ENVIRONMENTAL GEOSCIENCES

## ENV C22

M.Sc , 2nd Semester

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Internal structure of the Earth

The interior of the Earth is divided into layers by their chemical or physical properties. The outer layer of the Earth is a chemically distinct silicate solid crust, which is underlain by a highly viscous solid mantle. The crust is separated from the mantle by the Moho discontinuity, and the thickness of the crust varies: averaging 6 km under the oceans and 30–50 km on the continents. The crust and the cold, rigid, top of the upper mantle are collectively known as the lithosphere, and it is of the lithosphere that the tectonic plates are comprised. Beneath the lithosphere is the asthenosphere, a relatively low-viscosity layer on which the lithosphere rides. Important changes in crystal structure within the mantle occur at 410 and 660 kilometers below the surface, spanning a transition zone that separates the upper and lower mantle. Beneath the mantle, an extremely low viscosity liquid outer core lies above a solid inner core. The inner core may rotate at a slightly higher angular velocity than the remainder of the planet.

Internal structure of the Earth

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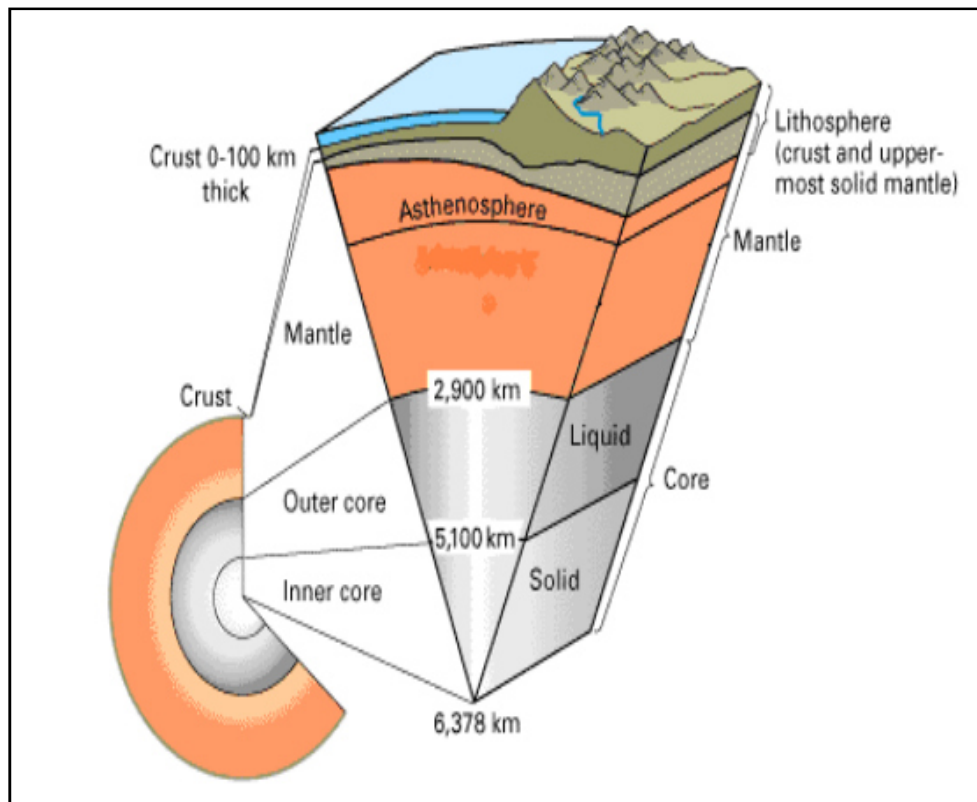
Region	Depth (km)	Fraction of Total Earth Mass	Fraction of Mantle and Crust
Continental crust	0–50	0.00374	0.00554
Oceanic crust	0–10	0.00099	0.00147
Upper mantle	10–400	0.103	0.153
Transition region	400–650	0.075	0.111
Lower mantle	650–2890	0.492	0.729
Outer core	2890–5150	0.308	—
Inner core	5150–6370	0.017	—

Inner core: 1.7% of the Earth's mass; depth of 5,150-6,370 kilometers (3,219 - 3,981 miles). The inner core is solid and unattached to the mantle, suspended in the molten outer core. It is believed to have solidified as a result of pressure-freezing which occurs to most liquids when temperature decreases or pressure increases.

