have swept across the Atlantic to our shores, and was made answerable for every unaccountable phenomenon in surface geology presented to their notice. A more probable theory is, that they were carried over by icebergs, but this necessitates that the land be submerged to the depth of 700 or 750 feet, and if that be granted, there can be no reason why the ice-floes should not have been occasionally stranded on some of the higher lands below the level of the water, and there have left evidence of their presence in heaps of travelled boulders, as well as in the lower parts of the valley; but such evidence is entirely wanting.

On the other hand, the glacial clays are extended across the mouth of the Calder, and the boulders derived from them may have been washed into the valley, during a slight submergence, by the action of the tides and waves and also borne up the valley by ice-floes. The statement of Prof. Green that a glacier at one time extended as far south as Barnsley, and left its detritus spread over the country northwards, furnishes a source for the boulders actually within the valley of the Calder as far west as Wakefield, and during the denudation of this district by marine action, the boulders would be naturally washed into the sheltered bay which the valley under those circumstances would form. It is not necessary that the land should be submerged more than 250 or 300 feet; but if it was lowered to the extent of about 350 feet, there is evidence of its former presence in the beds of sand and gravel which are found in many places on the hill-sides at a nearly uniform height above the sea-level.

NOTICES OF MEMOIRS.

Royal Society of London, May 1st, 1879.

On the Origin of the Parallel Roads of Lochaber, and their Bearing on other Phenomena of the Glacial Period. By Joseph Prestwich, M.A., F.R.S., F.G.S., etc., Professor of Geology in the University of Oxford.

A PAPER bearing the above title was read before the Royal Society on May 1st, in which the author gave a fresh interpretation to these well-known terraces. He commenced by stating that of the various hypotheses that have been brought forward since the time of Macculloch and Dick-Lauder to account for the origin of the Parallel Roads of Glen Roy, the one so ably propounded by Mr. Jamieson, in 1863, has been most generally received and adopted. It is a modification of the views originally expressed by Agassiz, to the effect that the barriers of the lakes—to the shore action of which both the above-named geologists attributed the "roads," but were at a loss to account both for the formation and removal of barriers—had been formed during the Glacial period by glaciers issuing from Glen Treig and Glen Arkaig, supplemented by others from Ben Nevis. The subsequent determination, by the Scotch geologists, of an intermediate milder period succeeded by a second cold period, led Mr. Jamieson, with whom the preglacial and

glacial deposits of Scotland had been a subject of especial investigation, to conclude that the extension of these two glaciers took place during the second cold period, which he thinks was of little less intensity than the first, and that, while the glacier from Glen Arkaig blocked up Glen Gluoy, the glacier from Glen Treig formed a barrier to Glen Roy. He observes, "Grant, then, these two ice-streams, one in the Great Caledonian Valley and the other at Glen Treig, and the problem of the Parallel Roads can be solved, provided we allow that glaciers have the power to dam such deep bodies of water as must have occupied Glen Gluoy and Glen Roy."

Mr. Jamieson, in support of this view, adduces the extensive glaciation apparent at the entrance both of Glen Arkaig and of Glen Treig, and shows that near the entrance of Glen Gluoy there are ice striæ, pointing W. 5° N., or in the direction that a glacier coming from Glen Arkaig would take, and that, in the Spean Valley, opposite Glen Treig, the ice striæ are transverse to the valley, or in the direction of the axis of Loch Treig, while on either side they point respectively up and down Glen Spean. He infers, consequently, that the central portion of the glacier ascended the opposite hill to the Col of Glen Glaster, while one branch passed down the valley blocking Glen Roy, and another branch travelled up the valley eastward to the Pass of Makoul, and thence into the valley of the Spey.

