier substances sank while lighter components floated upward.

Structural layering - represents materials of the same composition which have undergone a phase change.

Phase changes occur when rock has:

- 1) partially or entirely melted, or
- 2) when the atoms in minerals have rearranged themselves into tighter crystalline structures in response to the enormous pressures existing at great depths.

Based on seismological data, the earth has been divided into four major layers:

- 1) the **crust** - a very thin outer layer;
- 2) the **mantle** - a rocky layer located below the crust and having a maximum thickness of 2885 kms;

3) the **outer core** - a layer ~2270 kms thick that exhibits characteristics of a mobile liquid; and

4) the **inner core** - a solid metallic sphere, ~ 1216 kms in radius.

Earth's Structure

Mohorovicic (1909) discovered boundary separating crust from mantle.

Mohorovicic discontinuity - Moho.

Determined waves travelling through the mantle were faster than those travelling through the crust based on first arrivals at seismic stations.

Crust - average P wave velocity of 6 km/sec.

Upper mantle - average P wave velocity of 8 km/sec.

Below 30 kms there exists a layer with physical properties markedly different from those of the earth's outer shell.

A few years later Gutenberg discovered another zone.

Based on observation that P waves diminish and eventually die out completely about 105 degrees from an earthquake.

Then about 140 degrees away, the P waves reappear, but two minutes later than would be expected based on the travel distance.

This belt where direct seismic waves are absent is about 35° wide and was named the **shadow zone**.

The shadow zone could be explained if Earth contained a core composed of material unlike the mantle and had a radius of 3420 kms.

The core must have hindered the transmission of P waves. But instead of stopping P waves, the shadow zone is produced by the bending of P-waves which enter the core.

It was later learned that S-waves could not propagate through the core

geologist concluded that a portion of this region is liquid.

further supported by observation that P wave velocities suddenly decreased about 40% as they enter the mantle.

In 1936, the core, the last major subdivision of the earth's interior was predicted by the discovery of seismic waves believed to be reflected from a boundary within the core.

P waves passing through the inner core have faster velocities than those penetrating the outer core - evidence of the solid nature of the inner core.

Crust

Thinnest layer averaging 20 kms.

Continental crust - ~35 kms; maximum 60 kms in mountainous regions.
 Oceanic crust - ~5 kms

Compositional differences between oceanic and continental crust was first established by seismic waves:

P waves of 6 km/sec for continents vs. 7 km/sec for the oceans.

continental crust - average composition is granite. density 2.8
 oceanic crust - predominantly basaltic. density 3.1

large increase in temperature with depth in crust.

Mantle

Over 80% of the earth's volume is contained within the mantle.

A 2885 km thick shell of rock extending from the base of the crust (Moho) to the liquid outer core.

Information on the mantle comes from experimental data and intrusives
 e.g. kimberlite pipes (from 200 kms).

Kimberlites composed of peridotite - an ultramafic rock
 iron and magnesium - rich silicate minerals
 olivine and pyroxene.

Mantle - solid layer with upper part composed of peridotite.

the lower mantle is very hot

rock of the mantle must be capable of flow.

materials exhibit plastic behavior.

capable of flow

no earthquakes from brittle deformation

but behaves like a solid and transmit S waves

solid under certain conditions, and a fluid under other conditions.

Mantle - composed of hot, solid rock, which under extreme pressures exhibits the ability to flow.

The mantle also has finer subdivisions:

1) **low-velocity zone** - located between 100 and 250 kms.

P and S waves show a marked decrease in velocity

probably due to a small amount of melt.

This region of weak rock from 100-350 kms - the **asthenosphere**.

This weak rock layer exists because the rock is nearer its melting temperature than the rock above or below it.

The rock in this zone is easily deformed, and facilitates the motion of the rigid layer above.

lithosphere - a cool brittle layer ~100 kms thick above asthenosphere.
includes the crust as well as the uppermost mantle
a layer of Earth cool enough to behave like a brittle solid.

The Core

radius of 3486 kms.

extends from inner edge of mantle to center of Earth.
about one-sixth of Earth's volume and ~1/3 of its total mass.
Pressures far more extreme than at the earth's surface
temperatures estimated to be ~4000 - 5000° C.

split into a liquid outer core and a solid inner core.

Earth's magnetic field is thought to be generated by the vigorous mixing of molten iron alloy in the liquid outer core.

composition of core believed to be iron - based on density requirements.
density of core at center of Earth is 13.5 times that of water.