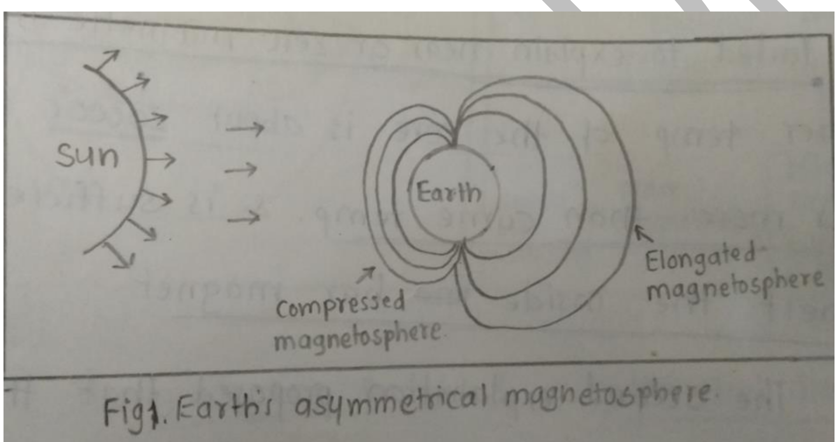
Geomagnetism

The study of rock magnetism developed during the 1950s with perfection of new, highly sensitive magnetometers. Certain rocks, such as basalt, are fairly rich in iron and become weakly magnetized by Earth's magnetic field as they cool. In a sense, the mineral grains in the rock become fossil magnets oriented with respect to Earth's magnetic field at the time when the rock was formed.

Geomagnetism is one of the unique properties of our planet where the earth acts as a magnetic dipole, with its sphere of influence surrounding the planet to as far as 528000 km from the surface known as magnetosphere. Our planet has an asymmetrical magnetosphere due to the solar flares from the sun with compression on the day side & elongation on the night side.



Basic Terminologies

1. Geographic Pole or True Pole
2. Magnetic Pole
3. Geomagnetic Pole

1. Geographic Pole or True Pole:-

A geographical pole is either of two points on the surface of a rotating planet. It is the place where the axis of rotation meets the surface of the planet. The north geographical pole of a body is 90 degrees north of the equator. The south geographical pole lies 90 degrees south of the equator.

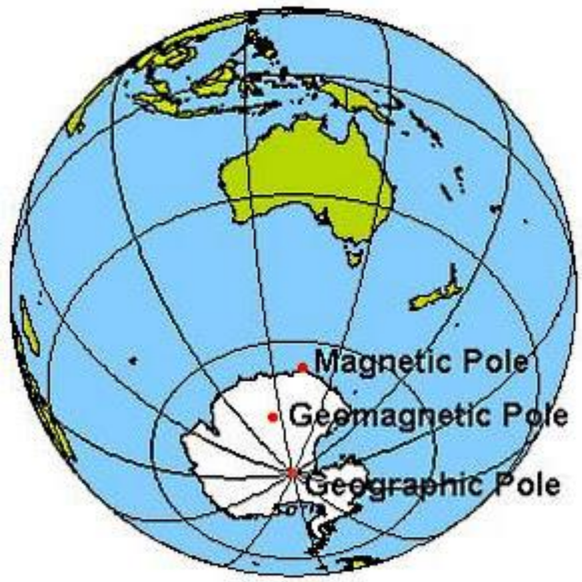
2. Magnetic Pole: Either of the two points on the earth's surface where the dipping needle of a compass stands vertical, one in the Arctic, the other in the Antarctic. The north pole of earth's bar magnet is called magnetic north lies near the geographical south and the south pole of the earth's bar magnet is called Magnetic South lies near the geographical north.

3. Geomagnetic Pole:- The Geomagnetic Poles are the poles of the Earth's geomagnetic field. The first-order approximation of the Earth's magnetic field is that of a single magnetic dipole (like a bar magnet), tilted about 11° with respect to Earth's rotation axis and centered at the Earth's core. The Geomagnetic poles are the places where the axis of this dipole intersects the Earth's surface. Like the Magnetic North Pole, the geomagnetic north pole is a south magnetic pole, because it attracts the north pole of a bar magnet.