The "roads" were, he considers, formed by long-continued shore action at each successive level of the lake, that level being determined by the height of the cols over which the lake waters escaped. In proof of the long duration of the lakes, Mr. Jamieson refers to the great extent of the "roads," and the large size of the mounds at the junction of Glen Turret and Glen Roy, and of that at the entrance of the Gulban in Glen Spean, which mounds he considers to be deltas formed by the respective streams flowing into the old lakes.

The author passed in review the opinions of Mr. Milne-Home, Prof. Nicol, Sir John Lubbock, Macculloch, Chambers, and other geologists, and whilst objecting to the hypothesis advanced by Mr. Jamieson, he considers that that theory affords the most satisfactory solution of the problem, only that he would suggest a different interpretation in explanation of the phenomena.

Dismissing the hypothesis of local glaciers of the second period of glaciation, the author falls back upon the original idea of Agassiz with the development acquired by more recent research, and assigns the Lochaber lakes to the close of the first period of great glaciation. He considers the phenomena are due to the peculiar physiographical conditions of the district, and shows that, owing to the configuration of the country, the drainage of the Ben Nevis range, instead of flowing off from the centre to two or more sides, is diverted to the north side only, because the two streams which receive the southern drainage, not only of Ben Nevis, but also part of that of the range of hills to the south of Ben Nevis, after flowing respectively east and west, turn nothward and debouche — one through Glen Treig and the other through Glen Nevis, into the lower part of the Spean Valley and the Great Glen near Fort William. These conditions, which

now give this area an excess of water drainage, must in the like manner, during the Glacial period, have there led to an exceptional accumulation of ice.

With the incoming of this Glacial period, local glaciers must have descended from every mountain range, and so long as the glacier of one steep glen became confluent with another of the same chain flowing in the same general direction, so long would their course be uninterrupted, and the propelling and abrading force maintained, as in the Alps at the present day; but when, emerging from these glens into valleys of small gradients dividing the several mountain chains, they met with glaciers descending from these other ranges, their progress was not only subject to be checked, and their forces neutralized, but their course diverted, for if the lines of natural drainage were barred, the ice took those of least resistance, although such might be up-hill and against the lines of drainage. This, however, could not be effected without excessive pressure and heaping up of the ice at the points of junction.

These interferences must have been especially frequent in the valley of the Spean. On the one side, the glaciers descending the steep ravines of Larig Leachach, the Cour and others, adjacent on the northern flank of the Ben Nevis range, would issue into Glen Spean and project across it to the Glen Roy hills opposite. Below to the west, the great Nevis Glen glacier emerged into the valley of the Lochy, while above to the east the great glacier, issuing from Glen Treig, would flow down Glen Spean; but, meeting with the aforesaid group of glaciers from Ben Nevis, was partly diverted over the flanks of Craig Dhu, and upon the entrance to Glen Roy.

While the glaciers from this system of mountains were becoming confluent in and filling Glen Spean, those from the opposite range of hills were descending Glen Roy, Glen Feitheil, the Rough Burn, and the other ravines of that chain, and coming into collision with those of the Ben Nevis range. In the same way, the valley of Loch Eil, Glen Nevis, Glen Mhuilinn, Glen Loy, and others were focussing their glaciers upon the end of the Great Glen north of Ben Nevis, barring in that direction the passage of the ice down Glen Spean, and diverting it northward towards Loch Lochy and Loch Oich.

Therefore, the great mass of ice descending Glen Spean, in consequence of meeting with these obstructions, was driven to accumulate in mass in the lower part of that valley opposite Glen Roy, until, overcoming further resistance and confluent with the Ben Nevis mass, it wheeled round into the Great Glen at Loch Lochy, where the united stream found not only a more contracted passage, but, meeting also at right angles the glacier issuing from Glen Arkaig, was forced against and up the entrance to Glen Gluoy opposite.

