The Riddle of the *Apparently* Hollow Himalaya

Ramesh Chander

We recall here an application of Newton's law of gravitation which suggested prima facie that the Himalaya may be hollow inside.

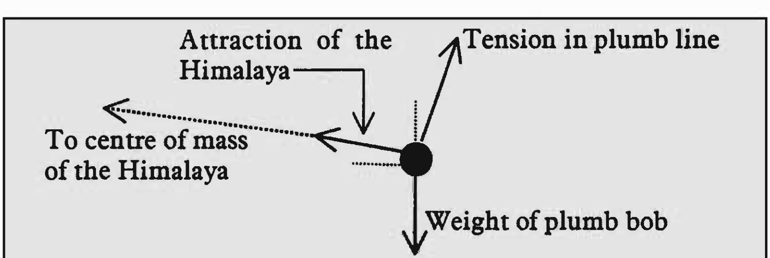
Ramesh Chander is a Professor at the University of Roorkee, engaged in diverse studies related to natural earthquakes in the Himalaya as well as modelling of reservoir-induced earthquakes in that region.

Background to the Riddle

Geodetic triangulation was the most reliable method of the pre-satellite era for determining latitudinal and longitudinal coordinates of a network of inter-visible benchmarks or observation points on land. Every conceivable precaution was taken to achieve high levels of accuracy in triangulation results. Since the astronomical coordinate system formed a basis of the geodetic[1] system also, observations of stars were taken at regular intervals in a triangulation network to control propagation of errors in the geodetic estimates of coordinates. Benchmarks where both geodetic and astronomic observations are taken are called *Laplace stations*.

[1] Geodesy is the science of measuring the earth. Recall that the very similar word 'geometry' today stands for branches of mathematics which go far beyond the earth, or even space as we know it.

The directors of the East India Company put high value on accurate maps of the dominions under their control. They accepted the proposal by William Lambton for geodetic triangulation in the Indian peninsula to facilitate preparation of accurate topographic maps of the region. Formal orders for the survey were issued on February 6, 1800. Lambton set up *interalia*, a series of benchmarks straddling the 78° E meridian from



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Kanya Kumari to the Krishna River. He hoped that the series would be extended northward to the foot of the Himalaya eventually. That task was completed a few decades later under George Everest, the surveyor general after whom the highest peak of the Himalaya is named. The coordinates of the new benchmarks were available circa 1854. But a riddle had cropped up.

Genesis of the Riddle

The riddle arose innocuously from a comparison of the geodetic and astronomic estimates for latitudes of the Laplace stations at Kalianpur in Central India and Kaliana near the Himalayan foothills. The geodetically estimated latitude difference was 5°23′ 42″.294 while that estimated astronomically was 5°23′37″.058. The discrepancy in the two values was only 5″.236. But it could not be ignored as the observations[2] were reliable.

[2] 1″=one arc second would be the angle subtended by an arc of length about thirty metres at the centre of the earth. So the surveyors were confident of the accuracy of their measurements to this level.

Pratt, the then Archdeacon of Calcutta, and Airy, the mathematician, communicated the discrepancy to the Royal Society of London on December 7, 1854 and January 25, 1855 respectively.

Astronomical determinations of latitudes were made at the Kalianpur and Kaliana bench marks by reference to the respective local vertical directions defined by plumb lines attached to the telescopes. Both Pratt and Airy surmised that the great mass of the Himalaya exerted an attractive influence on the lead bobs of the two plumb lines in accord with Newton's law of gravitation (*Figure 1*). It was estimated that this attraction should deflect the

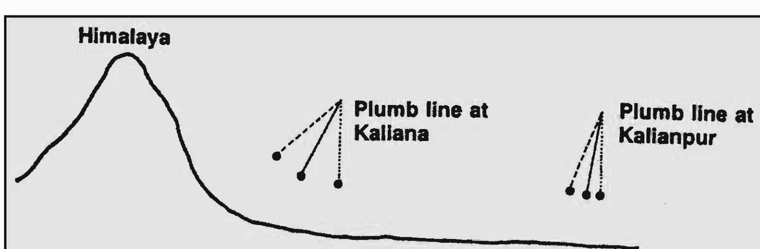

Figure 1. Influence exerted on the lead bobs of the two plumb lines by the Himalayas.

plumb line towards the Himalaya by about 27″.853 at Kaliana and about 11″.968 at Kalianpur. Thus the discrepancy between geodetically and astronomically estimated latitude should have been 15″.805, nearly three times the observed value of 5″.236. This meant that the Himalaya did not exert as much gravitational attraction on the plumb bobs as anticipated from their external massive appearance. It was as if the Himalayas were hollow inside.

