

INTERIOR OF THE EARTH

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The Earth is a dynamic planet and formed about 4600 million years ago, together with the Sun and the other planets in the Solar System (Figure 1). The Sun and the planets (including the earth) were derived from a rotating disc of dust and gas, called the "Solar Nebula". The Solar Nebula formed when a disc of gas and dust became detached from a larger molecular cloud in a spiral arm of the Milky Way galaxy and collapsed under gravitational attraction into a disc. The currently favored hypothesis is that the Earth and the other terrestrial planets (Mercury, Venus and Mars) accreted from a hierarchy of planetesimals of varying size, which were thought to have formed at a very early stage in the Solar Nebular. The planetesimals are thought to be the building blocks of the terrestrial planets (Mercury, Venus, Earth and Mars).

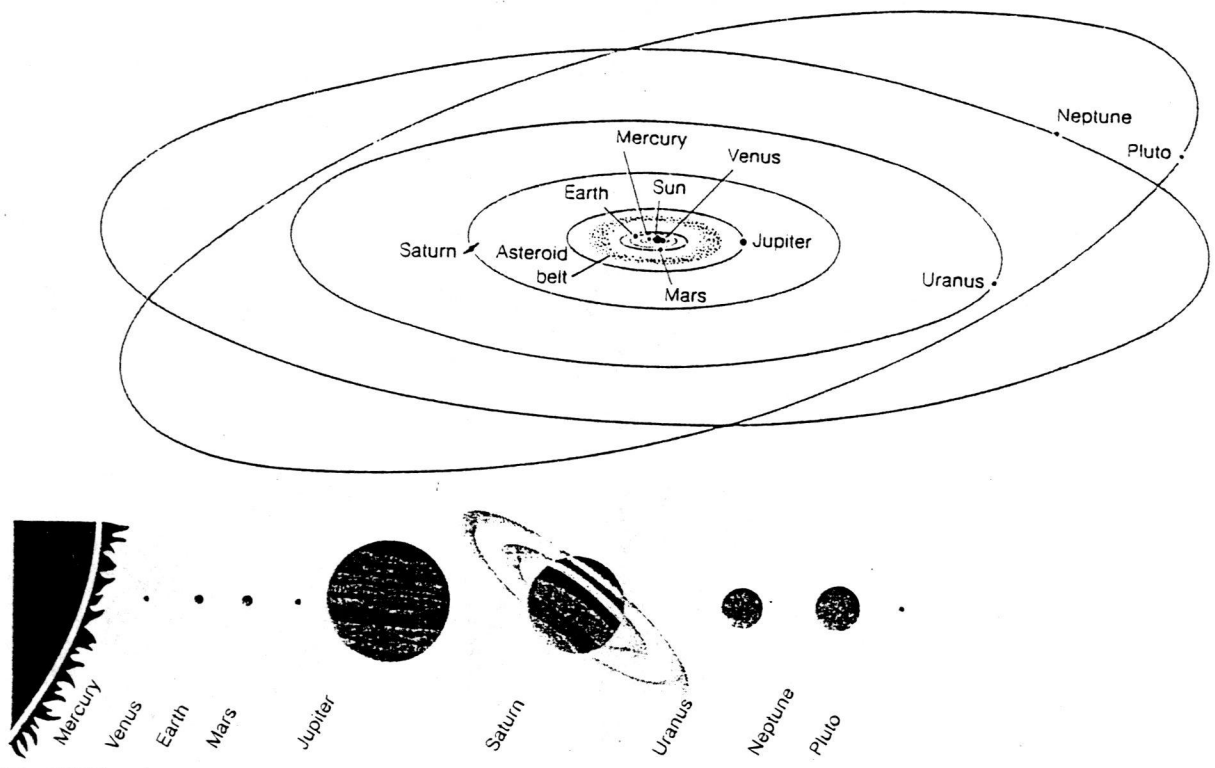


Figure 1. The solar system. Diagrammatic representations of the Sun and planets.

