

On a SHELLY BOULDER-CLAY in the so-called 'PALAGONITE-FORMATION' of ICELAND. By HELGI PJETURSSON, Cand. Sci. Nat.
(Communicated by Prof. W. W. WATTS, M.A., Sec.G.S.)

It is a fact well worthy of note that, while the basalt-formation of Iceland bears, geologically, a very close resemblance to the basalt-plateaux of the British Isles, the Tertiary volcanic phenomena of this latter region present nothing strictly analogous to the great tuff- and breccia- or so-called 'palagonite-formation' of Iceland. For it is obvious that the fragmental materials of the British volcanic region, which are intercalated with the basaltic lavas and only of 'trifling thickness,'¹ cannot have their geological equivalent in the great palagonite-formation of Iceland, which covers thousands of square miles, and in isolated patches is met with over a greater part of the total area of the island.

The palagonite-formation has been in several respects a puzzle to the geologists who have visited Iceland: some have been of the opinion that the tuffs and breccias are contemporaneous with the plateau-basalts or even older; but the more systematic investigations of Prof. Th. Thoroddsen have shown that in reality the fragmental masses are younger than the basalt-formation.² Prof. Thoroddsen thinks that towards the close of Tertiary time the central parts of Iceland were buried under a continuous covering of fragmental volcanic materials 3000 to 4000 feet thick, which formation was broken up into single mountain-masses and isolated fells before and during the Glacial Period.³

In the summer of 1899 it was observed that very considerable masses of ground-moraine are intercalated with the breccias which constitute hills rising out of, or bordering, the southern lowlands of Iceland⁴; and in subsequent years observations in distant parts of the country brought out the same general result, namely, that there exist in Iceland extensive traces of intense glacial action, older than those known to geologists before 1899, and that we are fully justified in speaking of a 'Glacial palagonite-formation.'⁵

The breccia-formation of the peninsula of Snæfellsnes, which I investigated in the summer of 1902, like that of other parts of the

¹ Sir Archibald Geikie: 'The Ancient Volcanoes of Great Britain' vol. ii (1897) p. 194.

² See, for instance, Prof. Thoroddsen's 'Vulkaner i det nordøstlige Island,' Bih. t. K. Svensk. Vet.-Akad. Handl. vol. xiv, pt. ii (1888), no. 5, p. 68.

³ Thoroddsen, Dansk. Geograf. Tidsskr. 1898, p. 2 (sep. cop.).

⁴ Helgi Pjetursson: 'The Glacial Palagonite-Formation of Iceland' Scot. Geogr. Mag. vol. xvi (1900) pp. 265-93; & 'Nýjungar i Jarðfræði Íslands Eimreidni' 1900, pp. 52-57 (Icelandic).

⁵ Helgi Pjetursson: 'Moræner i den islandske Palagonitformation,' Overs. Kgl. Danske Vidensk. Selsk. Forhandl. 1901, pp. 147-71; & 'Fortsatte Bidsrag til Kundskab om Íslands "glaciale Palagonitformation"' Geol. Fören. i Stockholm Förhandl. vol. xxiv (1902) pp. 357-69. This last paper embodied a few observations made during the summer of 1901.

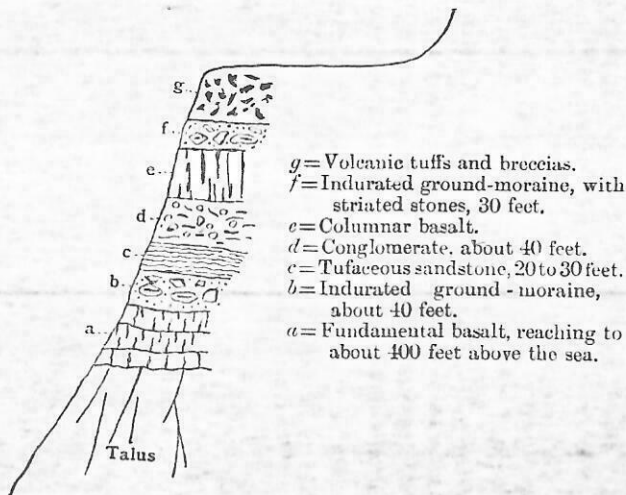
country, is built up chiefly of palagonitic tuffs and breccias, conglomerates (in part probably fluvio-glacial), and moraines. But, while in other parts of Iceland the rule is that, owing to subsidence, the basement of the breccia-formation has been hidden from view, in Snæfellsnes, on the contrary, the basaltic basement of the breccias, etc., can very commonly be seen.

