7

THEORY OF ISOSTASY

7.1 INTRODUCTION

Different relief features of varying magnitudes e.g. mountains, plateaus, plains, lakes, seas and oceans, faults and rift valleys etc. standing on the earth's surface are probably balanced by certain difinite 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 simply means a machanical stability between the upstanding parts and lowlying basins on a rotating earth'.

The word isostasy, derived from a German word 'isostasios' (meaning thereby 'in equipoise'), was first proposed by American geologist Dutton in 1859 to express his view to indicate 'the state of balance which he thought must exist between large upstanding areas of the earth's surface, mountain ranges and plateaus, and contiguous lowlands, etc.' (S.W. Wooldridge and R.S. Morgan, 1959). According to Dutton the upstanding parts of the earth (mountains, plateaus, plains and ocean basins) must be compensated by lighter rock material from beneath so that the crustal reliefs should remain in mechanical stability. According J.A. Steers (1961), 'this doctrine states that wherever equilibrium exists on the earth's surface, equal mass must underlie equal surface areas.'

7.2 DISCOVERY OF THE CONCEPT

Though the concept of isostasy came in the mind of geologists all of sudden but its concept grew out of gradual thinking in terms of gravitational attraction of giant mountainous masses. Pierre Bouguer during his expedition of the Andes in 1735 found that the towering volcanic peak of Chimborazo was not attracting the plumb line as it should have done. He thus maintained that the gravitational attraction of the Andes 'is much smaller than that to be expected from the mass represented by these mountains'. Similar discrepencies were noted during the geodetic survey of the Indo-Gangetic plain for the determination of latitudes under the supervision of Sir George Everest, the then Surveyor General of India, in 1859. The difference of latitude of Kalianpur and Kaliana (603 km due northward) was determined by both direct triangulation method and astronomical method. Kaliana was only 96 km away from the Himalayas. The difference between two results amounted to 5.23 seconds as given below—

Result obtained through triangulation	= 5^0 23' 42.294"
Result obtained through astronomical method	= 5^0 23' 37.058"
Difference	= 5.236"

This discrepancy between two methods was attributed to the attraction of the Himalayas due to which the plumb-bob used in the astronomical determination of latitude was deflected.

This interpretation, thus, brought the fact before the scientists that the enormous mass of the Himalaya was responsible, through its attractional force, for the difference in the results of two methods. Later on the matter was referred to Archdeacon Pratt for further investigation and clarification. He attempted to estimate the amount of attraction of the Himalayas on the basic assumption that all the mountains had the average density of 2.75. Thus, Pratt based on minimum estimate of the mass of the Himalayas calculated the gravitational effects on the plumbob at two places (Kaliana and Kalianpur) and to his dismay he discovered that the difference was surprisingly more than actually worked out during the survey.

Gravitational deflection at Kaliana	= 27.853"
Gravitational deflection at Kalianpur	= 11.968"
difference	= 15.885"

Thus, the difference of 15.885" was in fact more than 3 times the observed deflection of 5.236" during the survey. Pratt's calculation of the difference of the gravitational deflections brought another fact before the scientists that the Himalaya was not exerting the attraction according to its enormous mass. This interpretation gave birth to another problem-What reason is behind low attractional force of the Himalayas ? The following explanations were offered for this question.

(1) The Himalayas are hollow and are composed of bubbles and not the rocks. Due to this fact the weight and density of the Himalayas would be low and thus their gravitational force would also be low. This was the reason for the difference in the results of two locations as referred to above. This explanation cannot be accepted because such a high mountain, if composed of bubbles, cannot stand on the earth's surface.

(2) If the mountains are not hollow, the visible mountain mass must be compensated by defficiency of mass from below. In other words, the density of the rocks of the mountains 'must be relatively low down to considerable depth.' Thus, the total weight would be low and consequently the attractional force would also be low.

(3) The rocks of the Himalayas are of low density in themselves and thus their attraction is also low.

(4) It was suggested 'that there is such a level below the surface of the earth below which there is no change in the density of the rocks', density varies only above this level. Thus, all columns have equal mass along this level. It was therefore suggested on this basis that **'bigger the column, lesser the density, and smaller the column, greater the density.'**

Thus, the debate on the discrepancies of the gravitational deflections of the plumb-line and numerous explanations for these discrepancies resulted into the postulation of the concept of isostasy by different scientists, the views of a few of them are presented below.

7.3 THE CONCEPT OF SIR GEORGE AIRY

According to Airy the inner part of the mountains cannot be hollow, rather the excess weight of the mountains is compensated (balanced) by lighter materials below. According to him the crust of relatively lighter material is floating in the substratum of denser material. In other words. **'sial'** is floating in **'sima'**. Thus, the Himalayas are floating in denser glassy magma. According to Airy 'the great mass of the Himalayas was not only a surface phenomenon : the lighter rocks of which they are composed do not merely rest on a level surface of denser material beneath, but, as a boat in water, sink into the denser material' (J.A. Steers, 1961). In other words, the Himalayas are floating in the denser magma with their maximum portion sunk in the magma in the same way as a boat floats in water with its maximum part sunk in the water. This concept in fact involves the principle of floatation. For example, an iceberg floats in water in such a way that for every one part to be above water-level, nine parts of the iceberg remain below water level. If we assume the average density of the crust and the substratum to be 2.67 and 3.0 respectively, for every one part of the crust to remain above the substratum, nine parts of the crust must be in the substratum. In other words, the law of floatation demands that 'the ratio of freeboard to draught is 1 to 9.' It may be pointed out that Airy did not mention the example of the floatation of iceberg. He simply maintained that the crustal parts (landmasses) were floating, like a boat, in the magma of the substratum.