It has been argued that the Earth may have formed from bodies, which had already differentiated into metallic cores and silicate mantles. Scientists believe that growing planets were molten - at least partly, and at least once. At such times, their component materials had the opportunity to separate according to melting points and densities. After the accretion of the Earth, the temperature of its interior increased due to many reasons. After 1000 million years the interior heated to the melting point of iron at depths between 400 km and 800 km, and iron began to melt in this region (Figure 2). The heavy materials, especially iron, sank towards the interior of the Earth, creating what is called the core, and light ones rose to the surface, creating the outer layer of the Earth, called the crust (Figure 3.). The region between those two is called

the mantle, which itself became layered according to chemistry and density. The process of gravitational separation is usually called differentiation, which was responsible for the formation of a layered Earth, as shown in Figure 3. This differentiation has also created a light crust depleted in iron and enriched in O₂, Si, Al, Ca, K and Na (Figure 4).

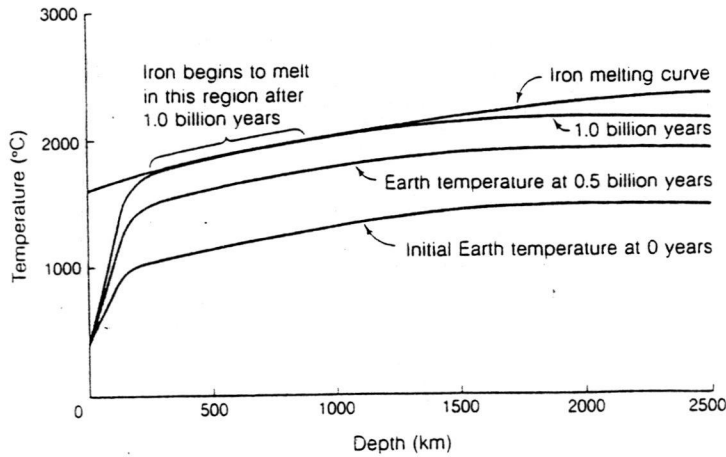


Figure 2. Temperature in the Earth's interior at different times in its history, according to a calculation by T.C. Hanks and D.L. Anderson. The lowest curve shows the initial temperature due to accretion and compression at 0 years. After 500 million years radioactivity warmed the Earth to the temperature shown by the next curve. After one billion years the interior heated to the melting point of iron at depths between 400 km and 800 km, and iron began to melt in this region.