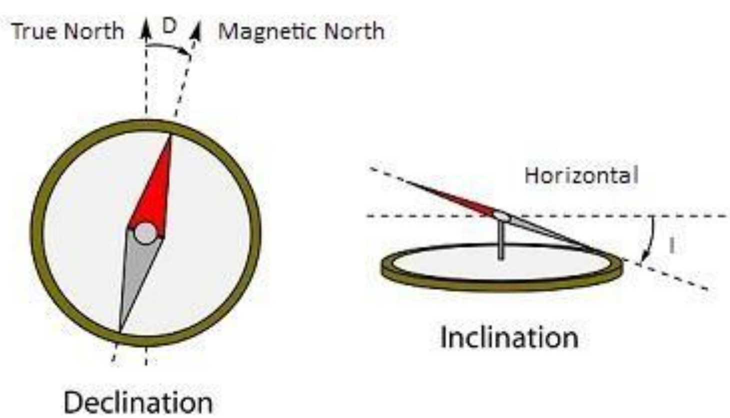
(The ***geomagnetic poles*** *are antipodal points where the axis of a best-fitting dipole intersects the surface of Earth. This theoretical dipole is equivalent to a powerful bar magnet at the center of Earth, and comes closer than any other model to describing the magnetic field observed at Earth's surface. In contrast, the magnetic poles of the actual Earth are not antipodal; that is, the line on which they lie does not pass through Earth's center.*

Owing to motion of fluid in the Earth's outer core, the actual magnetic poles are constantly moving. However, over thousands of years their direction averages to the Earth's rotation axis. On the order of once every half a million years, the poles reverse (north switches place with south).)

The current distance between the south magnetic pole – which is located in Antarctica near Russia's Vostok Station — and the geographic South Pole is approximately 1,776 miles (2,858 km). The magnetic North Pole is located near Canada's Ellesmere Island and is about 500 miles (800 kilometers) from the geographic North Pole.



Magnetic Declination and inclination



Magnetic Inclination is the angle that the magnetic needle of the compass dips (points downward) into the earth, measured from horizontal. It is horizontal (0 degrees) at the magnetic equator, and vertical (90 degrees) at the magnetic poles. The inclination is directly dependent on the distance from the poles.

Aclinic Lines: It is a circle on earth surface at every point of which dip angle is zero. This line is also called the magnetic equator of the earth.

Isoclinic Lines: These are the lines joining the points on the earth's surface which have same dip angle.

Magnetic Declination is the horizontal angle between the direction to the magnetic pole and the direction to the geographic pole. This angle is around 11.3 degree.

Agonic Lines: It is the circle on the earth's surface which passes through geographic as well as magnetic poles of the earth or this is the line on the earth's surface at every point of which magnetic declination is zero.

Isogonic Lines: These are lines on the earth surface joining the points where magnetic declination is same.

Causes of Geomagnetism:

Geomagnetism of the earth was first discovered by **Sir William Gilbert** in 1960 who proposed that the interiors of the earth have an embedded bar magnet with its south pole near geographical north pole & vice versa. Thus, he suggested that due to such bar magnet the earth exerts magnetic lines of force which show north to south magnetic direction of flow.

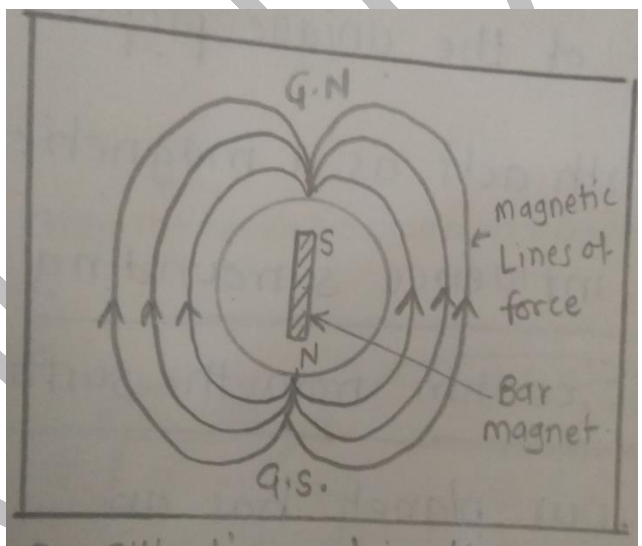


Fig2 Gilbert's explaination

However, questions like what is the source of earth's magnetism, why is the variations in magnetic intensity, reasons behind geomagnetic reversal, were not addressed by Gilbert.

Gilbert's bar magnet could only explain the concept of gradual weakening of magnetic intensity but failed to explain near or zero magnetic intensity. Further temperature of the core is far more than Currie temperature & is sufficient to melt the inside bar magnet.

The second explanation proposed that the magnetism is probably the rock's property on the lithosphere. But it failed to justify why the concentration of north & south poles in specific regions & why the outer lithosphere is more active & strong despite having core made up of highly magnetic materials i.e. iron & nickel.

Thus both the above explanations were based on static medium to earth's magnetism.

The third present day explanation is based on earth's internal dynamism. It is based on the unique interaction between the outer fluid & molten core which moves around the solid iron & nickel rich inner core. Thus, the variation in movement varies the associated magnetic intensity.