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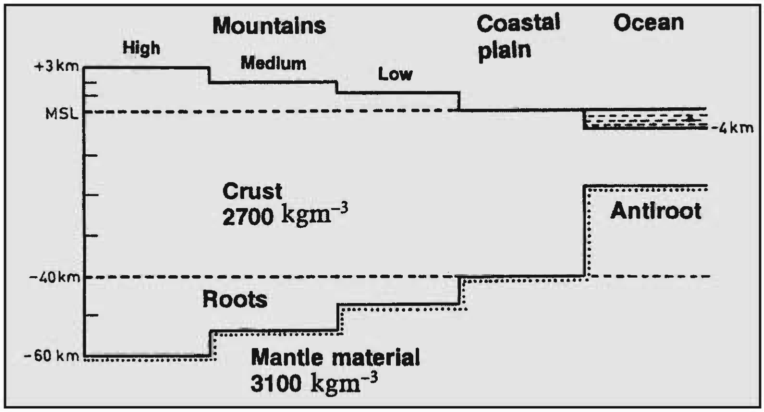
Explanation of the Hollowness

Pratt and Airy emphasised that the suggested hollowness of the Himalaya was only notional Both envisioned that the mountainous segments of the earth's outer layers are regions of relatively lower densities. Pratt suggested that the outer part of the earth consisted of vertical blocks of different densities floating on a denser underlying medium. The density in a given floating block would be consistent with the ground elevation in such a way that all blocks would exert the same pressure at a certain *isopeistic* depth, estimated to be of the order of 110 km. For example, a block with a 3 km high mountain and another with a 4 km deep ocean would exert the same pressure at a depth of 112.7 km if they have densities of 2624 and 2755kgm^{-3} respectively.

Airy suggested that the crust of the earth floats on a denser lava, which we shall call mantle material in modern terms because the region of the earth beneath the crust is called the mantle. He also postulated that the crust is relatively thicker under mountains and thinner under oceans so that mountains have crustal roots and ocean basins have mantle antiroots (*Figure 2*). Let the crustal and mantle materials have densities of 2700 and 3100 kgm^{-3}. Then, by Archimedes principle, a mountain having an elevation of 3 km above sea level should have a crustal root extending 20 km deeper into the mantle than the normal crust at sea level (*Figure 2*). Similarly an ocean basin with a depth of 4 km should have a mantle antiroot of 16 km thickness.

Figure 2.



Some Sidelights

Priority: Pratt and Airy were not the first to think of the *apparently hollow* mountains. The idea had occurred to Bouguer more than a century earlier from his geodetic observations in the Andes of Peru. But the evidence was not as compelling as that obtained from the geodetic and astronomical observations in India.

Alternative models and possible preference: Many refinements of the Pratt and Airy models have been proposed. Most recent efforts have focussed on modifying the earlier models so that they conform with the current plate tectonics paradigm of earth sciences. Independent evidence has been obtained that the crust in the Indian region is the thickest under the Himalaya and thinnest under the neighbouring seas. Thus the Airy model and its derivatives may have an edge over other competing models in explaining the riddle of the *apparently hollow* Himalaya. It is our preferred simple model and we adopt it for the rest of the article.

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Isostasy: The work of Pratt and Airy led earth scientists to the realisation that major topographic features on the earth's surface derive support in part at least from floating on a denser medium. The word '*isostasy*' was coined in 1889 for this concept.

