science
& technology
Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA

JOURNEY FROM THE CENTRE OF THE EARTH

What lies beneath our feet?

We can circum-navigate or orbit the Earth's surface with comparative ease, but yet when it comes to exploring its depth we barely leave the surface. The gold mines in South Africa go down to about 4-5 kilometres into the earth, and ultra-deep drilling by the Russians has gone down just about 15 kilometres. While these are incredible technological achievements, they still only represent about 0.2 % of total distance to the centre of our planet. Therefore, if we want to know our planet's structure, composition, temperature, pressure and other fundamental properties, we have to interpret the signals that originate from the great depths of the earth to understand our Planet.

How do we know that the Earth is round?

The simple fact that heavenly bodies such as the sun and the moon look round probably led many people (e.g. Pythagoras) to make the obvious conclusion that the Earth is no different. The invention of the telescope to view neighbouring planets confirmed earth's round shape. Eratosthenes utilised the sun's shadow at two points 800km apart in ancient Egypt, measured at noon on mid-summers day, to first of all to conclude that the Earth was a round ball and second to have a circumference of about 40,000 km, pretty close to the accepted value. Explorers like Ferdinand Magellan and Francis Drake who circumnavigated the earth, established beyond dispute that the Earth was a globe. And of course, more recent observations of earth from space confirmed that the earth is round. Because the Earth has a spherical shape, it means that it is likely that the other layers of the earth will probably occur as a series of concentric layers.

How do we know what the inside of the earth is made of?

Geomagnetism gives important clues: if you hold a compass in an open field the iron needle will align itself in a consistent direction that remains unaffected even when you turn around in a circle. This behaviour can be reproduced by placing a pocket magnet nearby and thus it can be deduced that the Earth has some natural magnetic property. This means that the inside of the Earth must contain some sort of metallic iron substance.

What is other evidence that our Earth contains metallic iron inside?

Clues from the force of gravity and the density of earth:

The Earth's average density is about 5.5 kg per cubic km. This value is significantly higher than that of the common rocks we encounter on the surface, e.g. Table Mountain sandstone has a value of 2.5. It therefore seems that something extremely dense must be present underneath to raise the average density of earth to 5.5. Metallic iron has a density of around 8 and so could provide a solution to this problem.