.**Outer core:** 30.8% of Earth's mass; depth of 2,890-5,150 kilometers (1,806 - 3,219 miles). The outer core is a hot, electrically conducting liquid within which convective motion occurs. This conductive layer combines with Earth's rotation to create a dynamo effect that maintains a system of electrical currents known as the Earth's magnetic field. It is also responsible for the subtle jerking of Earth's rotation. This layer is not as dense as pure molten iron, which indicates the presence of lighter elements. Scientists suspect that about 10% of the layer is composed of sulfur and/or oxygen because these elements are abundant in the cosmos and dissolve readily in molten iron.

D region: 3% of Earth's mass; depth of 2,700-2,890 kilometers (1,688 - 1,806 miles) this layer is 200 to 300 kilometers (125 to 188 miles) thick and represents about 4% of the mantle-crust mass. Although it is often identified as part of the lower mantle, seismic discontinuities suggest the D layer might differ chemically from the lower mantle lying above it. Scientists theorize that the material either dissolved in the core, or was able to sink through the mantle but not into the core because of its density.

Lower mantle: 49.2% of Earth's mass; depth of 650-2,890 kilometers (406 - 1,806 miles).The lower mantle contains 72.9% of the mantle-crust mass and is probably composed mainly of silicon, magnesium, and oxygen. It probably also contains some iron, calcium, and aluminum. Scientists make these deductions by assuming the Earth has a similar abundance and proportion of cosmic elements as found in the Sun and primitive meteorites.

Transition region: 7.5% of Earth's mass; depth of 400-650 kilometers (250- 406 miles).The transition region or mesosphere (for middle mantle), sometimes called the fertile layer, contains 11.1% of the mantle-crust mass and is the source of basaltic magmas. It also contains calcium, aluminum, and garnet, which is a complex aluminum-bearing silicate mineral. This layer is dense when cold because of the garnet. It is buoyant when hot because these minerals melt easily to form basalt which can then rise through the upper layers as magma.

Upper mantle: 10.3% of Earth's mass; depth of 10-400 kilometers (6 - 250 miles) The upper mantle contains 15.3% of the mantle-crust mass. Fragments have been excavated for our observation by eroded mountain belts and volcanic eruptions. Olivine $(Mg,Fe)_2SiO_4$ and pyroxene $(Mg,Fe)SiO_3$ have been the primary minerals found in this way. These and other minerals are refractory and crystalline at high temperatures; therefore, most settle out of rising magma, either forming new crustal material or never leaving the mantle. Part of the upper mantle called the asthenosphere might be partially molten.

Oceanic crust: 0.099% of Earth's mass; depth of 0-10 kilometers (0 - 6 miles) The oceanic crust contains 0.147% of the mantle-crust mass. The majority of the Earth's crust was made through volcanic activity. The oceanic ridge system, a 40,000-kilometer (25,000 mile) network of volcanoes, generates new oceanic crust , covering the ocean floor with basalt. Hawaii and Iceland are two examples of the accumulation of basalt piles.