The Tertiary basalts of the peninsula, however, are also traversed by faults and very clearly have subsided; and in the eastern portion of the cliffs of Ólafsvík-enni—a basal part of the great volcanic pile of Snæfellsjökull (4710 feet)—the 'fundamental basalt' has even disappeared below sea-level, while farther west it again appears, reaching however barely to a height of 100 feet above the sea.

Now, the basement-layer of the breccia-formation is seen in many places to consist of a greyish, indurated ground-moraine, varying in thickness, and containing glaciated basaltic blocks of all sizes up to 6 feet or more in diameter. Thus in the above-mentioned cliffs of Ólafsvík-enni, the fundamental basalt is succeeded above by an indurated ground-moraine, which in turn is overlain by a thickness of probably more than 1000 feet of tuffs, breccias, conglomerates, and probably also morainic deposits.

It is more profitable, however, to turn to the plateau of Mávahlíð, which projects in the promontory of Búlandshöfði. Here the escarpment can be scaled in several places, and every single layer of a section examined. The following diagram from the western face of the escarpment may perhaps be taken to represent the normal mode of composition of this plateau (fig. 1).

Fig. 1.—Section of the plateau of Mávahlíð.



The fundamental basalt (*a*) differs in colour, in texture, and in its

often being amygdaloidal and decomposed, from the sheets of basalt which are interbanded with the 'breccia-formation.'

The moraines (*b*) and (*f*) are of a bluish-grey colour, and contain numerous distinctly-striated stones of various sizes.

The volcanic breccias of different kinds and colours, from nearly black to yellowish-brown, attain—on both sides of the section exposed—a thickness of probably not less than 300 feet, and their maximal thickness is even much greater, for in places the breccias of the plateau rise into hills several hundred feet high. These breccias are not post-Glacial, for erratics and loose glacial rubbish are commonly found strewn over their surface.

Some little distance from the farm of Mávahlid, the sheet of columnar basalt (*e*), with the overlying moraine and the underlying conglomerate (*d*), is well seen; while the lower moraine can hardly be distinguished from the conglomerates, and the fundamental basalt only appears in the corrie towards the left. On the right, volcanic breccia, which thickens southward, is seen overlapping the upper moraine.

Nevertheless, interesting as are the sections briefly described above, showing as they do that Glacial conditions existed here at a time when the contour and relief of the region differed very greatly from what is now the peninsula of Snæfellsnes, they are surpassed in interest by a section near Búlandshöfði, on the northern face of the escarpment, where is clearly exposed a shelly Boulder-Clay, reaching a height of more than 600 feet above the sea and buried under hundreds of feet of conglomerate, lava, and volcanic breccias ('palægonitic breccias'), which show a glaciated surface (erratics and loose glacial rubble).

The succession of the beds is shown in fig. 2 (p. 359).

The top of the shelly Boulder-Clay (*b*) reaches a height of rather more than 600 feet above the sea,¹ and its total thickness is 70 to 80 feet. The clay is indurated, shows no stratification, and through it are scattered numerous blocks of basalt of various sizes, hardly exceeding, however, 8 inches in diameter. Some of the boulders are angular, others rounded; many, especially of the bigger blocks, are so well polished and striated that they could serve as beautiful types of glacier-stones.

This Boulder-Clay is more interesting than others of the moraines of the 'palægonite-formation' by reason of the shells, which occur in very great numbers throughout the whole thickness of the bed (*b*), with the exception of some 10 feet of laminated sandy clay (β) towards its base.