Table Mountain

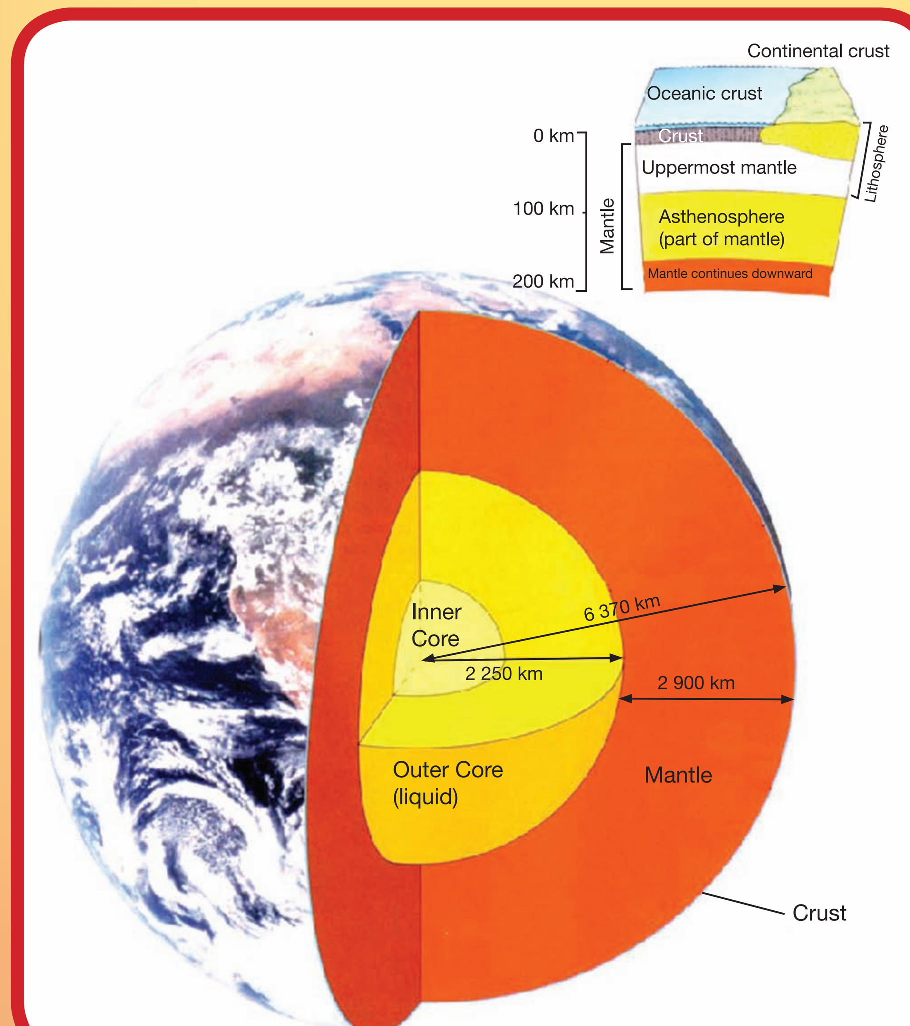
Meteorites

Meteorites are fragments of Earth-like planetary bodies that fall to earth. Large circular craters found throughout Southern Africa are good evidence for meteorite impacts, e.g. the Tswaing crater near Pretoria. Often remnants of the meteorites survive the impact and tell us about their composition. For example, the meteorites Hoba and Gibeon that fell onto Namibia are both solid iron with minor amounts of nickel and are interpreted as being derived from the interior of a long disrupted planet that now largely occupies the asteroid belt between the orbits of Mars and Jupiter.


Hoba Iron-Nickel meteorite, near Grootfontein, northern Namibia

Tswaing impact crater (Pretoria Saltpan)

View from the rim of Meteor Crater, Arizona, USA



What size is the metallic body inside the Earth?

The metallic core of earth is estimated to be at least half the diameter of the Earth! This is calculated by assuming a density of around 10 kg per cubic km for a Fe-Ni metal alloy body then some rough estimates of its size could be made by juggling values for the lighter rocks that surround it, which have densities in the range 2.5 – 3.5.

How can earthquakes help provide a more accurate estimate for the size of the Earth's core?

Earthquakes represent seismic energy released when rocks break under high pressures and the vibrations travel through the Earth and are felt at practically every point on the surface. The vibrational energy becomes a compressional P-wave that travels faster than the shear S-wave. If the location of the earthquake is known then detectors spread around the surface of the Earth can record the time it takes for the seismic waves to arrive.

The time taken for the earthquake to be felt at various locations allows the speed of the seismic waves to be calculated. The speed is controlled by the density of the rocks through which they travelled, and provides an independent estimate that can be compared to those obtained by other methods.

Some locations do not receive any P- and/or S-wave arrivals from a particular earthquake (i.e. the shadow zones) and their distribution has been used to estimate the size of the concentric Earth shells, particularly the boundary between the core (metallic part) and the surrounding mantle (rocky part).

What is the precise internal structure of the Earth?

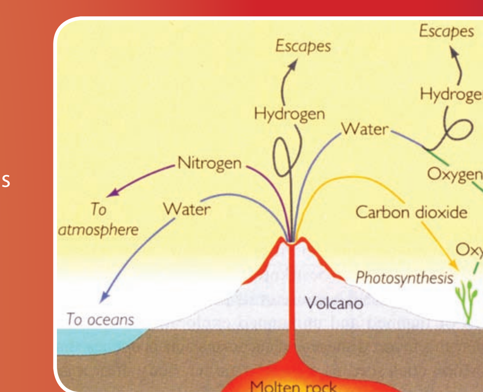
The outer part of the Earth to a depth of 2 900 km is made up of rock with densities in the range 3 – 5 kg per cubic km, while the inner heavy core is about 3 400 km. Seismic evidence further suggests that the core has a liquid outer zone with an approximate thickness of 2 300 km and a solid inner zone.

What do we know about the pressures within the Earth?

The pressure increases with depth due to the weight and magnitude of the overlying rock, and also depends on its density and ultimately its chemical composition. The pressure at the core – mantle boundary is estimated to be 135 GPa, increasing to a massive 360 GPa at the centre.