If we apply the law of floatation, as stated above, in the case of the concept of Airy, then we have to assume that for the 8848 m height of the Himalaya there must be a root, 9 times more in length than the height of the Himalaya, in the substratum. Thus, for 8848-m part of the Himalaya above, there must be downward projection of lighter material beneath the mountain reaching a depth of 79,632 m (roughly 80,000 m).

Joly applied the principle of floatation for the crust of the earth taking the freeboard to draught ratio as 1 to 8. According to him 'for every emergent part of the crust above the upper level of the substratum there are eight parts submerged' (J.A. Steers, 1961). If we apply Joly's view of flotation to the concept of Airy, there would be downward projection of the Himalaya upto a depth of 70,784 m (8848 m × 8) in the substratum.

Thus, according to Airy the Himalayas were exerting their real attractional force because there existed a long root of lighter material in the substratum which compensated the material above. Based on above observation Airy postulated that 'if the land column above the substratum is larger, its greater part would be submerged in the substratum and if the land column is lower, its smaller part would be submerged in the substratum.' According to Airy the density of different columns of the land (e.g. mountains, plateaus, plains etc.) remains the same. In other words, density does not change with depth, that is, **'uniform density with varying thickness.'**

This means that the continents are made of rocks having uniform density but their thickness or length varies from place to place. In order to prove this concept Airy took several pieces of iron of varying lengths and put them in a basin full of mercury. These pieces of iron sunk upto varying depths depending on their lengths. The same pattern may be demonstrated by taking wooden pices of varying lengths. If put into the basin of water these would sink in the water according to their lengths (fig. 7.1).

Though the concept of Sir George Airy commands great respect among the scientific community but it also suffers from certain defects and errors. If we accept the Airy's views of isostasy, then every upstanding part must have a root below in accordance with its height. Thus, the Himalaya would have a root equivalent to 79, 632 m (if we accept the

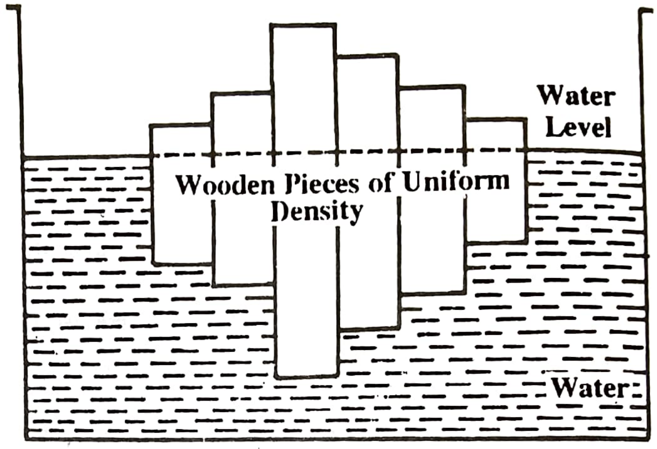

Fig. 7.1 : Illustration of the concept of Airy on isostasy.

freeboard to draught ratio as 1 to 9) or 70,784 m (if the freeboard to draught ratio is taken as 1 to 8). It would be wrong to assume that the Himalaya would have a downward projection of root of lighter material beneath the mountain reaching such a great depth of 79,632 m or 70,784 m because such a long root, even if accepted, would melt due to very high temperature prevailing there, as temperature increases with increasing depth at the rate of 1°C per 32 m.

"Quite recently, however, the fundamental concept of Airy, the continental masses floating as lighter (sial) blocks in a heavier (sima) substratum, has been rejuvenated, largely through the influence of Heiskanen's work, so that it is now probably true to say that most geologists favour Airy's explanation" (J.A. Steers, 1961, p. 75).

7.4 THE CONCEPT OF ARCHDEACON PRATT

While studying the difference of gravitational deflection of 5.236 seconds during the geodetic survey of Kaliana and Kalianpur Archdeacon Pratt calculated the gravitational force of the Himalaya after taking the average density of the Himalaya as 2.75 and came to know that the difference should have been 15.885 seconds. He, then, studied the rocks (and their densities) of the Himalaya and neighbouring plains and found that the density of each higher part is less than a lower part. In other words, the density of mountains is less than the density of plateaus, that of plateau is less than the density of plain and the density of plain is less than the density of oceanic floor and so on. This means that there is inverse relationship between the height of the reliefs and density.