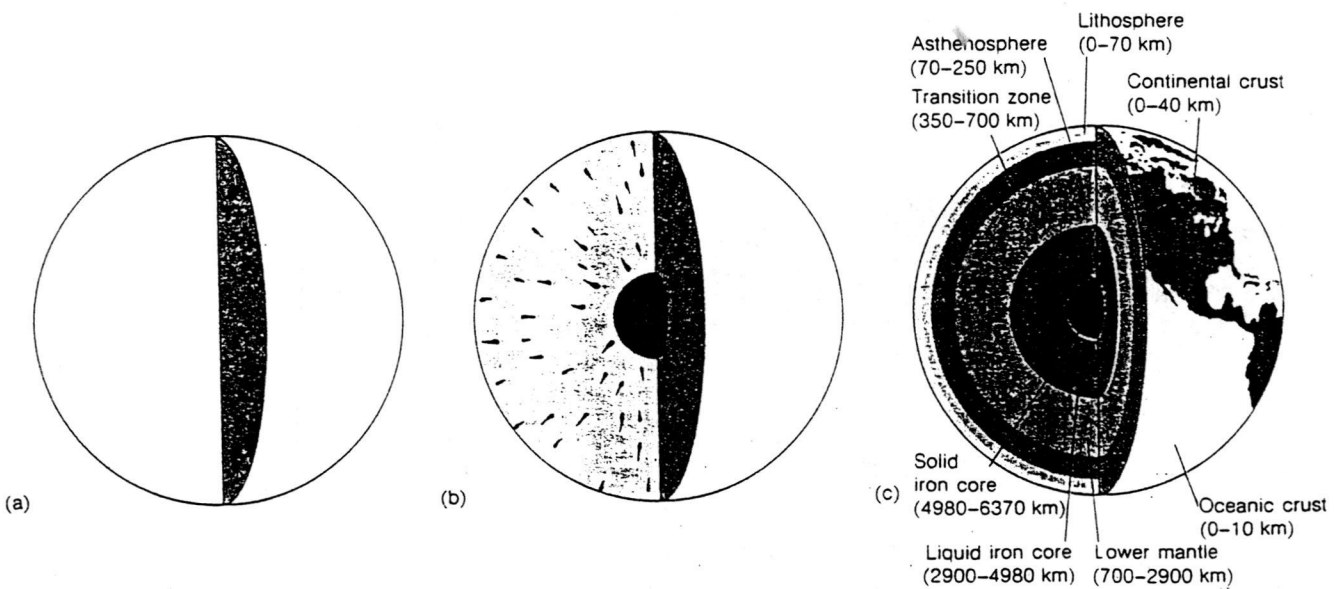


Figure 3. The early Earth (a) was probably a homogeneous mixture with no continents or oceans. In the process of differentiation, iron sank to the centre and light material floated upwards to form a crust (b). As a result, the Earth is a layered planet (c) with a dense iron core, a surficial crust of light rocks, and between them a residual mantle.

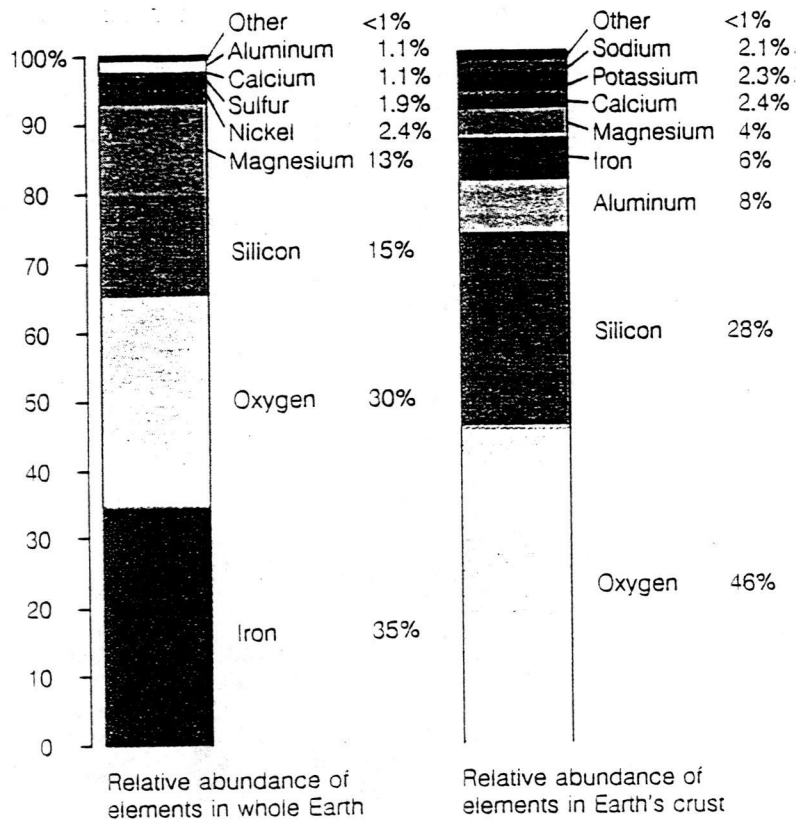


Figure 4. Relative abundance by weight of elements in the whole Earth and in the Earth's crust. Differentiation has created a light crust depleted in iron and enriched in oxygen, silicon, aluminum, calcium, potassium, and sodium.

