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XXXIII. Denudation and deposition

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grating used to print the impressions on the three positives. So well did they perform, that it seemed as if it might be possible in this way to build up satisfactory gratings of large size for spectroscopic work. Starting with a 1-inch grating of 2000 lines, I have built up a grating 8 inches square, which, when placed over the object-glass of a telescope, showed the dark bands in the spectrum of Sirius with great distinctness. No especial precautions, other than the use of the flat glass plate, were taken to insure absolute parallelism of the lines, and I have not had time to thoroughly test the grating. The spectra, however, are of extraordinary brilliancy; and on the whole the field seems promising. This matter will, however, be deferred to a subsequent paper.

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XXXIII. *Denudation and Deposition.*

By G. JOHNSTONE STONEY, M.A., D.Sc., F.R.S.*

IN a lecture to the Royal Geographical Society, of which a copious extract is given in 'Nature' of the 2nd of February, 1899, Dr. J. W. Gregory discusses many of the causes which may have led to the existing form of the earth. But there is one important factor in the problem left unnoticed, namely, the conspicuous alterations of level which may be attributed to the earth's compressibility, and which seem to have been brought about wherever either denudation or deposition have continued over wide areas and for a long time.

Dr. Gregory makes a convenient division of the earth into three parts:—(1) the unknown internal centrosphere; (2) the rocky crust or lithosphere; (3) the oceanic layer, or hydrosphere. These, with the atmosphere, which may be added as a fourth part, make up the whole earth.

If now we imagine a pyramid whose base is a square centimetre of the surface of the solid part of the earth and whose vertex is the earth's centre, it has a volume of about 212 cubic metres, which is the same as 212 millions of cubic centimetres. This pyramid passes first through the lithospheric shell, or outer crust, and then halfway across the centrosphere to the centre of the earth. All the materials of which it consists are compressible. Those which lie within the outer shell consist mainly of carbonates, silicates, and aluminates, and have probably a coefficient of compressibility about equal to that of glass; while the compressibility of the centrosphere is unknown, and may be either more or less. The observed form of the earth's surface seems to suggest that the average

* Communicated by the Author.

compressibility of the lithosphere and centrosphere taken together is not far from that of the more incompressible kinds of glass. Glass of this description yields to compression about $2\frac{1}{2}$ times more than solid cast iron, but less than mercury (which seems to be the only liquid metal that has been experimented on) in the ratio of 2 to 3. It is about 20 times more incompressible than water.

We shall then, as a provisional hypothesis, assume that the earth has the same compressibility as the more resistant kinds of glass, which lose about $2\frac{1}{2}$ billionths of their volume for each pressure of a dyne per square centimetre over their surface. Combining this with the volume of the earth-pyramid given above, we find that our hypothesis leads to the conclusion that if the sides of the pyramid were kept from yielding, and if the weight of a cubic centimetre of water were placed on its outer end, this would reduce its bulk by half a cubic centimetre. A cubic centimetre of stone, of specific gravity 3, would accordingly depress its outer end by $1\frac{1}{2}$ centimetres. It follows from this that if meteors rained upon the earth (supposed to be without an ocean) producing a deposit over its whole surface a centimetre thick, and of material as dense as stone, the result would be that the earth after this accession would be smaller; its surface would sink down about half a centimetre. Correspondingly, if by any agency a centimetre of the earth's crust could be removed over the whole earth, the earth's surface would stand $\frac{1}{2}$ a centimetre higher than before. These are the effects which deposition and denudation would respectively produce if they could operate over the whole earth. And, if they operate over any extensive area of the earth's surface, they will produce effects of the same kind, complicated a little by the displacement of the earth's centre of attraction, or rather locus of centres of attraction.

This may be well seen in the oldest parts of the oldest continents—parts of Asia and Africa—to whose present elevation denudation*, operating over an extensive area and for long ages, has probably chiefly contributed. And, correspondingly, there is a deepening of those parts of the ocean where the deposition of sufficiently heavy† material has been going on over a great area for an immense time.

* Underground waters produce the same dynamical effect as surface denudation, by reason of the materials they remove in solution.

