GEOLOGY

How Heavy Is a Mountain?

"A Classic of Science"

Pratt the Eminent Geodesist and Airy the Astronomer Discuss the Density and Thickness of Earth's Crust

Airy

ON THE COMPUTATION OF THE EFFECT OF THE ATTRACTION OF MOUNTAIN MASSES, as disturbing the Apparent Astronomical Latitude of Stations in Geodetic Surveys. By G. B. Airy, Esq., Astronomer Royal In Philosophical Transactions of the Royal Society of London. Vol. 145. London MDCCCLV (*1855*).

A PAPER of great ability has lately been communicated to the Royal Society by Archdeacon Pratt, in which the disturbing effects of the mass of high land northeast of the valley of the Ganges, upon the apparent astronomical latitudes of the principal stations of the Indian Arc of Meridian, are investigated. It is not my intention here to comment upon the mathematical methods used by the author of that paper, or upon the physical measures on which the numerical calculation of his formulae is based, but only to call attention to the principal result; namely, that the attraction of the mountain-ground, thus computed on the theory of gravitation, is considerably greater than is necessary to explain the anomalies observed. This singular conclusion, I confess, at first surprised me very much.

Nothing Surprising . . .

Yet, upon considering the theory of the earth's figure as affected by disturbing causes, with the aid of the best physical hypothesis (imperfect as it must be) which I am able to apply to it, it appears to me, not only that there is nothing surprising in Archdeacon Pratt's conclusion, but that it ought to have been anticipated; and that, instead of expecting a positive effect of attraction of a large mountain mass upon a station at a considerable distance from it, we ought to be prepared to expect no effect whatever, or in some cases even a small negative effect. The reasoning upon which this opinion is founded, inasmuch as it must have some application to almost every investigation of geodesy, may perhaps merit the attention of the Royal Society.

Although the surface of the earth consists everywhere of a hard crust, with only enough of water lying upon it to give us everywhere a *couche de niveau,* and to enable us to estimate the heights of the mountains in some places, and the depths of the basins in others; yet the smallness of those elevations and depths, the correctness with which the hard part of the earth has assumed the spheroidal form, and the absence of any particular preponderance either of land or of water at the equator as compared with the poles, have induced most physicists to suppose, either that the interior of the earth is now fluid, or that it was fluid when the mountains took their present forms. This fluidity may be very imperfect; it may be mere viscidity; it may even be little more than that degree of yielding which (as is well known to miners) shows itself by changes in the floors of subterraneous chambers at a great depth when their width exceeds 20 or 30 feet; and this yielding may be sufficient for my present explanation. However, in order to present my ideas in the clearest form, I will suppose the interior to be perfectly fluid.

In the accompanying diagram, fig. 1, suppose the outer circle, as far as it is complete, to represent the spheroidal surface of the earth, conceived to be free from basins or mountains except in one place; and suppose the prominence in the upper part to represent a table-land, 100 miles broad in its smaller horizontal dimension, and two miles high. And suppose the inner circle to represent the concentric spheroidal inner surface of the earth's crust, that inner spheroid being filled with a fluid of greater density than the crust, which, to avoid circumlocution, I will call *lava.* To fix our ideas, suppose the thickness of the crust to be ten miles through the greater part of the circumference, and therefore twelve miles at the place of the table-land.

Now I say, that this state of things is impossible; the weight of the table-land would break the crust through its whole depth from the top of the table-land to the surface of the lava, and either the whole or only the middle part would sink into the lava. . . .

If instead of supposing the crust ten miles thick, we had supposed it 100 miles thick, the necessary value for cohesion would have been reduced to 1/5th of a mile nearly. This small value would have been as fatal to the supposition as the other. Every rock has mechanical clefts through it, or has mineralogical veins less closely connected with it than its particles are among themselves; and these render the cohesion of the firmest rock, when considered in reference to large masses, absolutely insignificant. The miners in Cornwall know well the danger of a "fall" of the firmest granite or killas where it is undercut by working a lode at an inclination of 30° or 40° to the vertical.

Supported from Below . . .

We must therefore give up the supposition that the state of things below a table-land of any great magnitude can be represented by such a diagram as fig 1. And we may now inquire what the state of things really must be.

The impossibility of the existence of the state represented in fig. 1 has arisen from the want of a sufficient support of the table-land from below. Yet the table-land does exist in its elevation, and therefore it *is* supported from below. What can the nature of its support be?