Continental crust: 0.374% of Earth's mass; depth of 0-50 kilometers (0 - 31 miles). The continental crust contains 0.554% of the mantle-crust mass. This is the outer part of the Earth composed essentially of crystalline rocks. These are lowdensity buoyant minerals dominated mostly by quartz (SiO_2) and feldspars (metal-poor silicates). The crust (both oceanic and continental) is the surface of the Earth; as such, it is the coldest part of our planet. Because cold rocks deform slowly, we refer to this rigid outer shell as the lithosphere (the rocky or strong layer).
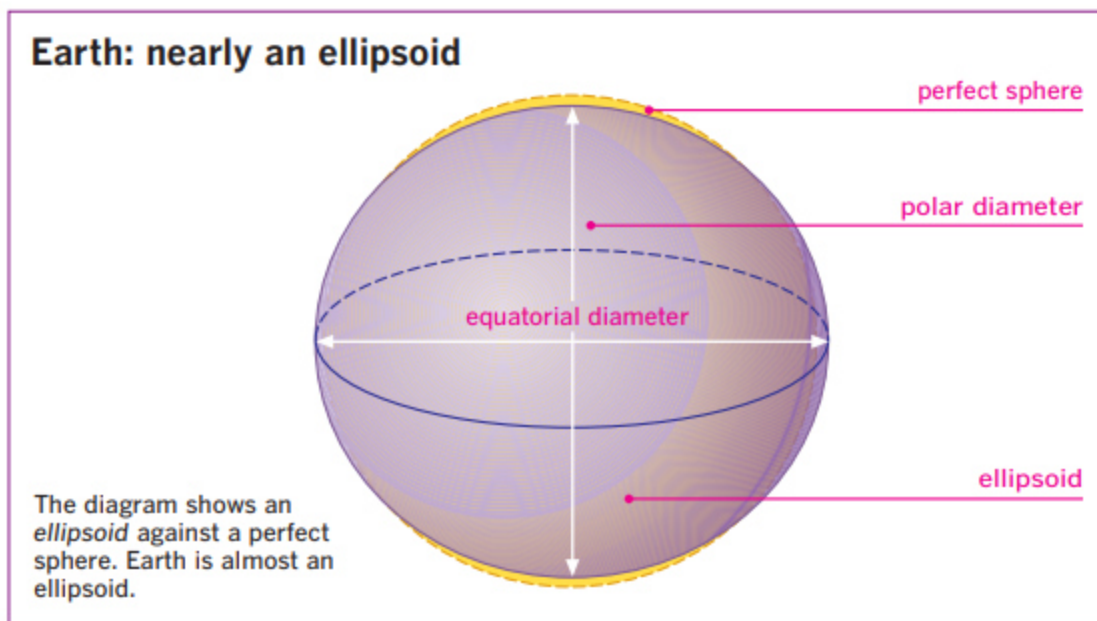
- *Asthenosphere :* *The asthenosphere is the region of the Earth between 100-200 km below the surface but perhaps extending as deep as 400 km that is the weak or "soft" zone in the upper mantle. It lies just below the lithosphere, which is involved in plate movements and isostatic adjustments. In spite of its heat, pressures keep it plastic, and it has a relatively low density. Seismic waves, the speed of which decrease with the softness of a medium, pass relatively slowly through the asthenosphere.*

- *Lithosphere:* *In the Earth, the lithosphere includes the crust and the uppermost mantle, which constitute the hard and rigid outer layer of the planet. The lithosphere is underlain by the asthenosphere, the weaker, hotter, and deeper part of the upper mantle. The boundary between the lithosphere and the underlying asthenosphere is defined by a*