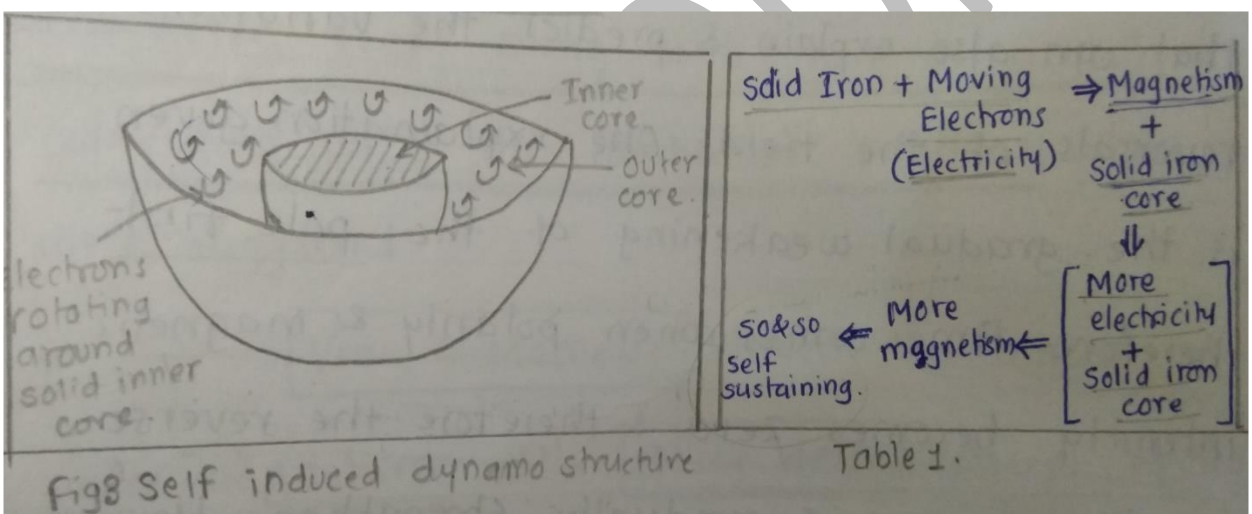


Fig8 Self induced dynamo structure

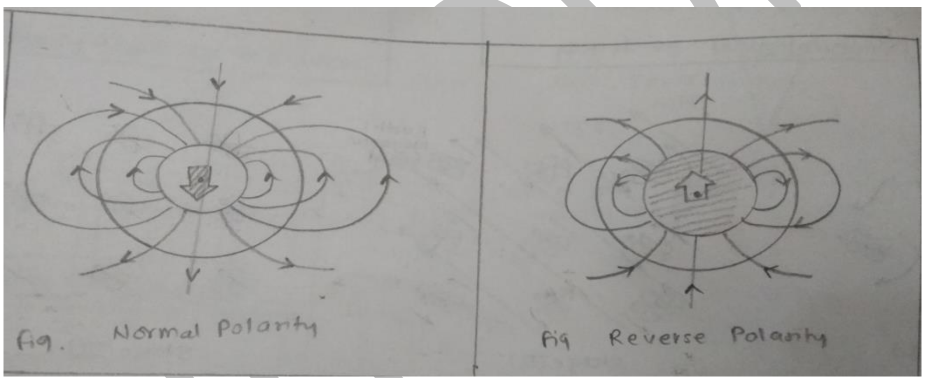
Table 1.

The given fig. & table suggest that how electricity is generated in the presence of moving electrons which creates the first magnetism. As the cycle of creating magnetism gets repeated the system acts as self induced dynamo. The above stated dynamo effect is also affected by the sun's geomagnetic field which helps the dynamo to maintain itself.

However the above theory fails to explain how the earth's magnetic reversal takes place although earth's rotation does not reverse. The spin of the earth has always been from west to east, hence, it is yet to be explained why the reversal takes place which is relatively sudden in terms of geological time scale.

Thus, we are yet to develop a universally acceptable theory, or the causes of geomagnetism that can also explain & predict the variations & reversals of the field. One explanation given is the gradual weakening of the pole first therefore time comes when polarity & magnetic intensity becomes zero & therefore the reverse polarity emerges & gradually strengthens. However this mechanism is not easily explained in terms of earth's rotation alone & more studies & causes need to be explored before coming to a valid conclusion.

Earth's magnetic field is subject to constant change (periods of strengthening and weakening) and shifts over time, eventually completely reversing its polarity. The last reversal happened 740,000 years ago and some researchers think our planet is overdue for another one, although nobody knows exactly when the next reversal of the Magnetic Poles might occur.



