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ART. I.—*Theory of an Interglacial Submergence in England* ;
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UP to a very recent date English geologists were very generally agreed that the British Isles have been visited by at least two distinct glacial epochs since Tertiary times, and that during the supposed interglacial period there was a subsidence in the northern part of England, amounting to from 1,400 to 2,000 feet. The evidence most relied upon in proof of this theory is the occurrence of interglacial stratified beds of sand and gravel containing sea shells at Moel Tryfaen, near Mount Snowdon, about 1,400 feet above sea-level, and at Macclesfield, near Manchester, about 1,200 feet above the sea. At other places, also, similar interstratified beds occur at lower levels; as at Wellington, in Shropshire, about 500 feet above tide; upon the east coast, near Flamborough Head, from 300 to 400 feet; and throughout Holderness, at lower levels. North of Flamborough, also, the glacial deposits pretty continuously show a threefold division, consisting of two strata of till separated by stratified material, but the deposits here nowhere rise more than 400 or 500 feet above the sea.

But in view of accumulating facts concerning the stratification that takes place about the margin of a great glacier whose front is subject to temporary oscillations, interglacial stratified beds cease in themselves to be evidence either of absolutely distinct glacial epochs or of subsidence. The occurrence of unbroken salt-water shells in some of these deposits appears more nearly like positive proof. It would seem, however, that even this must now be regarded not only as questionable

in itself, but as connected with a theory which creates greater difficulties than it explains.

As long ago as 1874 Mr. Belt* and Mr. Goodchild† suggested that the sea shells in question may have been pushed up from the bottom of the sea, like other pebbles, by the advance of the glacial current. In 1881 Mr. Clement Reid‡ also favored the suggestion, while a little later Prof. H. Carvill Lewis took up the theory and advocated it with great vigor.§ Prof. Lewis's advocacy is the more significant, in view of the fact that, in the light of his experience in conducting with me the survey of the glacial boundary in Pennsylvania, he had just devoted two years to a survey of the glacial boundary in Ireland, Wales, and England. But his sudden death interrupted both the further field work which he was proposing and the complete digestion and publication of the extensive field notes already taken.

Investigation, however, has not flagged since Prof. Lewis's death, and the opportunities for collecting additional information in a visit which I made to England for that purpose last summer, have been largely due to the interest aroused by his work. For the facts now presented I am indebted not only to the papers enumerated below,|| but in special degree to the

* *Nature*, May 14, 1874. † *Geological Magazine*, 1874, p. 496.

‡ *Geological Magazine*, 1881, p. 235.

§ *Proceedings of the British Association for 1886 and 1887*.

|| Dugald Bell, *Phenomena of the Glacial Epoch* (*Transactions of the Geological Society of Glasgow*, 1889); J. H. Blake, *On the Age and Relation of the so-called "Forest-Bed" of the Norfolk and Suffolk Coast* (address at the Anniversary Meeting of the Norwich Geological Society, Nov. 2, 1880); H. W. Crosskey and David Robertson, *The Post-Tertiary Fossiliferous Beds of Scotland: XV—Jordanhill Brickworks, and XX—Kyles of Bute* (*Transactions of the Geological Society of Glasgow*, vols. iv and v); H. W. Crosskey, *On a Section of Glacial Drift recently exposed in Icknield Street, Birmingham, and Notes on the Glacial Geology of the Midlands* (*Proceedings of the Birmingham Philosophical Society*, vols. iii and vi); J. R. Dakyns, *Glacial Deposits north of Bridlington* (A Paper read before the Geological and Polytechnic Society of the West Riding of Yorkshire, 1880); C. E. DeRance, *Notes on the Vale of Clwyd Caves* (*Proceedings of the Yorkshire Geological and Polytechnic Society*, 1888); *On the Post-Glacial Deposits of Western Lancashire and Cheshire* (*Quarterly Journal of the Geological Society for February*, 1871); J. G. Goodchild, *The Glacial Phenomena of the Eden Valley and the Western part of the Yorkshire-Dale District* (*Quarterly Journal of the Geological Society for February*, 1875); Percy F. Kendall, *On the Occurrence of Nassa Serrata Brocchi in the Glacial Drift of the North Shore, Ramsey, Isle of Man* (*Proceedings of the Manx Geological Society*, 1889); *On the Pliocene Beds of St. Erth* (*Quarterly Journal of the Geological Society for May*, 1886); G. W. Lamplugh, *On Glacial Shell-Beds in British Columbia* (*Quarterly Journal of the Geological Society for August*, 1886); *On the Larger Boulders of Flamborough Head and other parts of the Yorkshire Coast, Parts II-IV*. (*Proceedings of the Yorkshire Geological and Polytechnic Society*, 1889 and 1890); *Glacial Sections near Bridlington* (*Proceedings of the Yorkshire Geological and Polytechnic Society*, 1882 and 1889); *On a Recent Exposure of the Shelly Patches in the Boulder-clay at Bridlington Quay* (*Quarterly Journal of the Geological Society*, vol. xxxvi, p. 515 and xl, pp. 312-328); *On Photograph of Cliff-Section*