Convection: There is ample evidence in the Himalayan rocks that they have emerged out of a vast and deep ocean. Thus, under the Airy model, mantle antiroots must have existed where deep crustal roots are being postulated today. Also, the sand and silt being brought down by the Himalayan rivers is evidence of a process of mass wasting under way. The heights of the Himalayan peaks will be reduced and their roots will shrink with time. Similarly deposition of these sediments on the floors of the adjoining seas will lead to a gradual disappearance of the mantle antiroots. In other words, the near surface transport of material from mountain tops to ocean deeps should have a reflection in the reverse flow of mantle material from regions of disappearing antiroots to regions of shrinking roots. This is convection in a broad sense and it is expected to occur on the time scale of millions of years.

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Influence of external loads: A large external load in the form of a thick ice sheet, as observed today in Antarctica or Greenland, should produce crustal subsidence. The same should happen if a large new lake, comparable to the great lakes of the United States and Canada, is formed. But if the ice melts or the lake dries up then the subsidence should disappear. The rate of response of the crust to such external load changes should depend on the viscosity of the mantle material. Ground levels are rising today in parts of Norway, Sweden and Finland where a thick ice sheet existed about 11000 years ago. They are also rising in the western United States where large lakes existed until relatively recent geologic times. Thus the mantle material should be substantially viscous.

Dual rheological behaviour of the mantle material: All the above evidence requires liquid like behaviour of the mantle material on the time scale of thousands of years and longer. But propagation of earthquakes generates transverse elastic waves through the mantle suggesting that its material behaves as a solid on the time scale of the periods of these waves. The periods range from a fraction of a second to hundreds of seconds for the travelling waves. The transverse elastic waves having the longest observed period of about 43 minutes are actually standing waves corresponding to toroidal free oscillations of the earth. Such

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dual behaviour on different time scales is well known in rheology. It is exhibited by many materials of which coal tar is perhaps the most familiar. It fractures like glass under a hammer blow and flows like a liquid over weeks and months.

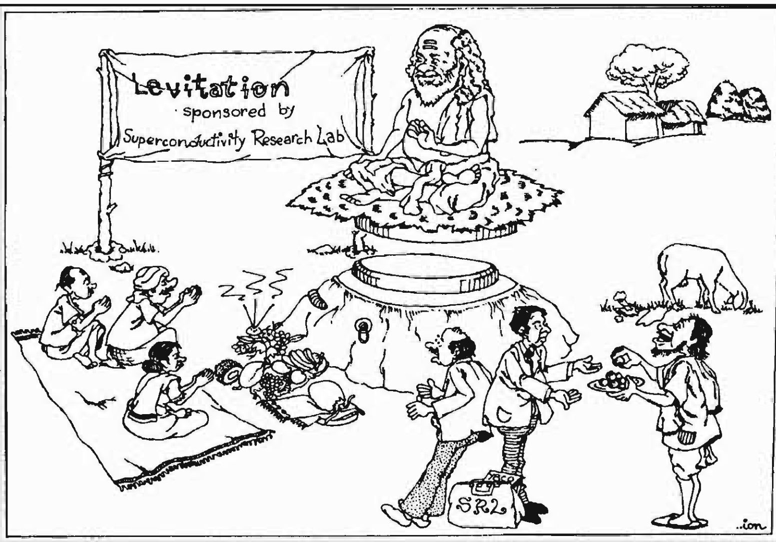
Vertical and horizontal movements: Vertical crustal movements under gravity suggested by many of the above considerations impressed the earth scientists of the late nineteenth and early twentieth centuries so much that for a long time they vehemently resisted the 1915 suggestion of continental drift by Wegener, a German meteorologist, because it called for horizontal movements of crustal fragments over thousands of kilometres in some cases. But today, possibility of both vertical and horizontal movements of crustal blocks is accepted.

In short: Thus, in hindsight, the formulation of the riddle of the *apparently hollow* Himalaya was a significant event in the history of earth sciences.

Suggested Reading

- R A Daly. *Strength and structure of the earth*. Prentice-Hall. Englewood Cliffs. N.J., 1940.
- R H Phillimore. *Historical records of the Survey of India*. Vol. 1. Survey of India, Dehra Dun UP, 1945.

Address for Correspondence
Ramesh Chander
Department of Earth Sciences
University of Roorkee
Roorkee 247 667, India.



Well done guys... next year push HIM 5 centimeters higher.