II.—ON THE PROBABLE GLACIAL ORIGIN OF CERTAIN PHENOMENA OF DENUDATION.

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THE pages of the GEOLOGICAL MAGAZINE have lately contained some interesting articles on denudation. I wish to add some further remarks on the subject, which I think will, if duly considered, add important elements to the discussion of that problem.

In my paper "On the Denudation of Soft Strata," read before the Geological Society in 1861, I combated the view then generally held, that the present contour of the country was due to the ordinary action of the sea, as the land was slowly elevated above the waters. At that time I had perceived that the denuding agent must have flowed from higher to lower levels, and I suggested the flowing off of water owing to a sudden elevation of the land. I am not prepared entirely to recant those views, for I believe we shall err in this, as we are liable to do in all physical problems, by summarily excluding any possible explanation of the phenomena.

Messrs. Foster and Topley did me the honour to quote my argument against the possibility of escarpments being Old Sea Cliffs, in their paper "On the Denudation of the Weald;"¹ and Mr. Topley has repeated the argument in the last number of this Magazine.² His explanation of the formation of escarpments in that article is very good, and, in general, I believe the true one, in as far as he has shown how a denuding agent has worked to cut out the valleys and leave the escarpments. But the point I wish to discuss at present is what that denuding agent has been.

Rain and rivers are the agents now chiefly relied upon. They have, no doubt, done much, and are still at work: so that we can judge of their past labours by their present effects. But I believe I have succeeded in proving in my paper "On the Warp," in the forthcoming number of the Journal of the Geological Society, that the present surface of this country has been eroded into channels by a plastic mud or gravel derived from higher grounds, and forcibly indented into the surface. The materials in these furrows (and sometimes we have extensive coverings of it, not mere furrows³) I have called "trail." The junction of the trail with the subjacent bed, where that is clay, is constantly marked with "slickenside;" and my own impression is, that pebbles near the surface of junction are somewhat polished. I do not believe it possible that any theory of denudation can be of the least value which ignores the existence of this almost universal coating of the surface. It is necessarily the

¹ Quart. Jour. Geol. Soc., Vol. xxi. p. 463.

² GEOL. MAG. Vol. III. p. 435.

³ An excellent exhibition of the trail, under this aspect, will be found in the brick-pit at Uphall, near Ilford, the same pit from which came the head and tusks of *Elephas primigenius* in the British Museum. Here I saw from the trail an angular block of grey weather sandstone, weighing about twenty-five pounds.

key to the *last* denuding agent. The unstratified character of this trail, the large blocks of stone which it sometimes contains, while the subjacent bed perhaps contains none, the unscattered condition of lumps of clay, crag, and sand, which sometimes occur in it, the force which evidently acted to push it forward, all point to *land-ice* as the moving agent.

We need not be surprised at the existence of land-ice at comparatively recent geological periods, even in the south of England, for Mr. Jukes has described Glacial Striæ in Devonshire,¹ and in the south-west of Ireland;² and the Hon. W. O. Stanley informs me that Anglessea, which is not high ground, is generally ice-marked. The reason why such markings are rare in the south of England is probably that the surfaces are so often of materials liable to disintegration and solution. This is exceedingly well illustrated by Mr. Green's remarks, "On the Bloody Stone in Derbyshire,"³ where scratches are preserved on chert, but usually effaced on the containing limestone.

Thus far, then, we see that the general covering of the surface indicates ice-action, and that it is probable, from other independent indications, that land-ice has lately covered the existing surface. The next point is to balance the probable efficacy of ice, as compared with water, to mould the surface to its existing form.

Conceive the actually existing surface of any district, which consists of soft strata, to be intersected by a nearly horizontal plane. The curves of intersection will be full of cusps or sharp angles, running up into the secondary (or tributary) valleys. It seems self-evident that a river gradually deepening its bed (which in the case supposed would be represented by the gradual lowering of the horizontal plane) could not excavate a level area of such a configuration.