Causes of Magnetic reversal

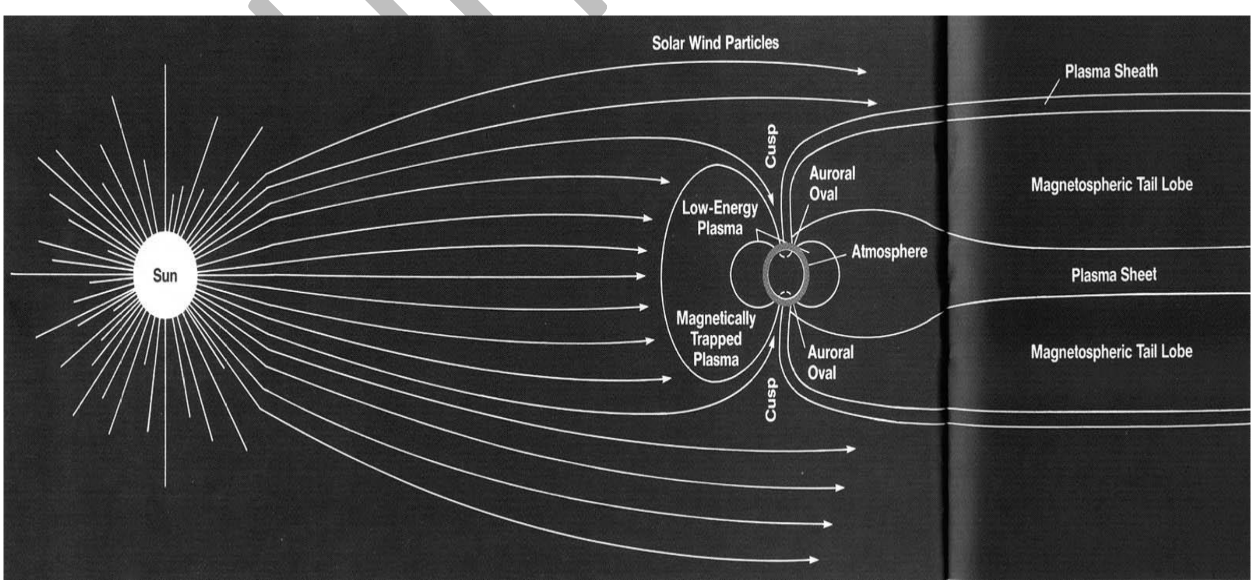
The Earth's magnetic field is thought to be generated by fluid motions in the liquid, outer part of the Earth's core, which is mainly composed of iron. The fluid motions are driven by buoyancy forces that develop at the base of the outer core as the Earth slowly cools and iron condenses onto the solid, inner solid core below. The rotation of the Earth causes the buoyant fluid to rise in curved trajectories, which generate new magnetic field by twisting and shearing the existing magnetic field. Over 99 percent of the Earth's magnetic energy remains confined entirely within the core. We only observe the small portion of the magnetic field that extends to the surface and beyond, where its basic structure is a dipole--that is, a simple north-south field like that of a simple bar magnet. There are also smaller, non-dipolar structures in the Earth's field; these change locally and very slightly on a century timescale.

The dipole part of the field is usually aligned fairly closely with the Earth's rotation axis; in other words, the magnetic poles are usually fairly close to the geographic poles, which is why a compass works. Occasionally, however, the dipole part of the field reverses, causing the locations of the north and south magnetic poles to switch. This reversal process can be seen in the paleomagnetic record, locked into rocks of the ocean floor and in some lava flows. The reversal process is not literally 'periodic' as it is on the sun, whose magnetic field reverses every 11 years. The time between magnetic reversals on the Earth is sometimes as short as 10,000 years and sometimes as long as 25 million years.

According to the computer simulated model, the solid inner core, being magnetically coupled to the eastward fluid flow above it, should rotate slightly faster than the surface of the Earth. Fluid motions try to reverse the field on a few thousand-year timescale, but the solid, inner core tries to prevent reversals because the field cannot change (diffuse) within the inner core nearly as quickly as in the fluid, outer core.

Only on rare occasions do the thermodynamics, the fluid motions and the magnetic field all evolve in a compatible manner that allows for the original field to diffuse completely out of the inner core so the new dipole polarity can diffuse in and establish a reversed magnetic field.