The author then points out the many mounds and terraces in the Spean Valley formed of moraine detritus, though since levelled and often masked by a covering of gravel due to subsequent water action. To this cause also he attributes the large accumulation of *débris* at the entrance to Glen Roy, between Bohuntine and Glen Glaster, where he shows it to be in places 200 or 300 feet deep and to

consist of a light grey argillaceous unstratified matrix with angular fragments of the local rocks capped by stratified gravel. The mass rises nearly to the level of the lower parallel road.

The author next discussed the height of the land in relation to the sea at the period of the great glaciation, and he sees reason to conclude that the land then stood at not less than from 1000 to 1500 feet higher than at present, so that the Irish Channel was then above the sea-level, and land extended a considerable distance westward from the present coast of Scotland.

This was followed by a submergence of not less than 1200 to 1500 feet in central and northern England, Wales, and Ireland, and of 600 feet in the southern part of Scotland, as proved by the occurrence of marine shells at those heights.

The influence of difference in level upon climate was next discussed, and its effect was stated to be, probably, not less than from 12° to 15° F., which is about equivalent to the difference of climate between Paris and St. Petersburg.

It is well known that the Parallel Roads are terraces composed of perfectly angular fragments of the local rocks with a few rounded pebbles, both local and foreign to the district. The former show an entire absence of any prolonged beach wear. The wear of the latter is due to other causes. There is also an entire absence of any notch or cliff line such as would be due to the wearing back of a shore line, and of any projecting ledge such as would result from the throwing forward of the shore *débris*. The slope of the hills above and below the "roads" varies from 25° to 40°, and the inclination with the horizon of the "roads" themselves, which are from 50 to 70 feet wide, varies within the limits of from 5° to 30°.

Although therefore the "roads" indicate a line of water-level, there is nothing in their form or structure to show that they have been formed by the long-continued action of lake waters on a shore line. To what then are they to be ascribed?

The first or highest "roads" is confined to Glen Gluoy, the second and third to Glen Roy, and the fourth or lowest to Glen Roy and Glen Spean. What the conditions were immediately antecedent to the formation of the first, second, and fourth road, is not shown; but in the case of the third road, the conditions preceding its formation are to be traced uninterruptedly from the conclusion of No. 2 "Road." When the lake stood at the level of "Road" No. 2, its waters escaped by the col leading to Glen Spey, while when they stood at the level of No. 3 "Road," they escaped by the Glen Glaster Col. Now as there is a difference of 76 feet between the height of the two cols, it is evident that a barrier must have existed on the latter col during the time the lake stood at the higher level. Whether the barrier was detrital or ice-formed is immaterial for the argument. In both cases, either by gradual weathering or melting, the time would come when the barrier would be lowered in some place to the level of the lake.

Now, it is well known to engineers that a breach once established in a detrital barrier becomes so rapidly enlarged that, if not at once stopped, nothing can stay the rapid destruction of the barrier, as in

the case of the Holmfirth, Crinan, and other floods. Nor is evidence wanting of similar catastrophes in connexion with glacier lakes. In the notable case of the Gietroz Glacier barring the valley of the Drance, a lake was formed which attained a length of nearly two miles, and a depth at the barred end of 200 feet. So rapid was the discharge when the barrier yielded, that the lake was drained in twenty minutes. The still greater flood recorded by Vigne, which descended a branch of the Indus in one day for a distance of 125 miles, has since been shown by Mr. Drew to have been caused by the bursting of a detrital barrier formed by a landslip. In consequence of this a lake had been formed, which he estimates to have been 35 miles long by one mile broad and 300 feet deep at its lower end. The whole was drained in a day.

In the same way, it is to be assumed that the Glen Glaster barrier, which was probably formed by a remnant of the glaciers descending from the mountain ranges (2,994 feet) at the head of the glen, at last gave way with great suddenness, and caused the rapid fall of the waters from the level of the higher "road" in Glen Roy to that of that Glen's second "road," at the height of the Glen Glaster Col, when the escape of the waters was stopped.