I conceive that there can be no other support than that arising from the downward projection of a portion of the earth's light crust into the dense lava; the horizontal extent of that projection corresponding rudely with the horizontal extent of the table-land, and

What happens when a liquid turns into a gas? Andrews describes the

CRITICAL PHASE

in the next

CLASSIC OF SCIENCE

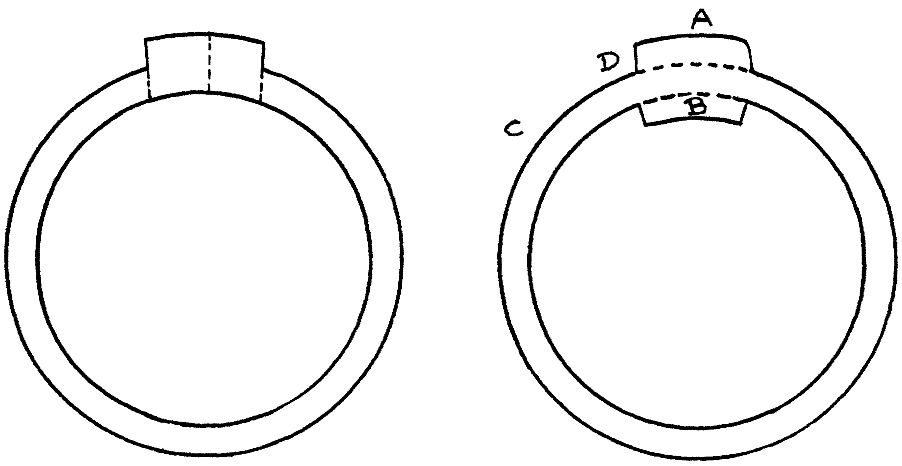

Fig. 1 Fig. 2

MOUNTAINS AND THE EARTH'S CRUST

Airy used diagrams like these to illustrate his idea that mountains are not extra loads on the crust of the earth, but masses floating on the more or less fluid material of its core. Pratt modified this theory to make the crust much thicker, and believed that there is a deficiency of matter below mountains and an excess below the oceans, so that the amount of matter in every part of the crust is the same. Pratt's theory is the basis of the modern science of isostasy.

the depth of its projection downwards being such that the increased power of flotation thus gained is roughly equal to the increase of weight above from the prominence of the table-land. It appears to me that the state of the earth's crust lying upon the lava may be compared with perfect correctness to the state of a raft of timber floating upon water; in which, if we remark one log whose upper surface floats much higher than the upper surfaces of the others we are certain that its lower surface lies deeper in the water than the lower surfaces of the others.

This state of things then will be represented by fig. 2. Adopting this as the true representation of the arrangement of masses beneath a table-land, let us consider what will be its effect in disturbing the direction of gravity at different points in its proximity. It will be remarked that the disturbance depends on two actions; the positive attraction produced by the elevated table-land; and the diminution of attraction, or negative attraction, produced by the substitution of a certain volume of light crust (in the lower projection) for heavy lava.

The diminution of attractive matter below, produced by the substitution of light crust for heavy lava, will be sensibly equal to the increase of attractive matter above. The difference of the negative attraction of one and the positive attraction of the other, as estimated in the direction of a line perpendicular to that joining the centres of attraction of the two masses (or as estimated in a horizontal line), will be proportional to the difference of the inverse cubes of the distances of the attracted point from the two masses. . . .

Pratt

ON THE DEFLECTION OF THE PLUMB-LINE IN INDIA, caused by the Attraction of the Himmalaya Mountains and of the elevated regions beyond; and its modification by the compensating effect of a Deficiency of Matter below the Mountain Mass. By the Venerable John Henry Pratt, M.A., Archdeacon of Calcutta. In Philosophical Transactions of the Royal Society of London. Vol. 149. London: MDCCCLX (1860).

THE Astronomer Royal, in a paper published in the Transactions for 1855, suggested that immediately beneath the mountain-mass there was most probably a deficiency of matter, which would produce, as it were, a negative attraction, and so counteract the effect on the plumb-line. This hypothesis appears, however, to be untenable for three reasons: (1) It supposes the thickness of the earth's solid crust to be considerably smaller than that assigned by the only satisfactory physical calculations made on the subject—those by Mr. Hopkins of Cambridge. He considers the thickness to be about 800 or 1000 miles at least. (2) It assumes that this thin crust is lighter than the fluid on which it is supposed to rest. But we should expect that in becoming solid from the fluid state, it would contract by loss of heat and become heavier. (3) The same reasoning by which Mr. Airy makes it appear that every protuberance outside this thin crust must be accompanied by a protuberance inside, down into the fluid mass, would equally prove that wherever there was a hollow, as in deep seas, in the outward surface, there must be one also in the inner surface of the crust corresponding to it; thus leading to a law of varying thickness which no process of cooling could have produced.

It is nevertheless to this source—I mean a Deficiency of Matter below—that we must look, I feel fully assured, for a compensating cause, if any is to be found. My present object is to propose another hypothesis regarding deficiency of matter below the mountain-mass, as first suggested by Mr. Airy; and to reduce my hypothesis to the test of calculation. . . .