Magnetospheres

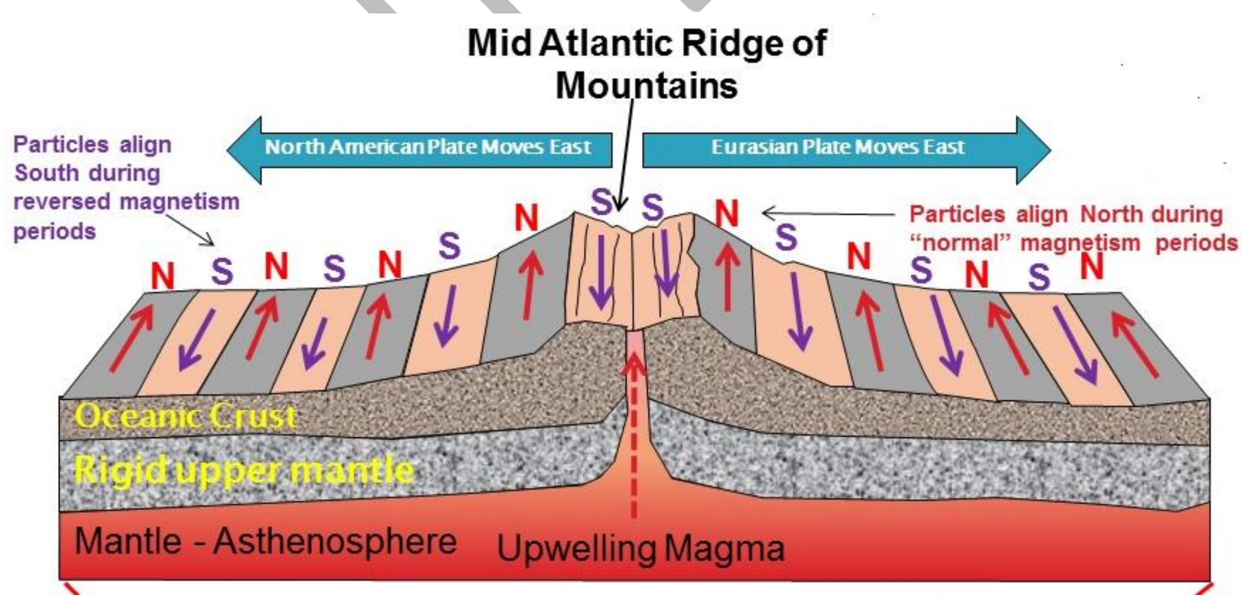


A magnetosphere is the region around a planet dominated by the planet's magnetic field. Other planets in our solar system have magnetospheres, but Earth has the strongest one of all the rocky planets: Earth's magnetosphere is a vast, comet-shaped bubble, which has played a crucial role in our planet's habitability. Life on Earth initially developed and continues to be sustained under the protection of this magnetic environment. The magnetosphere shields our home planet from solar and cosmic particle radiation, as well as erosion of the atmosphere by the solar wind - the constant flow of charged particles streaming off the sun.

Constant bombardment by the solar wind compresses the sun-facing side of our magnetic field. The sun-facing side, or dayside, extends a distance of about six to 10 times the radius of the Earth. The side of the magnetosphere facing away from the sun - the nightside - stretches out into an immense magneto tail, which fluctuates in length and can measure hundreds of Earth radii, far past the moon's orbit at 60 Earth radii.

Application:

The concept of geomagnetism was used in paleomagnetic concept as an evidence of continental drifting. It was observed that certain basaltic & volcanic rocks were found in their present day positions which do not have their magnetic lines of force aligned along the present earth's magnetic field along with their dip angle's not coinciding with the latitudinal positions where they were located.



Vine and Mathews linked the concept of paleomagnetism with Harry Hess' concept of sea floor spreading. The sets of magnetic bands of reversed polarity were explained by Vine and Mathews that along the ridges with fresh accumulations of magma on either side of the ridge, the rocks would acquire the magnetism of the then existing magnetic fields of the earth, thus with every changing magnetic field of the earth the new rocks will acquire that magnetic field. Thus earth's geomagnetism was a conclusive evidence to the concept of sea floor spreading and PT theory.

It is also proven fact that strength of the magnetosphere has important role in protecting the planet earth from harmful solar flares from the sun. The phase of zero magnetic intensity during reversal of polarity seems to coincide with some of the largest extinction on the planet. Thus the concept & study of earth's geomagnetism emerge as a unique property of our planet in understanding the geological history of our planet & its behavior & consequences as a magnetic dipole.

Theory of Isostasy

The term "Isostasy" is derived from "Isostasios", a word of Greek language meaning the state of being in balance.

The mountains have many peaks and relatively great heights. Similarly plateau and plain have flat surfaces. They have moderate and lower height, respectively. On the contrary oceanic beds and trenches have greater depths. There is a great difference in height among these features.

Moreover the earth is rotating while keeping perfect balance among its various features. Thus, our earth is considered to be in isostatic equilibrium.

Example:- Suppose you are holding one stick each in your both hands vertically with varying heights, say 5' and 15' and you are moving in a particular direction. Do you have any difficulty in maintaining a balance in congruence with your body as well as two sticks together? Definitely, smaller stick will be easy to make a balance than the longer one. It is just because of the centre of gravity.

The centre of gravity with smaller stick will be nearer to your holding hand in comparison to the longer stick. In the same way smaller surface features like plains are more stable than the tall mountains.