difference in response to stress: the lithosphere remains rigid for long periods of geologic time and deforms elastically and through brittle failure, while the asthenosphere deforms viscously and accommodates strain through plastic deformation. The lithosphere is broken into tectonic plates. There are two types of lithosphere Oceanic lithosphere, which is associated with Oceanic crust and exists in the ocean basins and Continental lithosphere, which is associated with Continental crust. Oceanic lithosphere is typically about 50-100 km thick while continental lithosphere has a range in thickness from about 40 km to perhaps 200 km
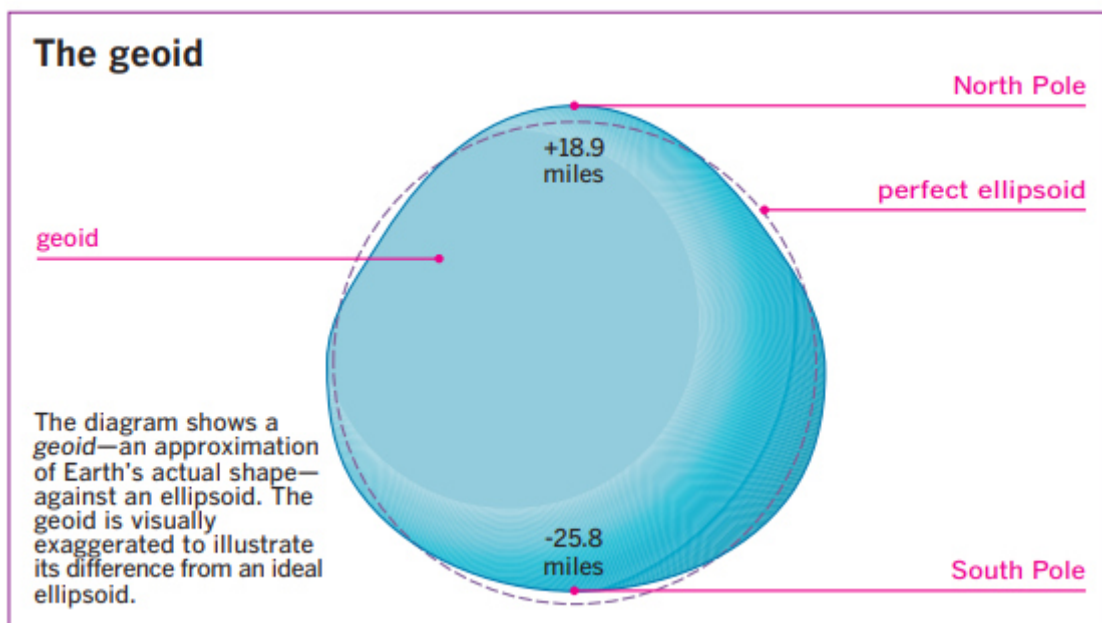
Earth: nearly an ellipsoid (spheroid)

● The distance from the North Pole to the South Pole of 7,900 miles (12,714 km) is 26 miles (42 km) shorter than the distance across the equator, which is 7,926 miles (12,756 km).

● The shape of Earth can be represented as a near-ellipsoid by visually exaggerating the differences between its polar and equatorial diameters.

Earth: nearly an ellipsoid

perfect sphere

polar diameter

equatorial diameter

ellipsoid

The diagram shows an *ellipsoid* against a perfect sphere. Earth is almost an ellipsoid.

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The geoid: Earth's actual shape

● The geoid is Earth's actual shape calculated to take account of its mass, elasticity, and rate of spin. It follows mean sea level in the oceans and is slightly pear-shaped, with the North Pole 18.9 miles (30 km) further from Earth's center than other places and the South Pole 25.8 miles (42 km) nearer

The diagram stresses Earth's pearlike shape by visually exaggerating small differences in distance from surface to center The diagram shows a geoid—an approximation of Earth's actual shape— against an ellipsoid.

The geoid

North Pole

+18.9 miles

perfect ellipsoid

geoid

The diagram shows a *geoid*—an approximation of Earth's actual shape— against an ellipsoid. The geoid is visually exaggerated to illustrate its difference from an ideal ellipsoid.

-25.8 miles

South Pole

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Isostasy

Isostasy (Greek ísos "equal", stásis "standstill") is the state of gravitational equilibrium between Earth's crust (or lithosphere) and mantle such that the crust "floats" at an elevation that depends on its thickness and density. This concept is invoked to explain how different topographic heights can exist at Earth's surface. When a certain area of Earth's crust reaches the state of isostasy, it is said to be in *isostatic equilibrium*. The term is used to describe an equilibrium to which the Earth's crust and mantle tend, in the absence of disturbing forces (Watts, 2001). Geological processes like volcanism, sedimentation, glacial movements, etc., disturb the equilibrium or static state of the Earth's outer shells - the crust and mantle. In general, Isostasy explains how Earth's crust and mantle responds to volcanic loads to maintain its state of equilibrium for a range of spatial and temporal scales. Isostatic observations are important tools to study the Earth's rheology, composition, structure and dynamics.