According to Pratt there is a level of compensation above which there is variation in the density of different columns of land but there is no change in density below this level. Density does not change within one column but it changes from one column to other columns above the level of compensation. Thus, the central theme of the concept of Pratt on isostasy may be expressed as **'uniform depth with varying density.'** According to Pratt equal surface area must underlie equal mass along the line of compensation. This statement may be explained with an example (fig. 7.2).

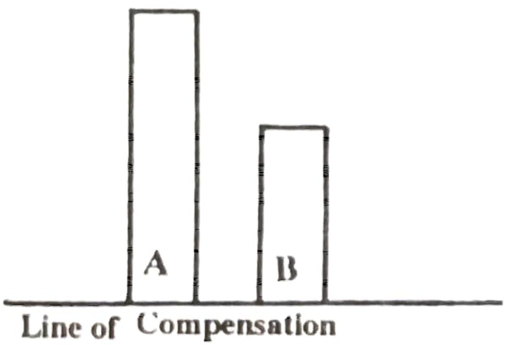

Fig. 7.2 : Line of compensation according to Archdeacon Pratt.

There are two columns, A and B, along the line of compensation. Both the columns, A and B, have equal surface area but there is difference in their height. Both the columns must have equal mass along the line of compensation, so the density of column B should be more than the density of column A so that the weight of both the columns become equal along the line of compensation. Thus, the Pratt's concept of inverse relationship between the height of different columns and their respective densities may be expressed in the following manner—**'bigger the column, lesser the density and smaller the column, greater the density.'** According to Pratt density varies only in the lithosphere and not in the pyrosphere and barysphere. Thus, Pratt's concept of isostasy was related to the **'law of compensation'** and not to **'the law of floatation.'** According to Pratt different relief features are standing only because of the fact that their respective mass is equal along the line of compensation because of their varying densities. This concept may be explained with the help of fig. 7.3.

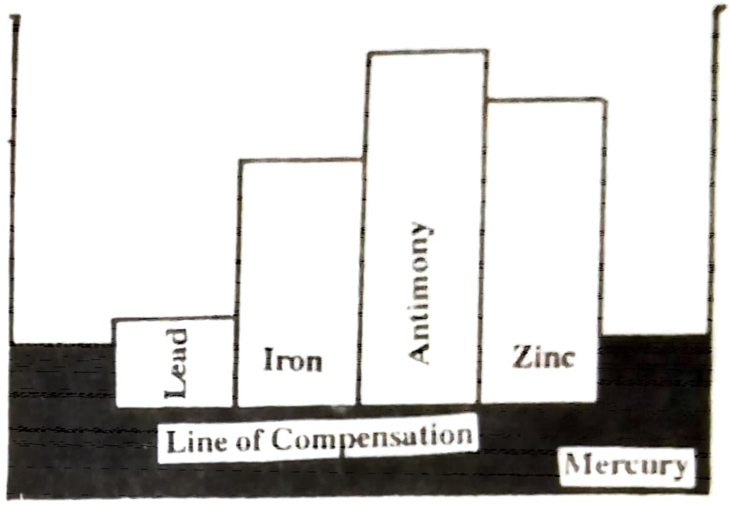

Fig. 7.3 : Explanation of the concept of Pratt on isostasy.

Bowie has opined that though Pratt does not believe in the law of floatation, as stated by Sir George Airy but if we look, minutely, into the concept of Pratt we certainly find the glimpse of law of floatation indirectly. Similarly, though Pratt does not believe directly in the concept of **'root formation'** but very close perusal of his concept on isostasy, does indicate the glimpse of such idea (root formation) indirectly. While making a comparative analysis of the views of Airy and Pratt on isostasy Bowie has observed that **'the fundamental difference be-**

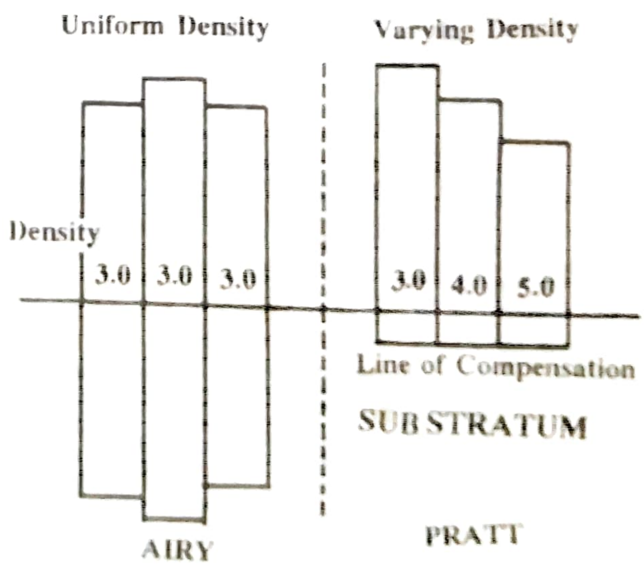

Fig. 7.4 Comparison of the views of Airy and Pratt on isostasy

tween Airy's and Pratt's views is that the former postulated a uniform density with varying thickness, and the latter a uniform depth with varying