Different relief features of varying magnitudes E.g. mountains, plateau, plains, lakes, seas & oceans, faults & rift valleys etc. standing on the earth's surface are probably balanced by certain definite principle, otherwise these would have not been maintained in their present form. Whenever this balance is disturbed, there start violent earth movements and tectonic events. Thus, **isostasy is the mechanical stability between the upstanding parts and lowlying basins on a rotating earth. Also it deals with the distribution of the material of the earth's crust above and below the earth's surface.**

The concept of isostasy grew out of the need of searching the reasons for the gravitational anomaly observed in Andes by Perrie Bouger in 1705, gradual upliftment over extensive areas & upliftment of the mountains etc. Thus explanation for these discrepancies resulted into the postulations of the concept of isostasy by various scientists as follows.

Concept of Sir George Airy

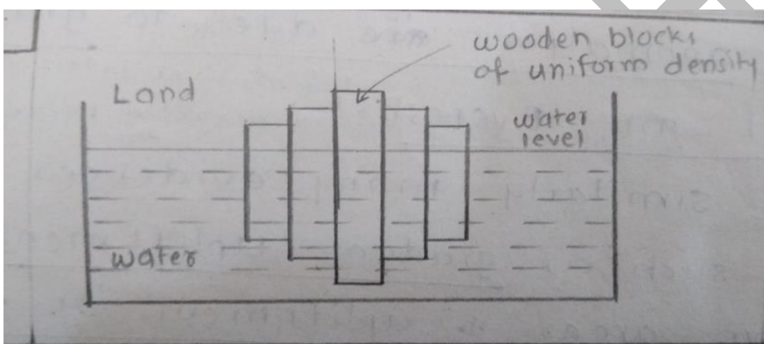


Fig1 illustration of Airy's concept

- Airy, a geologist, considered the density of different columns (plains, plateaus, mountains, etc.) to be the same. Hence, he proposed the idea of **'uniform density with varying thickness'**.
- We know that the upper crust of the earth is made up of lighter material. In this layer, silica and aluminium are found in abundance, hence it is known as 'Sial'.
- It is less denser than the lower one. Airy assumed that the Sialic crust is floating over the Sima (silica and magnesium, lower denser layer).
- Crustal layer is uniform in terms of density with varying length of columns. Therefore, those columns are projecting down into the asthenosphere depending upon the proportions of the column.
- It is due to this reason that the root has developed or the sima has been displaced from below.
- To prove this concept, Airy took an example of wooden blocks of various sizes and immersed them into water.
- All blocks are of same density & they get immersed differently in proportion to their sizes.

- In the same way higher features with great height seen on the surface of the earth have deeper roots whereas short in length has shorter roots beneath.
- It is the concept of root which is sustaining the higher elevation. He is of the opinion that the landmasses are floating like a boat in the substratum (magmatic asthenosphere).
- According to this concept, the root beneath the Mt. Everest would be 8848X9 = 79632 metre below the sea level.
- On this bases Airy has been criticized that the root is not possible to be at such a great depth. Because the root material will melt due to higher temperature found at that depth.

Concept of Archdeacon Pratt

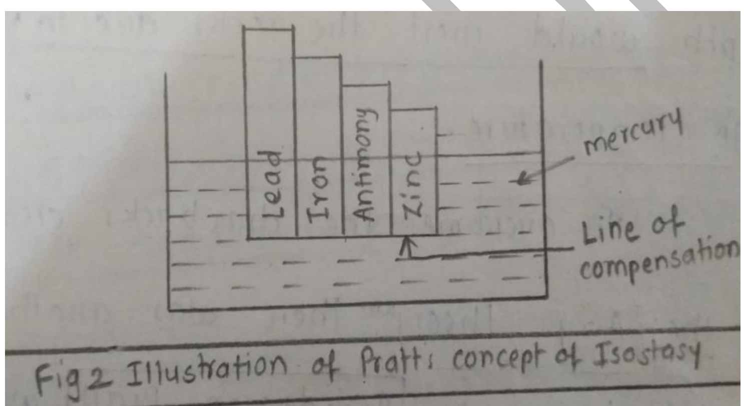


Fig 2 Illustration of Pratt: concept of Isostasy

- Pratt considered land blocks of various heights to be different in terms of their density.
- The taller landmass has lesser density and smaller height features to be denser. In other words, there is an inverse relationship between height and density.
- If there is a higher column, density will be lesser and if there is a shorter column, density will be higher.
- Assuming this to be true, he accepted that all blocks of different height get compensated at a certain depth into the substratum.
- In this way a line is being demarcated above which there is equal pressure with varying heights.
- Thus, he denounced the root concept of Airy and accepted the ‘concept of a level of compensation’.
- For proving his concept he took a number of metal bars of varying density with same weight and put them into mercury.

- In this way they form a line by all those bars, which he regarded to be the level of compensation.

Concept of Hayford & Bowie

Hayford & Bowie have propounded their concepts of isostasy almost similar to the Pratt. According to them there is a plane where there is complete compensation of the crustal parts. Densities vary with elevations of columns of crustal parts above this plane of compensation. There is such a zone below the plane of compensation where density is uniform in lateral direction. Thus according to them, there is inverse relationship between the height of columns of the crust & their respective densities above the plane of compensation. The plane of compensation is supposedly located at the depth of about 100km.