The idea of isostasy was first put forwarded by Leonardo Da Vinci in fifteenth century, wherein he had explained the rise of mountain with the removal of materials. However, the development of isostasy further grew in eighteenth century, that was the time scientists have attempted to estimate the mean density and shape of the Earth. One notable contribution has come from the French scientist, Pierre Bouguer, who had attempted to determine the Earth's mean density by measuring the deflection of the plumb-line (vertical direction) by the mass of a nearby mountain. His experiments ended with contrasting results; the ratio of density of crust to the mean density of the Earth estimated for Mt. Chimborazo in Ecuador, is quite higher than half to that of Mt. Quito in Peru. The erroneous result indicated that the deflection of the vertical caused by the mountain was too small for its estimated mass.

In the first half of the nineteenth century (1806-1843), the English geodesist George Everest carried out triangulation surveys in India. He observed that the distance measured by triangulation between Kalianpur on the Indo-Ganges plain and Kaliana in the foothills of the Himalayas differed substantially from the separation of the sites computed from the elevations of stars (Everest, 1857-59). He opined that that the discrepancy must have caused by errors in geodetic measurements. However, Pratt (1855) attributed the discrepancy to deflection of the plumb-line by the mass of the Himalayas and observed that the minimum deflection of the plumb-line that might be caused by the mass of the Himalayas, is about three times larger than the observed deflection. These observations further lead to a conclusion that the attraction of the mountain range on the plumb-line was not as large as it should have been.

Isostatic Compensation Mechanisms

The plumb-line deflection problem was explained with two contrasting mechanisms by Airy (1855) and Pratt (1855). Both mechanisms suggest local compensation of the extra mass of a mountain above sea-level by a less-dense region (or root) below sea-level, but they differ in the way the compensation is achieved. Hayford (1909) derived a mathematical model to describe

the Pratt hypothesis. As a result, this theory of isostasy is often called the Pratt—Hayford scheme of compensation. Whereas, Heiskanen (1931) derived sets of tables for calculating isostatic corrections based on the Airy model. This concept of isostatic compensation has since been referred to as the Airy—Heiskanen scheme. In 1889 C. E. Dutton referred to the compensation of a topographic load by a lessdense subsurface structure as isostasy. In the first half of twentieth century Putnam (1912) and Barell (1914) put forward the idea of regional isostasy, in which the geological loads are supported by the rigidity of the crust. Further, Vening Meinesz worked on these aspects and proposed a third model, in which the crust acts as an elastic plate. As in the other models, the crust floats buoyantly on a substratum, but its inherent rigidity spreads topographic loads over a broader region.

Three principal models of isostasy are used:

1. The Airy–Heiskanen model – where different topographic heights are accommodated by changes in crustal thickness, in which the crust has a constant density
2. The Pratt–Hayford model – where different topographic heights are accommodated by lateral changes in rock density.
3. The Vening Meinesz, or flexural isostasy model – where the lithosphere acts as an elastic plate and its inherent rigidity distributes local topographic loads over a broad region by bending.

Airy and Pratt isostasy are statements of buoyancy, but flexural isostasy is a statement of buoyancy when deflecting a sheet of finite elastic strength.

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The Earth's magnetic field

Earth's magnetic field or **geomagnetic field**, is the magnetic field that extends from the Earth's interior out into space, where it interacts with the solar wind, a stream of charged particles emanating from the Sun. The Earth's magnetic field is generated in the fluid outer core by a self-exciting dynamo process. Electrical currents flowing in the slowly moving molten iron generate the magnetic field. In addition to sources in the Earth's core the magnetic field observable at the Earth's surface has sources in the crust and in the ionosphere and magnetosphere. The geomagnetic field varies on a range of scales and a description of these variations is now made, in the order low frequency to high frequency variations, in both the space and time domains. The reason why, A bar magnet, when suspended freely, points in north - south direction is due to earth's giant magnetic field. It is believed that the electric currents circulating from earth's core to the space give rise to the earth's magnetic field. The earth's magnetic field is supposed to save earth from the solar wind which might cause the ozone layer of the earth to strip away.