personal attention of Dr. Crosskey and Mr. Martin, of Birmingham; of Mr. Kendall, of Stockport, and various members of the Northwestern Boulder Committee, of which he is president, and of Mr. Lamplugh of Bridlington,—all of whom have kindly accompanied me to the typical exposures of glacial deposits in the vicinities where they reside. The aid of Dr. Crosskey was specially important from the fact that he had just completed the editing of Professor Lewis's field notes, which are soon to be published. For Mr. Kendall's views I am further indebted to a systematic statement of the facts which he has prepared for me to be used as a chapter in a volume, on "Man and the Glacial Period," which is soon to be published in the International Scientific Series.

At the outset the theory of deep interglacial submergence to account for the shell-beds of Moel Tryfaen and Macclesfield encounters many most formidable objections: 1st. The subsidence must have been one which affected the north of Wales and central England, without affecting the region south of the Bristol Channel and the Thames; for confessedly there are no marks of subsidence or of glaciation over that area. 2d. There is in other places a remarkable absence of marks of subsidence over the northern part of the center of England, where it is supposed to have been the greatest. This is the more noteworthy, since in the glaciated region farther north kames abound, while at Glen Roy, a prominent feature in the landscape is the beaches formed during the existence of temporary glacial lakes, showing that the time which has elapsed since the glacial period has been too short to permit such features to be obliterated. But throughout all England there is a conspicuous absence both of such beach lines at high levels and of any other marks which would have been left by a sea margin had it continued for any appreciable time at the level of the shell-beds under consideration. 3d. This is still more remarkable from the fact that the Pennine Chain is not more than 25 or 30 miles wide from east to west, and east of

at Hilderthorpe (Proceedings of the Yorkshire Geological and Polytechnic Society, 1887); D. Mackintosh, On High-Level Marine Drifts (Quarterly Journal of the Geological Society, 1881, pp. 351-369); Fred W. Martin, On Some Sections of the Drift between Soho and Perry Barr, near Birmingham (Proceedings of the Birmingham Philosophical Society, vol. iv. part II, pp. 364-370); First Report upon the Distribution of Boulders in South Shropshire and South Staffordshire (Proceedings of the Birmingham Philosophical Society, vol. vi. part I); Aubrey Strahan, On the Glaciation of South Lancashire, Cheshire, and the Welsh Borders (Quarterly Journal of the Geological Society, 1886); C. Reid, Geology of Holderness and of Cromer (Geol. Survey); Woodward's Geology of England and Wales is a storehouse of accurate information upon this as upon all other subjects of which it treats; R. M. Deeley, The Pleistocene Succession in the Trent Basin (Quarterly Journal of the Geological Society for November, 1886); G. W. Lamplugh, On the Drifts of Flamborough Head (Quarterly Journal of the Geological Society for August, 1891).

Macclesfield there is an entire absence upon its flanks both of glacial deposits and of beach lines. 4th. The shell-beds are strictly confined not only to the area which was demonstrably covered by glacial ice, but to those more limited areas which were reached by ice that is known to have moved in its way over shallow sea bottoms. 5th. The assemblage of shells is not such as could have occurred in one place in the ordinary course of nature. There are associated together in these deposits cold-water forms with warm-water forms, rock-haunting species with sand- or mud-loving species, and in no case has a shell been found in these beds with its valves in apposition.

An interesting illustration of this latter point is brought out in Mr. Kendall's paper "On the Occurrence of *Nassa serrata* Brocchi, in the Glacial Drift of the Northern Shore, Ramsey, Isle of Man." This mollusk is now characteristic of the Mediterranean Sea, and cannot endure even the present temperate climate of the Irish Channel, yet specimens of it are found in the glacial deposits on the Isle of Man. It is in the highest degree improbable that this mollusk could have lived where it was found under any conditions that have been supposed to exist since the close of the Tertiary period. The theory that it was transported from the remains of Pliocene beds on the shallow bottom of the Irish Sea is certainly the most natural if only one can grant that it is conceivable. Other shells found in the glacial deposits in Northwestern England and Wales almost as much out of place are *Cytherea chione* L., *Mitra* sp., and *Turritella triplicata* Brocchi. It is worthy of note, also, that Prof. Edward Forbes early called attention to the fragmentary condition of the shells in the beds of the northwest of England, and to their general distribution through the till. Speaking of the Moel Tryfaen shells he says: "I have lately examined them carefully with a view to see whether they indicate an ancient coast-line or beach, or an ancient sea-bottom. But they cannot be regarded as indicating either, being a confused mixture of fragments of species from all depths, both littoral and such as invariably live at a depth of many fathoms. . . Such deep- and shallow-water species mingled could at no time have lived together, or been thrown upon one shore."*