I will now state the hypothesis on which my present calculation proceeds. At the time when the earth had just ceased to be wholly fluid, the form must have been a perfect spheroid, with no mountains and valleys nor ocean-hollows. As the crust formed, and grew continually thicker, contractions and expansions may have taken place in any of its parts, so as to depress and elevate the corresponding portions of the surface. If these changes took place chiefly in a vertical direction, then at any epoch a vertical line drawn down to a sufficient depth from any place in the surface will pass through a mass of matter which has remained the same in amount all through these changes. By the process of expansion the mountains have been forced up, and the mass thus raised above the level has produced a corresponding *attenuation* of matter below. This attenuation is most likely very trifling, as it probably exists through a great depth. Whether this cause will produce a sufficient amount of compensation can be determined only by submitting it to calculation, which I proceed to do. . . .

ON THE CONSTITUTION OF THE SOLID CRUST OF THE EARTH. By Archdeacon Pratt. In Philosophical Transactions of the Royal Society of London. Vol. 161. London: MDCCCLXXI (1871).

A FEW years ago I proposed the following hypothesis regarding the Constitution of the Earth's Solid Crust, viz.:—that the variety we see in the elevation and depression of the earth's surface, in mountains and plains and ocean-beds, has arisen from the mass having contracted unequally in becoming solid from a fluid or semifluid condition: and that below the sea-level under mountains and plains there is a deficiency of matter, approximately equal in amount to the mass above the sea-level; and that below ocean-beds there is an excess of matter, approximately equal to the deficiency in the ocean when compared with rock; so that the amount of matter in any vertical column drawn from the surface to a level surface below the crust is now, and ever has been, approximately the same in every part of the earth.

The process by which I arrived at this hypothesis I will explain. In the Philosophical Transactions for 1855 and 1858 I showed that the Himalayas and the Ocean must have a considerable influence in producing deflection of the plumb-line in India. But by a calculation of the mean figure of the earth, taking into account the effect of local attraction, it appeared that nowhere on the Indian Arc of meridian through Cape Comorin is the resultant local attraction, arising from all causes, of great importance. This result at once indicated that in the crust below there must be such variations of density as nearly to compensate for the large effects which would have resulted from the attraction of the mountains on the north of India and the vast ocean on the south, if they were the sole causes of disturbance,—and that, as this near compensation takes place all down the arc, nearly 1500 miles in length, the simplest hypothesis is, that beneath the mountains and plains there is a deficiency of matter nearly equal to the deficiency in the ocean itself. . . .

Science News Letter, May 21, 1932

MEDICINE

Yellow Fever Susceptibility Determined by New Test

A TEST for determining the success of the new vaccine against yellow fever, dread plague which claimed five victims out of every hundred persons in New Orleans fifty-eight years ago, was discussed at the meeting of the American Medical Association there.

Drs. T. P. Hughes and W. A. Sawyer of the Rockefeller Foundation, New York City, who just announced that they were able to give lasting protection against yellow fever by a newly-developed method that makes use of mouse serum, described the test.

In this test the germ or virus of yellow fever is mixed with the blood serum of the person being tested and injected into mice. If the person has in his blood protective substances that guard against yellow fever, they will neutralize the yellow fever virus and the mice stay well. If the mice get the disease it proves that the person's blood lacks the protective substances and hence that he is susceptible to the disease.

The specific nature of this test was proved by trying it on Canadians, who have never been exposed to yellow fever. As was expected, it showed that they did not have the protective substances.

Science News Letter, May 21, 1932

Platinum melts at a temperature of 3200 degrees Fahrenheit, a heat some 500 degrees higher than is needed to melt steel.

PHYSIOLOGY

Reactions of Normal Eyes Timed with Movie Camera

MEASUREMENTS with the motion picture camera of the time it takes the pupils of normal eyes to contract and to dilate were reported by Dr. Harry S. Gradle of Chicago, at the meeting of the American Medical Association. He found that when light is flashed on a normal eye accommodated for the dark, there is a latent period of about one-tenth of a second before the pupil starts to contract. Then, in a little over four-tenths of a second, the pupil jumps to its maximum contraction. When the light is removed, the pupil starts to dilate at a uniform rate. In making his studies, Dr. Gradle was obliged to use young, blue-eyed, blond persons, because the dark irises of brunets did not photograph clearly enough.

Science News Letter, May 21, 1932

ENGINEERING

Iodine From Oil Brines Breaks Former Monopoly

LARGE scale production of iodine from salty brines in California and Louisiana has freed America from a South American monopoly of this essential chemical element.

This was revealed at a review of recent chemical progress arranged by the American Institute.

For years this comparatively rare chemical element has been controlled by interests in Chile that restricted the amount sold and charged a high toll. Several years ago Los Angeles petroleum engineers analyzing brackish waters from oil wells near Long Beach, Calif., discovered iodides in paying quantities. Difficulty was experienced in freeing the iodine from the large amount of worthless salts with which it was associated, but processes were perfected that resulted in commercial production of the element from both Californian oil well brines and a salt-water well in Louisiana. This assures the continuance of the supply of iodine necessary for drug, disinfectant, photographic and other uses even during a possible wartime blockade. It may reduce the price of iodine so materially as to allow new uses.

The successful production of milk of magnesia from sea water in California was also reported by S. D. Kirkpatrick, editor of *Chemical and Metallurgical*