Theory of Earth's Magnetism

There is no valid reason for the cause of earth's magnetism or why earth has giant magnetic field but there are some theory related to earth's magnetic field which helps us to understand that why earth behaves as a giant magnet.

- It is believed that the magnetic field of earth is due to dynamo effect. Dynamo effect is caused by the motion of metallic fluids in the outer core of the earth which results in electric current. It is because of this electric current that the earth has its own magnetic field lines.
- Another theory suggests that the rotation of earth in its own axis produces strong electric current since the outer layers of earth is ionized. As a result of which when the earth rotates, there is a movement of charged ions, which in return produces electric current.

Distinctive Aspect of Earth's Magnetism

A hypothetical giant magnetic dipole is supposed to be located at the centre of the earth. It does-not coincides with the axis of earth. The dipole is tilted by 11.3° with respect to earth's axis as shown in the diagram given below:
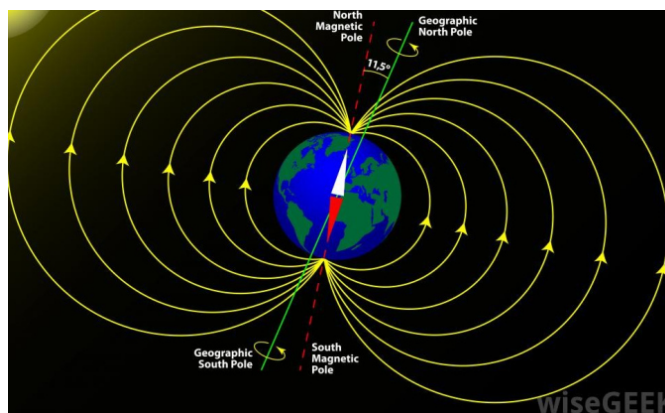
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- As it can be seen from the above diagram that there are two north (magnetic north and geographic north) poles and two south (magnetic south and geographic south) poles located on the poles of the earth. The magnetic north and magnetic South Pole is the result of the dipole. The magnetic north pole is located at 79.74° N (latitude) and 71.8° W (longitude). Similarly, the magnetic south pole is located at 79.74° S (latitude) and 108.22°E (longitude)
- If we observe carefully the magnetic field lines of the earth, we observe that the magnetic field lines enter the North Pole and leaves the south pole unlike Bar magnet, where the magnetic field lines enter the south pole and leaves the north pole. This is because the magnetic north pole actually behaves like the south pole of a bar magnets and vice versa. It was named as magnetic north because the magnetic needle (North Pole) of the bar magnet pointed in this direction.

Component of Earth's Magnetic Field

The components that are responsible for the magnitude as well as the direction of earth's magnetic field at a particular place is given by:

- Magnetic Declination
- Horizontal Component of Earth's Magnetic Field
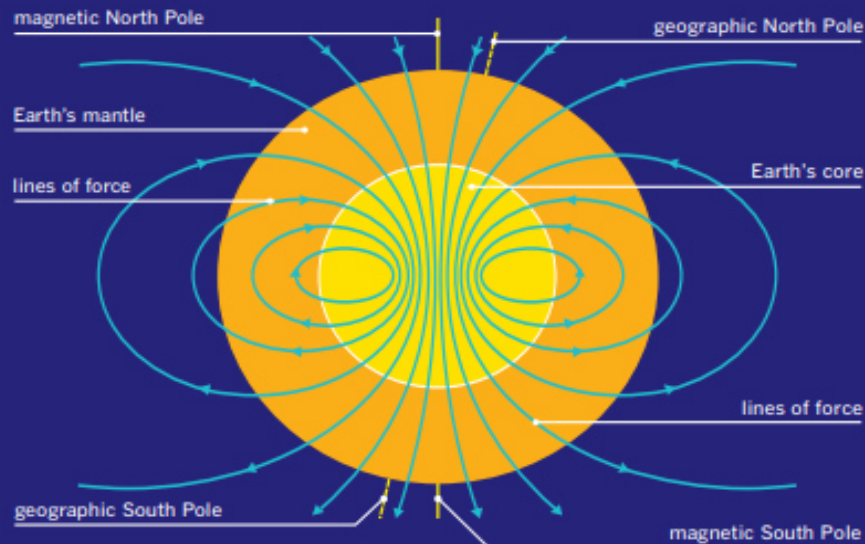- Angle of Dip or Magnetic Inclination