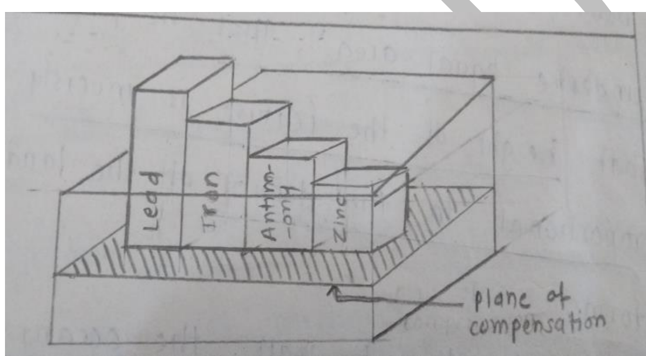


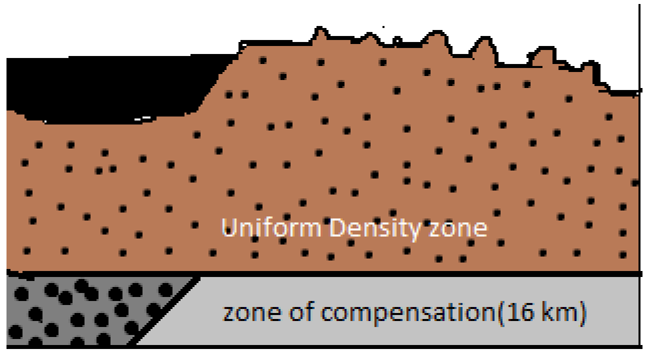
Fig3 Illustration of Hayford & Bowie's Plane of compensation

From the above figure it can be concluded that the height of the various columns varies but they are balanced by their varying densities. The assumption is that the varying volume of matter in the several columns is compensated by their density, in such a fashion that they exert equal downward pressure at the level of compensation and thus balance one another.

Concept of Joly

Joly along with Bowie later suggested that it is actually a zone of compensation rather than just one plane. The concept of zone of compensation suggests that different relief features & rocks compensate at different depths under the earth's surface & not exactly at one line & not one plane.

Thus Joly assumed the level of compensation as not a linear phenomenon but a zonal phenomenon.



Concept of Heiskenen

Heiskenen presented a new concept of isostasy in 1933 in which he combined the concepts of both Airy (uniform density with varying thickness) and Pratt (varying density in different columns). According to him density of rocks varies within the column (section of the earth) and between the columns. For example, rocks of a column at sea level have higher density (say 2.76 gram cm^{-3}) than at higher elevation of the same column (say 2.70 gram cm^{-3}) which means as we go downward the rocks of a section of the earth's crust become denser i.e. density increases downward. Similarly, density of rocks of different sections (columns) of the earth's crust also varies. Thus, it appears that density of rocks varies both vertically and horizontally.

Plate Tectonics Interpretation

According to the PT theory the earth's interior is divided into crust and mantle & the continental crust along with the oceanic crust & the part of the upper mantle floats on the semi-molten or plastic asthanosphere. The asthanosphere with its high olivine content in peridotite rocks have semi-moltem properties which is capable of deformation under sustain or prolonged stresses.

Thus in condition of loading or extensive sedimentation in any form, the force is exerted on olivine underneath to flow out causing depressions on the earth's surface.

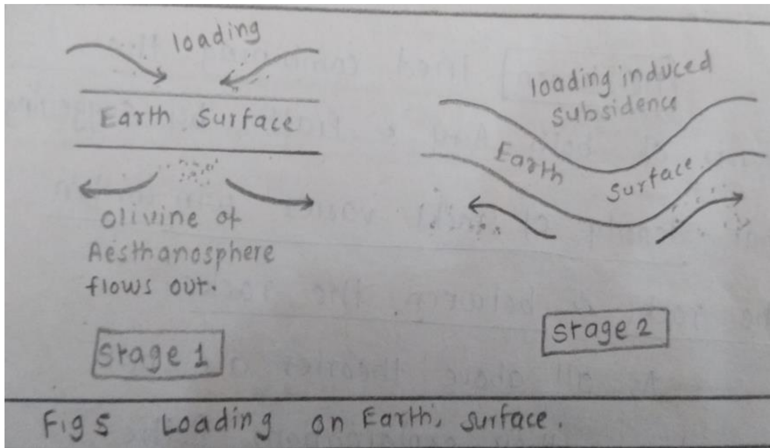


Fig5 Loading on Earth's surface.

Similarly, the condition of unloading can force the flow back of olivine & the earth surface may rebound back & regain its earlier level.