† Where the sub-aqueous deposit is spread over only a small part of the surface of the globe (which is the only case we need consider), the compression is due, not to the whole weight of the deposit, but only to its excess over the weight of an equal bulk of water. Hence to produce an equivalent effect the material must be denser than it would need to be if the deposition had been on land.

The *extent* of the area is an essential condition, *i. e.*, the *lateral* dimensions of the inverted pyramid which has the area for its base and the centre of the earth for its vertex. If the area is small or narrow, oblique forces exerted by the parts surrounding this pyramid come more into play. They enable the part within the pyramid to act like a bridge; and the support thus given enables denudation, if limited to a small area, to scoop out valleys, and deposition to produce ridges, as may be seen in the glaciers and moraines of mountainous countries. On the other hand, if the erosion due to glacial action takes effect over a great stretch of country, as it does in Greenland, and as it formerly did in Ireland, it causes the surface to rise.

A nearly even balance between the two opposite tendencies may be seen in Egypt, where borings exhibit fluvial deposits at great depths below the present surface, although the surface is only about as much raised above the sea now as it was when those ancient deposits were laid down by the Nile. Each year's deposit makes the surface go down, but only about as much as its own thickness, so that the new surface each year is not far from being at the same level as that of the preceding year. If the deposit had taken place over a much greater breadth of country, the whole would have gone down. It would have become a ridge if it had been confined to a much narrower strip and if the river could have been kept from diverging.

A similarly instructive case is that of Brazil, where an immense plateau is continuously being denuded by the vast rivers that drain it. But here there is also an equally uninterrupted addition to the solid materials of the earth by the luxuriant tropical vegetation which everywhere prevails; and it is probably because the accessions and withdrawals are nearly equal to one another, that the level of the surface has been but little changed.

Denudation may cause the surface to rise within a space which is in a considerable degree more circumscribed than the areas of elevation hitherto considered, if the conditions are such that the stresses that come into existence round the boundary of this limited space can produce faults, and prevent the material which is outside the pyramid from being in a position to help to keep down the material which is within. This seems to have happened in the case of that vast mass of mountains—the Himalayas, the Hindu Kush, and their associated ranges—where excessive denudation accompanied by the isolation secured by faults has occasioned a proportionately great elevation above what was probably a humble beginning;

where the deposits in the Bay of Bengal are probably the cause of its great depth; and where earthquakes in the intervening regions betray when the faults are establishing themselves which render the rising and the descending areas independent of one another, and allow the denudation on the one side and the deposition on the other to produce each its full effect, without mutual interference.

Of course all compressions and dilatations must be accompanied by other movements within the earth, and at all depths; which may be slow but are no less sure. In fact, there is no material which can resist yielding to differences of pressure, however feeble, if they act for a long time and over a large surface; and such pressures, urging in various directions, must arise both from the compressions and dilatations spoken of above, and from other causes, among which movements of heat and the heterogeneous character of the materials of which the earth consists are prominent. The earth, therefore, is in a state of never-ending change, which to become conspicuous to man would only need to be placed in some kind of kinematograph arrangement which would hurry over millions of years in fractions of a second. These effects mix with and complicate those which have been taken account of in the present paper.

It is interesting to note how the agencies we have been considering would operate upon other bodies of the universe. Events equivalent to denudation and deposition which cause excessively slow movements in our small earth, would act with increased promptness upon such great planets as Jupiter, Saturn, Uranus, and Neptune, and with violence upon bodies that attain the size of the sun and stars. On the other hand, on bodies with the dimensions of the moon they are relatively feeble, and must be very slow in producing any appreciable effect.

XXXIV. *On the Transmission of Light through an Atmosphere containing Small Particles in Suspension, and on the Origin of the Blue of the Sky.* By Lord RAYLEIGH, F.R.S.*

THIS subject has been treated in papers published many years ago†. I resume it in order to examine more closely than hitherto the attenuation undergone by the primary light on its passage through a medium containing small particles, as dependent upon the number and size of the particles. Closely connected with this is the interesting

* Communicated by the Author.

† Phil. Mag. xli. pp. 107, 274, 447 (1871); xii. p. 81 (1881).