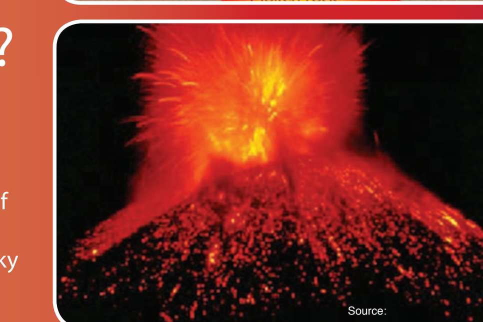
How hot is it within the Earth?

That the interior of the Earth is hot is obvious from the eruption of molten magma from active volcanoes and there is abundant evidence that this has been going on during the Earth's entire history. Descent into mines confirms the rise in temperature and provides an estimate of the temperature changes for the first few km. Considering these changes in temperature, it is estimated that the core – mantle boundary temperature is about 3700 degrees Celsius, while centre temperature is about 6700 degrees Celsius.



Where does the heat come from?

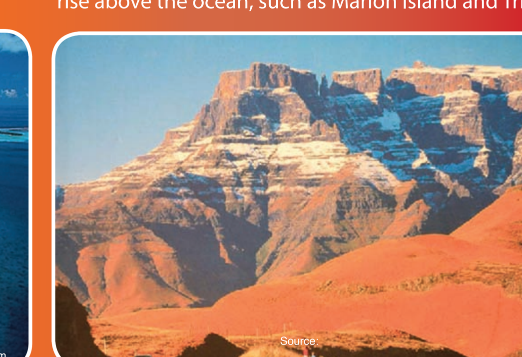
When the Earth was originally formed from a swirling cloud of rocky and metallic fragments, dust and gases of the early solar system, the kinetic energy was partly transformed into heat. The thermal consequences of this gravitational collapse would have been sufficient to melt metal and some of the rocky material, thereby allowing the heavier metal to sink towards the centre of the young Earth, forming the core. It is thought that the outer rocky mantle probably also melted and then re-solidified as the heat was lost by conduction to the surface and radiation into space. Estimates of the time taken for the planet to cool (about 40 million years) is significantly shorter than the age of the Earth (about 4500 million years), so there must be an additional source of heat energy to sustain the geothermal gradient and the intense temperatures still evident in the interior. The most likely source of the present day Earth's internal heat engine is radioactivity, an exothermic process involving the decay of long-lived isotopes of elements that occur within the mantle and core. Elements such as Potassium (K), Uranium (U) and Thorium (Th) are abundant and possess radioactive isotopes that are a similar age as the Earth (billions of years).



Volcanic islands

How important is this planetary heat source?

The hot interior of the Earth is capable of convective movement, since the high temperature can reduce viscosity of all materials, liquid or solid, rock or metal. Convection in the liquid outer core explains the geomagnetic field and is likened to a dynamo where a circulating electric current is maintained in the moving metal. Slow convection in the mantle is thought to drive the movement of continental plates and the intense volcanic activity along their boundaries. Phase changes at the core – mantle boundary are thought to be responsible for narrow plumes of hot material rising towards the Earth's surface, causing volcanic centres like Hawaii and other remote islands that rise above the ocean, such as Marion Island and Tristan Da Cunha. One such mantle plume rose up under the Gondwanaland super continent about 180 million years ago and generated a huge eruption of lava that probably covered most of what is Southern Africa. The remains of the vast volcanic plateau are what is now the Drakensberg Mountains.

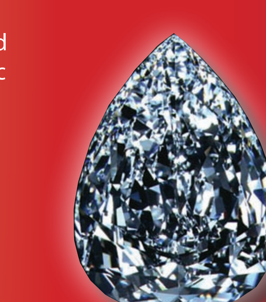


Drakensberg Mountains

What do diamonds tell us about the mantle?

The Big Hole at Kimberley

Convection of the sub-continental mantle has been used to explain the eruption of many smaller pipes of volcanic material that are distributed across Southern Africa, the most significant of which occur around Kimberley. The diamond pipes of Kimberley contain fragments of the Earth's mantle from depths of up to 200 km below the surface. In fact our best estimate of mantle composition and mineral content is based on this sample that was transported within the kimberlite magma. Our studies indicate that most of the diamonds are themselves derived from the mantle, formed under conditions of high temperature and pressure.



The Cullinan Diamond - the world's biggest cut diamond at 530 carats

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