Frequently one meets with evident instances of the erosion which a stream has produced, and I never saw a case in which it was not possible to distinguish readily the work of the stream upon the previous configuration of the surface which had been left by the more general ancient denuding agency. Messrs. Foster and Topley rely much, in their paper "On the Denudation of the Weald," upon a river gravel at an elevation of 300 feet. I do not know the locality; but does it follow that because the river has once flowed at a higher level, therefore the subsequent degradation of the surface is the work of the river?

Mr. Maw, at p. 445 of the last number of the Magazine, very justly distinguishes between the excavation by a river at the bottom of a valley, and the denudation of the valley itself. But upon comparing the absolute quantity of material abraded by the river, with that removed from the valley sides by some other cause, we see how much larger the latter is; and on the supposition that the

¹ GEOLOGICAL MAGAZINE, Vol. II., p. 473.

² Juke's School Manual (1863), p. 326.

³ GEOLOGICAL MAGAZINE, Vol. II., p. 440.

work has been effected, simultaneously from its commencement, by atmospheric causes on the sides and river action at the bottom, we arrive at the conclusion that the abrading power of the atmosphere far exceeds that of the river, which, when once the sides have reached the angle of repose, seems very improbable.

Sir Roderick Murchison, in his address to the geological section at the last meeting but one of the British Association, said: "I do not believe that the wear and tear due to atmospheric subaërial erosive agency could, even after operating for countless ages, have originated and deepened any of the valleys and gorges which occur in countries as flat as the tract in which we are now assembled" (which was the neighbourhood of Birmingham). In this sentence the argument rests upon the *flatness* of the surface. It is impossible to conceive a very rapid flow of water caused by rain upon a moderately flat surface of upland. A current of water of a given velocity cannot move an ordinary pebble which is above a given size. A current which can just move a given pebble can, roughly speaking, move any smaller pebble of the same or less specific gravity. Yet, in a mixed gravel, pebbles too large for the flow of water to move will, nevertheless, progress by the washing away of smaller stuff in front of them. A temporary inclined plane is thus formed, down which the pebble rolls partly by its own weight. Thus it happens that where the stream is too slow to move the larger pebbles, if there be sufficient fall in the ground they nevertheless slowly progress, but the small stuff moves off faster, and the pebbles accumulate behind. Thus the gravelly bottoms of rivers are formed. If then, the degradation of gravelly strata has been produced by rain wash, we ought to have most of the larger pebbles corresponding to the denuded material left behind. This is certainly not the case. A still more obvious difficulty is the removal of large blocks from escarpments. Take, for instance, such blocks as those which form the upper portion of the Greensand in Dorsetshire, which are notably seen at Eggerdon-hill and Bincombe-down. What has become of those which must have fallen as the hills were cut back? We see a few lying about on one side of Eggerdon, where a landslip has occurred, but those which must have fallen as the Chalk was degraded, if by atmospheric agency, ought to cover the spurs of the hill and the bottoms of the valleys.

Let us now suppose the land to have been covered with a sheet of ice, what would be the character of the denudation? I endeavoured to explain, in a letter to the "Reader,"¹ what I conceived to be the *modus operandi* of ice in the particular case of excavating a lake basin, and Mr. Jamieson has very well illustrated the nature of the motion of a sheet of ice by that of a quantity of corn heaped up upon a floor.² As its height is increased the grains in contact with the floor move outwards from the centre. Provided, then, that a sufficient thickness of snow were supplied, the ice would always move outwards from some central region towards the sea.

¹ Reader, April 25, 1865.

² Quart. Journ. Geol. Soc., Vol. xxi., p. 166.

In the first place, then, the smallness of the inclination of a surface would not prevent motion, and consequent friction and denudation. Secondly, there would be no selection made of the materials carried away, while a certain quantity of *till* containing all the ingredients of the surface derived from an area in rear, would be interposed between the ice and the land. The remains of this I suppose to constitute what I have ventured to call the trail. The softer strata would be worn away most quickly, and, in general, each successive outcrop would be maintained at a uniform level depending upon its hardness.¹ I should expect that, when a soft rock had been denuded to a certain depth in proportion to the thickness of the ice-sheet, a fissure would be formed, causing an ice-fall, which would excavate a steep escarpment at the junction of a harder with a softer stratum. We know that it is the tendency of an ice-sheet to "descend towards the sea in successive steps, leading up to as many icy-platforms, the ridges and valleys (of the land) being levelled up to one uniform plane, and concealed by these tabular masses of ice." (See Sir C. Lyell's account of the continental ice of Greenland: "*Antiquity of Man*," p. 235, ed. 1863.) The thicker the ice-sheet the more uniform its action upon the surface would be, and the less it would tend to form minor features. But as the climate gradually became milder, and the ice-sheet thinner, features would be formed on a smaller scale, and it would be these which we should now see.