These three elements of earth's magnetic field give us sufficient knowledge about the magnitude and direction of earth's magnetic field. However, these elements sometimes undergoregular or irregular changes at times at all places on earth. Some of the important variations of the elements are listed down below:
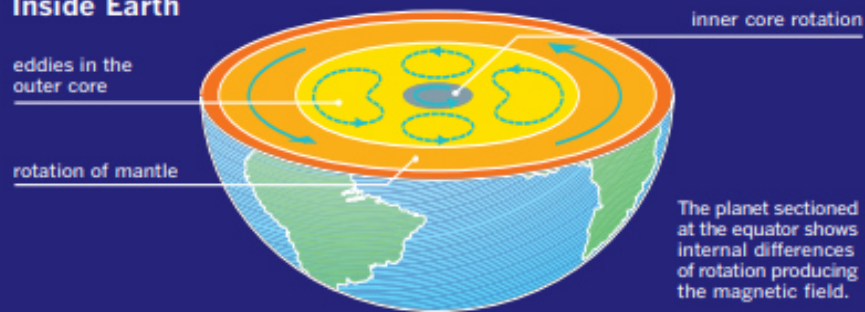
Variations in Earth's Magnetic Field

- **Secular Variation:** The magnetic axis undergoes a periodic change because of its spin around its own axis from east to west. The time cycle of this variation Id 960 years.
- **Eleven-year Sunspot Cycle:** Once in every eleven year the earth faces the sunspot which is a region of strong magnetic field. Thus the magnetic activity of the earth is very much influenced during this variation.
- **Daily and Annual Variation:** The earth's atmosphere is ionized by the ultraviolet rays from the sun. As a result of which current is generated which further produces the magnetic field. This is the result of daily and annual variations.
- **Lunar Variations:** Apart from sun, the moon also influences the magnetic activity of earth. Due to the tidal motions of the earth's ionized layer during lunar eclipse, there is variation in earth's magnetic field. This variation is known as **Lunar Variation**.

- **Irregular and Aperiodic Variation:** During a particular period of time when the solar activity of the sun is more active, the radiations from the sun cause the atmosphere of the earth to get ionized. This causes current when the earth revolves around its own axis resulting in magnetic field.
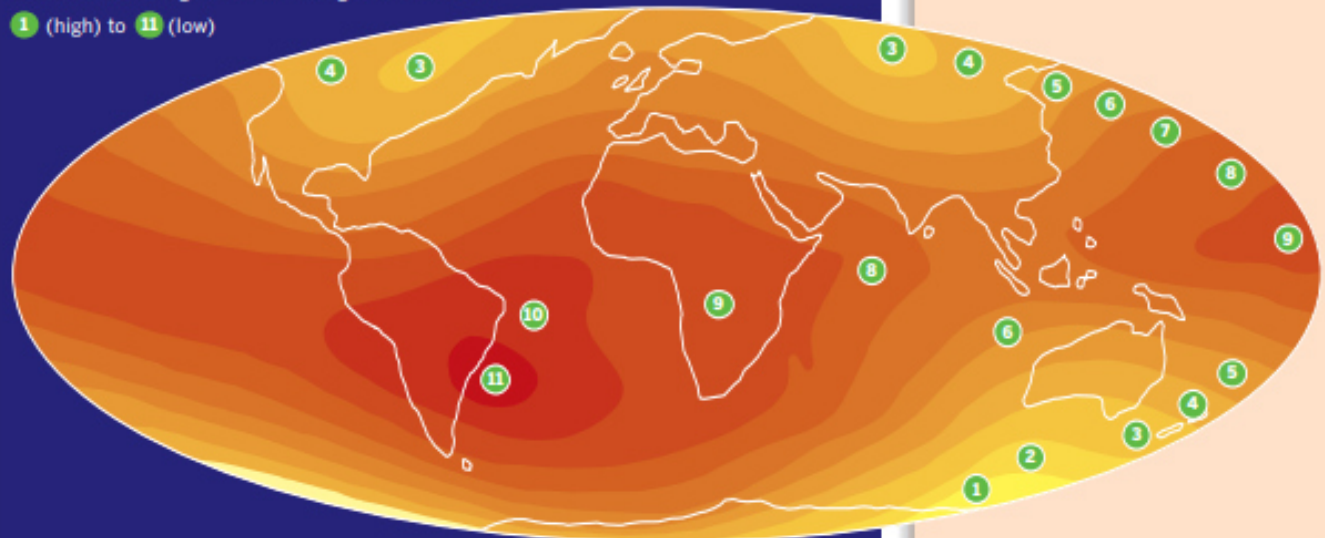