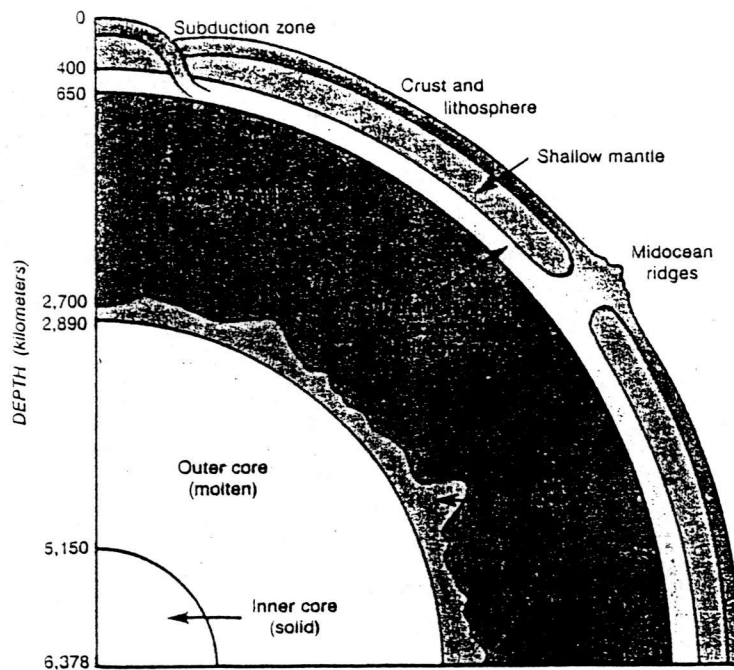


Figure 5. Cross section of the interior of the Earth showing different layers.

Earthquakes that occur in technically active regions of the world (see course notes on Earthquakes and Volcanoes) generally generate a large amount of elastic energy, which transmits through the Earth as seismic waves. The wave fronts of earthquakes are refracted (bent) and reflected by discontinuities and gradients in material properties in the Earth's interior and recorded at seismic stations on the surface of the Earth. The seismic waves are of two types. These are (i) body waves and (ii) surface waves. Velocities of these seismic waves depend upon elastic module and density of the medium through which they travel. From analysis of seismic waves, seismologists have confirmed the layered nature of the Earth's interior and have divided the planet into a crust, mantle and core and into numerous smaller subdivisions such as the upper mantle, transition region, lower mantle, outer core and inner core (Figures 3, 5, 6).

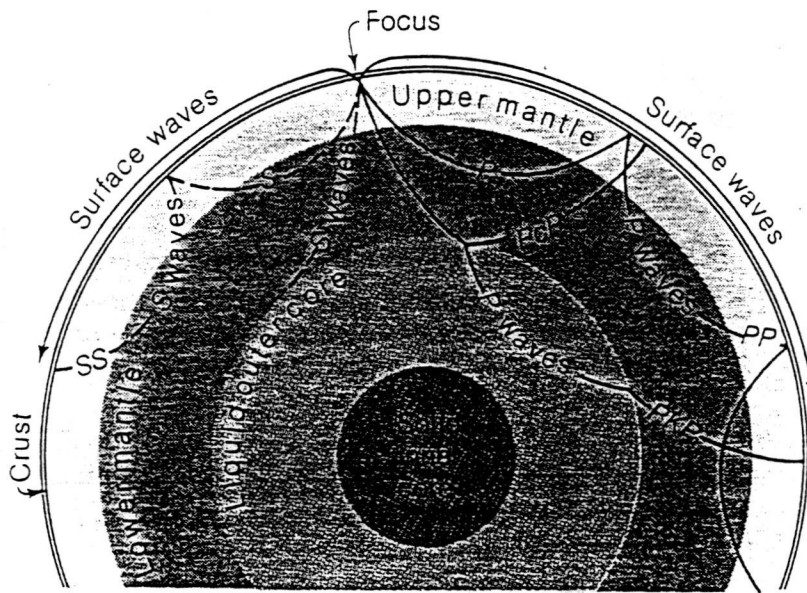


Figure 6. *P* and *S* waves radiate from an earthquake focus in many different directions. Waves reflected from the Earth's surface are called *PP* or *SS*. *PcP* is a wave that bounces off the core, and *PKP* is a *P* wave transmitted through the liquid core. *S* waves cannot travel in a liquid.

Crust:

The crust consists of the region above the Moho and is divided into two as oceanic crust (containing oceanic part) and continental crust (continental part). The thickness of the crust changes from about 3 km in some oceanic regions to about 80 km in some continental areas.

Upper mantle:

The upper mantle extends from the top (~650 km depth) of the lower mantle to the base of the crust (Figures 5, 7). The upper mantle and the crust are separated by a seismic discontinuity called *Mohorovicic* discontinuity or *Moho*. The depth to the Moho varies from place to place: 10-12 km beneath the oceans and 30-35 km beneath the continents. The rocks of the base of the oceans (oceanic crust) are derived from the upper mantle.

Lower mantle:

The lower mantle is the largest subdivision of the Earth. It extends from the top of D'' layer (Figure 5) (about 2740 km depth) to the major seismic discontinuity at a depth near 650 km. (Figure 5).