As far as I have had opportunities of examining the furrows that I have described, I have noticed that they are largest and most numerous in the neighbourhood of valleys, and are either parallel or inclined at a small angle to them.² This is what we should expect: for, according to the theory, the valleys represent the directions in which the ice flowed off during the later periods of its existence; and since the sheet would partake of a similar motion for some distance on both sides of the line of maximum flow, we should find the surface scored, in a minor degree, nearly in the same direction as the valley.

Finally, the sheet would be confined to the higher grounds with glaciers descending towards the plains.

To seek for the beds of extinct glaciers among Chalk downs might be thought fruitless. Nevertheless, I have noticed combs in the Wiltshire downs which have much that appearance. There is one in particular above the village of Heddington, near Calne, up which the footpath to Devizes runs. Its sides are steep walls of Lower Chalk, and in general form and inclination it most closely resembles

¹ An excellent illustration of the effect of the comparative hardness of material, in determining the form of the ground, may be noticed in the neighbourhood of Cromer. The landscape suddenly changes from one of a rather monotonous character to one of rapidly varying hill and dale, on account of the extremely irregular collocation of masses of clay, chalk, and gravel, among the glacial deposits of that district.

² The workmen at Ilford told me that the furrows all ran nearly in the same direction, which was one inclined at an angle of about 45° to the River-valley adjoining.

a small glacier bed. In the same down there are also some very singular combs just beneath Oliver's Camp, which have all the appearance of glacier beds. At their lower end, a dry bed of a former torrent suddenly commences, as if it were the seat of the old glacial river.

About Tollard Royal, in the Chalk downs north of Tisbury, some of the combs are very deep, and their sides steeper than will allow the Chalk, as it disintegrates, to lie upon them. It forms a talus at the bottom. This points to an agency which has left nearly perpendicular walls upon the sides of the combs, an effect which glaciers would produce.

Agreeing, as I do, with Professor Ramsay in his theory of the erosion of lake basins by ice, I look to that agent for the formation of such basins as the Broad, of Norfolk;¹ and I think that many of the basins in other districts now occupied by lacustrine deposits may have been formed in a similar manner. Indeed, on any other theory, it is hard to account for peat bogs and lacustrine deposits in certain situations.

It is obvious that the view I have taken of the mode of denudation is not in any way inconsistent with those phenomena which have been attributed to the effects of solution, such as pipes in Chalk and Limestone strata, or with the formation of caverns by solution of the rock. A constant supply of water to the surface would be afforded by the liquefaction of the lower surface of the ice.

After the disappearance of the ice, the surface of the country would become gradually covered with vegetation, while the work of rain and rivers and frost would commence to modify the form and condition of the surface. But the grand general features, which, to my apprehension, are not attributable to the last-named agents, would have been already impressed upon it.

We have geological evidence of constantly alternating conditions of an arctic and a temperate climate in these latitudes, at least, since the period of the Norwich Crag.

But I am much mistaken if, in the eastern plain of England, any part of the configuration of the surface dates further back than the great submergence which deposited the Boulder-clay containing so much Chalk and Oolitic *debris*—the "Upper-drift" of Mr. S. V. Wood, Jun. Since that period the surface has been under constantly varying conditions; the glacial periods having in all probability become less and less severe. The present contour of the surface is the accumulated result of these varied conditions throughout long ages. My object in this article has been to suggest that the glacial periods have been those to which the form of surface is chiefly due.

¹ Possibly Norfolk, from its situation, may have been colder than other parts of England, being in the neighbourhood of an arctic current; and its valleys may have been filled by ice while, in other places, alluvial beds were in course of formation.