During a visit this summer to Ketley, near Wellington in Shropshire, in company with Dr. Crosskey, Mr. Martin, and Prentiss Baldwin, we were fortunate enough to discover an unusually large collection of nearly perfect shells in the interstratified glacial deposits of that place. We could not indeed determine that there was till underneath the sand (which was here twenty-five or thirty feet at least in thickness), but there

* Memoirs, Geological Survey, vol. i, p. 384; quoted by Dugald Bell.

were several feet of till overlying the sand, and a thin stratum of gravel at the junction of the two. In this gravel Mr. Baldwin discovered several slightly worn shells and on further examination forty or fifty well-preserved specimens were brought out. All these were identified by Dr. Crosskey as belonging to species now common on the English coast. The elevation above the sea would vary only a little from 500 feet. A few miles from the same locality, at an elevation above the sea of about 700 feet, Dr. Crosskey had previously discovered in the glacial deposits other shells which were of a decidedly arctic type. It is extremely improbable that both could have lived in that locality amid the conditions involved in the interglacial hypothesis, as the temperature which would be favorable to one would be destructive to the other. But on the supposition that both had lived and died in succession upon the bottom of the Irish Sea, and then had been transported by the moving ice to near their present position, where the till was subjected to temporary water action sufficient to sort out a portion of its material, everything is intelligible and consistent.

Various reports have also come from Scotland of arctic shells in glacial deposits at some distance above sea-level. Those found near Airdrie have been most written about, and were the highest reported, being 510 feet above the sea. But closer examination shows that they also may be explained in accordance with the theory of Professor Lewis. This Sir Archibald Geikie practically admits in the second edition of his "Text-book of Geology," saying that "the layer containing them may have been transported by an ice-sheet" (pp. 897, 902). Mr. Dugald Bell informs me that after carefully examining all the alleged instances of elevated shell-beds in the glacial deposits of Scotland, there is no clear proof of any glacial submergence of more than 200 or 300 feet, and the evidence for even that amount is questionable.

As to the conceivability of the transportation of shells in the till, many significant facts have recently been brought to light. The till in the vicinity of the shell-beds mentioned, and in other places where the ice has moved inland from the sea-bottom, contains a great number of shell fragments indiscriminately mixed with the mass. I have even seen in a mass of boulder clay the half of a bivalve, with its cavity filled with sand, which had kept its place under the shell as it was shoved along; thus serving to protect it from being crushed. As long ago as 1884, Mr. Lamplugh, in examining the dry dock which was then being excavated in Esquimaux Harbor, Vancouver, discovered evidence that most of the glacial shells which were found in the drift there had "been pushed up into

the gulley by ice in its passage southward across the harbor," for they were so scattered through the unstratified mass that it was impossible to draw a line between the shelly and the shell-less clay.* In the glacial deposits surmounting the chalk cliffs near Flamborough Head, Mr. Lamplugh showed me elongated masses of sandy material containing well-preserved shells, but which were included in till, and had evidently been drawn out by the shearing movement to which the whole mass was subjected. There could be little question that in this instance the mass had in some way been pushed up from the sea bottom by the same ice-movement which had carried thither the rest of the till. Here the elevation was between 200 and 300 feet, and I see no reason why the causes operating to produce that amount of movement and elevation might not under favorable conditions have transported similar masses to the elevation of the shell-beds at Moel-Tryfaen.

In recent speculations upon the movement of ice too exclusive attention has been given to its analogies with the motion of a semi fluid, forgetting that under a mechanical thrust ice moves like a solid, and may plough up and push along before it whatever is in its way. Indeed, as I recall the phenomena at Muir glacier, I feel confident that this is what is taking place on the bottom of the inlet. A large number of the icebergs are formed by the falling off of the precipitous ice-front, owing doubtless to the fact that in the ordinary motion of the glacier the upper strata move faster than the lower. At times I saw such masses break off in columns more than 250 feet in height, and extending below the surface of the water, but the fractures did not reach to the bottom of the ice, for occasionally an immense mass in front of the ice-wall would rise bodily out of the depths of the water, bringing up much dirt with it. This projecting foot of the ice may perhaps have been moved forward bodily at the bottom of the inlet by successive mechanical thrusts of the moving mass of ice behind. So in analogous situations where there is a concentration of lines of pressure from behind, we can conceive that material would be gradually thrust up in front of the ice without much attrition. At any rate, the fact that the material is so raised and pushed along in front of the ice I think will have to be accepted.