Outer core:

This extends from the boundary of the inner core (5155 km depth) to the core-mantle boundary, which is at a depth near 2900 km (Figure 5). The outer core, about 30% of the Earth's mass, is liquid and composed of iron-sulphur mixture containing roughly 12% sulphur and probably 2% nickel.

Inner core:

The inner core, 1.7% of the Earth's mass, is solid and composed of iron-nickel alloy (probably about 20% Ni and 80% Fe). The inner core is about the size of the moon.

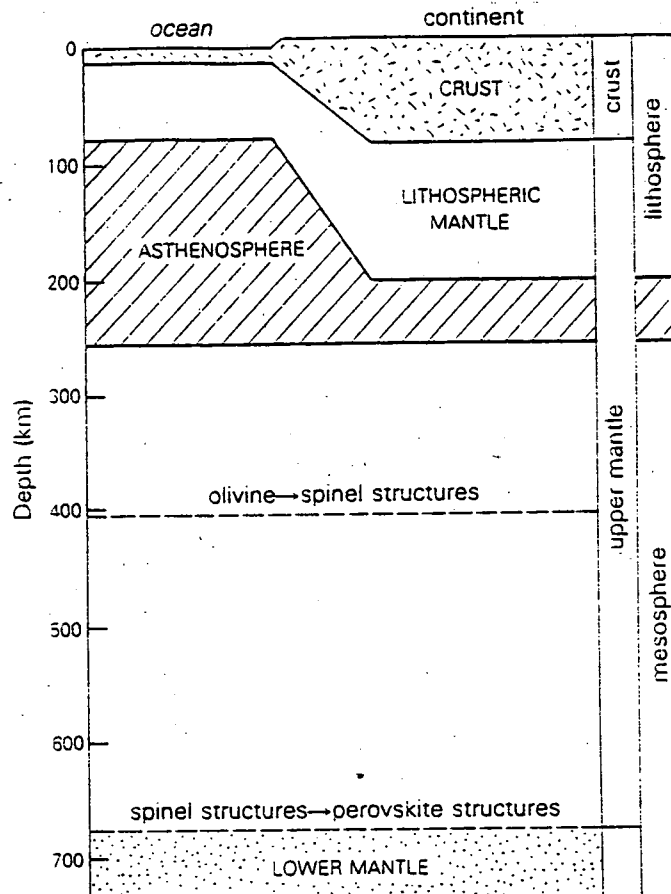


Figure 7. The major regions of the upper 700 km of the Earth.

Lithosphere and asthenosphere

According to the seismic velocity changes the upper 700 km of the Earth has been subdivided into three main regions. These are, from top, lithosphere, asthenosphere and mesosphere (Figure 7). The lithosphere contains the complete crust and the upper part of the upper mantle and its thickness varies from 50 km to 150-200 km (Figure 7). This is the strong outer layer of the Earth and forms plates, which move about the surface according to the plate tectonic theory. This is discussed in the course note on "Plate Tectonics and Continents". The asthenosphere is a weak layer, on which the lithospheric plates move, and extends from the base of the lithosphere down to about 250 km.

The Earth's magnetic field

Some minerals (e.g. magnetite) and rocks (e.g. ironstone and other iron-rich rocks) in the Earth's crust exhibit magnetic properties. These materials have acquired their magnetism from the Earth's magnetic field existed at the time of their formation. Not all the planets have a magnetic field associated with them. For example, Venus and Mars show no magnetic fields. To a good approximation, the magnetic field at the surface of the Earth is like that due to a powerful bar magnet situated at the Earth's centre and aligned roughly along the axis of its rotation. Since the core of the Earth is likely to be made largely of iron, it might be thought that the solid inner core behaves like a permanent magnet. Scientists have found that the strength and position of the Earth's magnetic field have changed with time. The Earth's magnetic field is a highly variable and dynamic system on all scales of time, a system that has been in existence for most of its history and which is not due to permanent magnetism in the Earth's core. How, then, is the magnetic field generated in the Earth's core? The Earth's magnetic field is thought to originate as a self-exciting dynamo. The Earth's outer core, which consists of fluid iron, generates its own magnetic field. Large scale fluid movements in the core seem to offer the best possibility for explaining the Earth's magnetic field. The magnetic field of the Earth has reversed many times in the past, which is referred to as geomagnetic reversal.