Now, it must be borne in mind that, at this time, the great mantle of snow and ice which had so long covered the country, was passing away, leaving the surface of the hills in Glen Roy covered with a thick coating of angular local *débris* mixed with sand and clay, the result of the intense cold and of the decomposition of the underlying schistose and granitic rocks. This and the glacial *débris* must have long remained bare and unprotected by vegetation; at all events, that below the water-line was so. Now, the angle of repose of purely angular and subangular *débris* varies within the limits of from 35° to 48°, but that of clayey sands, which when dry is from 21° to 37°, becomes, when saturated with water, as low as 14° to 22°. The angle of repose of the hill-side *débris* would, therefore, depend on the relative proportion of the angular materials and their matrix, and on the extent of saturation. The slopes of the hills being on the whole greater than that of the angle of repose of the saturated under-water rubble, this latter, easily set in motion owing to the settlement of its constituent parts as the water drained from it would, as the level of the lake water fell, tend to slip or slide down with the falling water, and this slip would continue until the disturbing cause ceased, and the momentum of the mass was checked by the inertia of the water gradually coming to rest on reaching the level of the col of escape. The effect of the arrested slip, combined with the state of maximum saturation of the mass, would be to project it more horizontally forward, and form a ledge. This ledge, modified slightly by subsequent subaërial action and weathering, and by the dressing of its slope on the occasion of the next fall of the lake, constitutes the "road."

Although in the case of the other "roads" there is not the same evidence of a minor col-barrier, as the results are alike in all, the causes which led to them must have been the same; and it is shown

that there is nothing incompatible in the features of the ground with the existence of such barriers, or rather that there is some evidence in each glen, however slight, of water lines at levels higher than the "roads." There are difficulties in the way of the lower "road," No. 4, which extends through Glen Roy and Glen Spean, that need discussion, but they are not considered more serious than these which attend the other hypothesis.

This is followed by a discussion on the Till; on the parallelism of the Roads; and the general conclusions drawn by the author from the phenomena in Lochaber and the surrounding district.

REVIEWS.

I.—The Gault, being the Substance of a Lecture Delivered in the Woodwardian Museum, Cambridge, 1878, and before the Geologists' Association, 1879. By F. G. Hilton Price, F.G.S. (London, Taylor and Francis, 1879.)

FEW formations have received a larger share of attention of late years than the Gault, and this may be partly due to the extensive exploitation of the Cambridgeshire Phosphate-bed, whose organic remains have been so largely derived from its denudation.

As the Upper Cretaceous geology of England has been much studied by French geologists, and especially by Dr. Barrois, the Gault and its equivalents have naturally come in for close scrutiny, and the French classification differs somewhat from that usually adopted in this country. Much of this misunderstanding arises from our using the lithological term "Gault," originally a Cambridgeshire provincialism, for all the blue and grey marly clays at the base of the Chalk, whilst the similarly situated glauconitic sands and other beds have been called Upper Greensands, Red Chalks, etc.

For purposes of mapping, and for economic geology, this is by far the best plan, and indeed the only one that could well be adopted, as the tracing of a merely palæontological line over a large extent of country where there is only an occasional exposure is practically impossible. The surveyor must therefore be guided in the main by the composition of the beds he is mapping; where all is clay, he may easily class two very different faunas under one denomination, whilst, on the other hand, as the composition changes, he will be apt to give beds more or less contemporaneous very different titles.

This is exactly what has happened in the case of the Gault in England. Nothing can be clearer, when, by the help of Mr. Price, we have studied the Folkestone section, which for many reasons must be deemed the typical one, that under the general term "Gault" are included two extremely different formations.

The one known as the Lower Gault consists of black clays, much subdivided by nodule-beds, and is remarkable for the abundance of its Gasteropoda, and grooved Ammonites, of which *A. interruptus* may be taken as the type. It is the equivalent of the Albien in part, and would seem to be more extensively developed in France than throughout England generally. Not a single Brachiopod is