Returning now to the specific glacial phenomena in England, it would seem that they can be generalized under one glacial epoch, upon the following scheme, which is based upon the facts as they are now reported. The beginning of the glacial period was marked, in the seas surrounding England,

* Quarterly Journal of the Geological Society, Aug. 1886, p. 283.

by the southerly retreat of the Pliocene fauna and the incoming of subarctic and arctic species; so that shells of diverse nature became commingled all over the bottom of the Irish and North Seas. Scandinavian glaciers advanced over the shallow North Sea till they reached the shores of England at Flamborough Head, where they were met by the glaciers that had been slowly coming down from southeastern Scotland and northeastern England. This latter movement of the ice was compelled to hug the shore by the Scandinavian glacier, and its boulders are found only as far south as Flamborough Head. The Scandinavian movement reached pretty generally to the line extending from Flamborough Head to London.

Contemporaneous with this movement over the North Sea, glaciers began to push out in all directions from the northern part of Wales, having their center in the broad elevated area of the Arenig mountains about twenty-five miles southeast of Snowdon. Towards the east this movement extended across Shropshire and the southern part of Staffordshire to a line extending from Litchfield, through Birmingham, and Bromsgrove to the Severn Valley. But meanwhile a more powerful ice-movement was under way, originating in the snowfields of Eastern Ireland, Southwestern Scotland, and the Lake District in England. The glaciers from these centers, meeting in the Irish Sea, advanced to the north shore of Wales, and in divided currents passed over Anglesey on the west, and on the east through the broad Vale of Chester which separates the Welsh Mountains from the Pennine Chain by a distance of 60 or 70 miles. Immense quantities of Scotch and Lake boulders were thus transported into the valley of the Severn as far as Wolverhampton, about half way between Wellington and Birmingham. This northern ice seems to have predominated over, and pushed aside, the weaker movement from the Welsh Mountains, which had deposited the band of boulders just mentioned, extending from Litchfield to Bromsgrove. I shall be surprised if future explorations do not reveal Welsh boulders underneath the Scotch drift, so extensively developed near Wolverhampton. It is in this northern drift that the shell-bed discovered by Mr. Baldwin at Wellington occurs.

The triple stratification spoken of as characterizing the marginal deposits near Flamborough Head, and in Lancashire and Shropshire, need not necessitate anything more than a local recession of the front, followed by a subsequent corresponding advance. Indeed, it is evident that the problems of the glacial margin in England closely resemble those in the United States, and Professor Lewis's observations require the same corrections for the personal equation in England that we have had to make for him in America,—corrections which he

himself had begun to make at the time of his lamented death. When, in 1880, Professor Lewis conducted the glacial survey of Pennsylvania with me, we were laboring under the mistaken idea that the margin of the glaciated area was everywhere marked by a pronounced terminal moraine, and we did not pay sufficient attention to the so-called "fringe" of glacial deposits which nearly everywhere extends a greater or less distance in front of the moraine. In my own subsequent work west of Pennsylvania I devoted my main efforts to the determination of the boundary of this fringe, leaving the interior moraines to be filled at leisure. The correction of our determinations which has been made by Mr. Max Foshay in Western Pennsylvania, and that by Messrs. Salisbury and McGee of Professor Cook's work in New Jersey, had already been foreshadowed both by Professor Lewis and by myself,* but, as we rightly supposed, nowhere in Pennsylvania and New Jersey does the fringe extend many miles south of our moraine.

In England Professor Lewis's moraine as reported to the British Association needs about the same correction to determine the extreme limits of the ice as is required in Pennsylvania. Almost everywhere in England there was a fringe of glacial debris in front of Lewis's moraine, but in England no more than in America does it seem to be necessary to interpret this fringe as the remnants of an earlier and distinct glacial period. The close conformity of the boundary of the fringe to that of the more pronounced glacial deposit seems to point clearly to the operation of a common cause; for it would seem in the highest degree improbable that two distinct glacial periods should so closely correspond in the marginal line of their deposits. Certainly we should not make this supposition except in the presence of facts which will not allow of a simpler explanation.

Oberlin, O., Oct. 16, 1891.

* See *The Ice Age in North America*, pp. 135, 136.