Earth's magnetic field

magnetic North Pole

geographic North Pole

Earth's mantle

lines of force

Earth's core

lines of force

geographic South Pole

magnetic South Pole

Inside Earth

inner core rotation

eddies in the outer core

rotation of mantle

The planet sectioned at the equator shows internal differences of rotation producing the magnetic field.

Regional variations

Variations in strength of Earth's magnetic field from
1 (high) to 11 (low)

Earth as a magnet

- Earth's crust and mantle rotate rather faster than its metallic core. This difference in speed produces a dynamo effect creating an immense magnetic field.
- This *geomagnetic* field consists of imaginary flux lines (lines of magnetic force) that curve around Earth between its north and south magnetic poles.
- Compass needles point to the magnetic poles.
- The magnetic poles do not coincide with the geographic poles, and their positions shift through time.
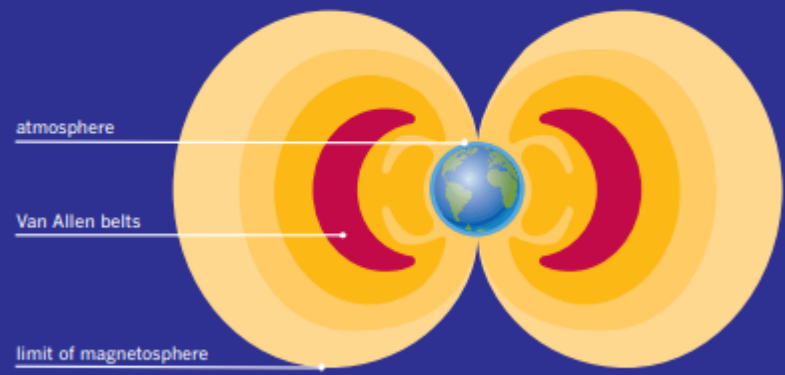
Regional variations

- Earth's magnetic field varies in intensity from place to place across the planet's surface. Its intensity is greatest near the magnetic poles.
- Local variations indicate differences in subsurface rocks.

Earth's magnetosphere

Van Allen belts

- The inner Van Allen belt has highly energetic protons produced by cosmic rays hitting atoms in the atmosphere. The satellite *Explorer 1*, designed by James Van Allen (b. 1914), discovered this belt in 1958.
- The outer radiation belt has electrons and various ions, but fewer high-energy particles than the inner belt. Like the inner belt, it was found by observations made by artificial satellites.

Hypothetical undisturbed field

atmosphere

Van Allen belts

limit of magnetosphere

Effect of the solar wind

solar wind

bow shock wave

upwind magnetosphere

polar cusp

Van Allen belts

Van Allen belts

downwind magnetosphere

magnetopause

atmosphere

5 Earth diameters

about 1 million miles

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