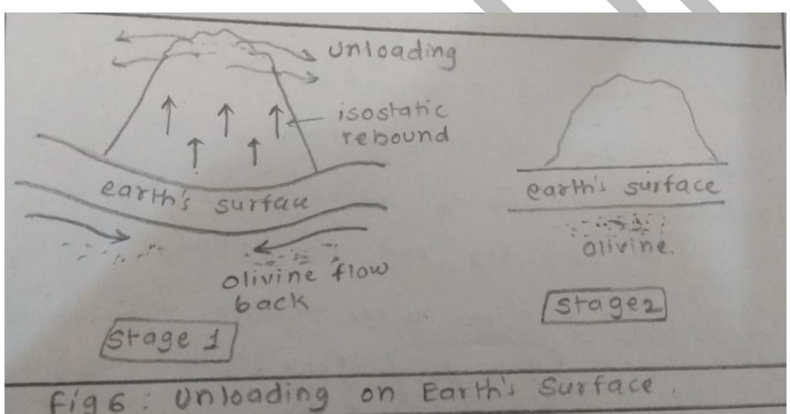


Fig6 : Unloading on Earth's Surface.

Thus above concept of plate tectonics explains the reasons behind upliftment of the Norwegian coast & existence of huge fold mountains despite excessive erosion since millions of years.

Isostatic balance principles are also invoked or used in explaining the negative fallouts of large scale massive crustal changes & modification because of human activities such as deforestation, massive construction projects like urban infrastructure or dams or mining etc. which can lead to earthquakes.

Isostatic balance is not local in nature but it is global in nature because the earth's crust & asthenosphere has flexible rigidity.

In reality the individual landform are not floating on the asthenosphere independent of other landforms rather each landform as a part of the crust & the lithosphere are together floating on the asthenosphere. So isostatic imbalance in one area can have impact on areas which are relatively farther away & thus it is called as global isostatic imbalance.

Global Isostatic Adjustment

It may be pointed out that there is no complete isostatic adjustment over the globe because the earth is so unresting and thus geological forces coming from within the earth very often disturb such isostatic adjustment. It appears from the result of various expeditions, experiments and observations that if the isostatic adjustment does not occur at local level, it does exist at extensive regional level.

The endogenetic forces and resultant tectonic events cause disturbances in the ideal condition of isostasy but nature always tends towards the isostatic adjustment. For example, a newly formed mountain due to tectonic activities is subjected to severe denudation.

Consequently, there is continuous lowering of the height of the mountain. On the other hand, eroded sediments are deposited in the oceanic areas, with the result there is continuous increase of weight 'of sediments on the sea-floor. Due to this mechanism the mountainous area gradually becomes lighter and the volcanic floor becomes heavier, and thus the state of balance or isostasy between these two areas gets disturbed but the balance has to be maintained.

It may be stated that the super-incumbent pressure and weight over the mountain decreases because of continuous removal of material through denudational

process. This mechanism leads to gradual rise in the mountain. On the other hand, continuous sedimentation on the sea-floor causes gradual subsidence of the sea-floor. Thus, in order to maintain isostatic balance between these two features there will be slow flowage of relatively heavier materials of substratum (from beneath the sea floor) towards the lighter materials of the rising column of the mountain at or below the level of compensation.

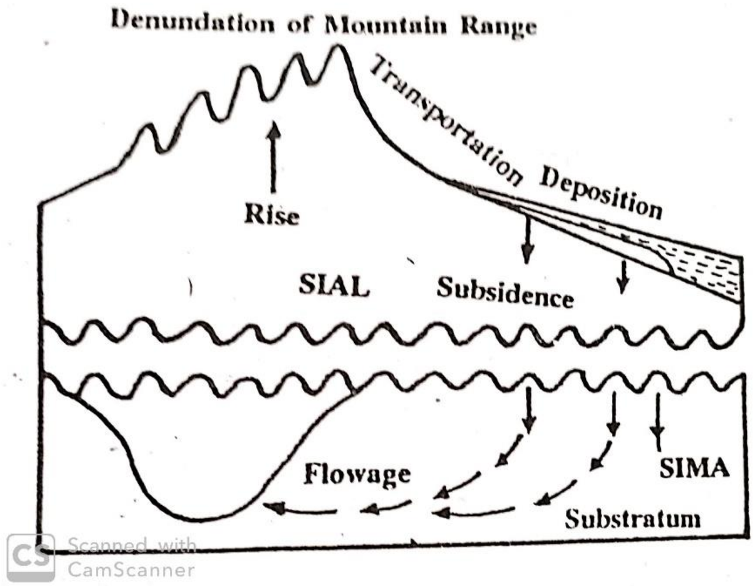


Fig. Mechanism of isostatic adjustment at global

scale

According to an estimate major parts of Scandinava and Finland have risen by 900 feet. The land masses are still rising at the rate of one foot per 28 years under the process of isostatic recovery. The isostatic adjustment in these areas could not be achieved till now.