The shells are, as a rule, highly triturated, unbroken specimens

¹ This, even though the shells are of derivative origin, must probably be taken as evidence of a much greater submergence of the country than was previously suspected. The highest level at which a marine fossil had been found was about 200 feet above the sea. This was a *Balanus*, obtained in 1899 in a bank of the Thjórsá, in marine clay probably corresponding in age to the later *Yoldia*-beds of Scandinavia.

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as indicative of cold (Glacial) conditions. In fact, the above-named six species of molluscs are among those found in the Scandinavian deposits of the *Foldia*-sea; and it can hardly be doubted that here too they lived in an icy sea before they got into the ground-moraine of an advancing glacier—which took place before the eruption of the 'pre-Glacial dolerites' of Prof. Thoroddsen and others. On Prof. Thoroddsen's new geological map of Iceland, published in 1901, the doleritic lavas are shown as pre-Glacial and Glacial; while on his special maps published before 1900 they are shown only as pre-Glacial. As a matter of fact, they are largely inter-Glacial, or at any rate inter-morainic.

A discussion of the facts alluded to above, and many others connected with them, must be deferred until I am able to give a fuller account of the investigations which I carried out in 1901 and 1902; only a few points may be here briefly mentioned.

I take it to be an unquestionable fact that the basement-layer of the 'breccia-formation' of Snæfellsnes is a ground-moraine; and in other parts of the country beds of indurated ground-moraine are found very deep in this formation, buried under hundreds of feet of rock—not to say more. Now, I do not mean to contend that the shelly Boulder-Clay of Búlandshöfði is necessarily of the same age as the lower moraine of other sections of the Mávahlid-plateau (fig. 1), but we learn from this section (fig. 2) that at least some of the older moraines ('palagonite-moraines') are of Pleistocene age.

I do not believe that the tuff- and breccia-formation ever had an average thickness of 3000 or 4000 feet, but rather that the fragmental materials have been piled up to this great thickness around centres of eruption only. Indeed, I imagine that, on further examination, it would not be difficult to point out a considerable number of the wrecks of the volcanic cones of the breccia-formation; although I must confess that I did not recognize any of them until the summer of 1902, after I had had occasion to see the quite unmistakable remnant of such a volcano near Kerlingarskard, Snæfellsnes.¹

It is highly probable that further research will tend to confirm the hypothesis, not only that volcanic activity continued uninterruptedly in Iceland during the Glacial Period, but that it was of great intensity, especially perhaps towards the beginning and the close of a glaciation, and that the eruptions, unlike the fissure-eruptions of pre-Glacial and in part also of recent times,² resulted to a great extent in the building-up of bulky hills of scoriæ and ashes, some of which have survived the Glacial Period as volcanoes (and are still covered with snow and ice, and belching forth, not lava, but scoriæ and ashes); while others have become extinct and

¹ It ought perhaps to be mentioned here that Prof. Thoroddsen wrote in 1898 in regard to Súður (Dansk. Geograf. Tidsskr. vol. xv, p. 11): 'Perhaps we have here the wreck of a volcano dating from the close of the Tertiary Era.'

² See Sir Archibald Geikie's 'Ancient Volcanoes of Great Britain' vol. ii (1897) chap. xl.

their materials have in part gone to make up the 'palagonite-moraines.'

In short, I think that the evidence of the Snæfellsnes sections lends a strong support to the view that the palagonite- or breccia-formation of Iceland, is volcanic and glacial, resulting from the action and the interaction of both causes, and corresponds—at any rate, to a very considerable extent—in age to the Pleistocene deposits of Europe: the glaciated doleritic lavas ('pre-Glacial dolerites') representing the most marked of the inter-Glacial epochs.

And here we have returned to the question raised at our starting-point: Is it not possible that the absence of a palagonite-formation in Great Britain may be ascribed to the fact that there the volcanic fires had become extinct before the setting-in of Glacial conditions?

In conclusion, I desire to express my heartiest thanks to Mrs. Disney Leith, of Westhall (Aberdeenshire), who has been kind enough to give a most necessary polish to my somewhat angular mode of expression.

DISCUSSION.

The CHAIRMAN (Mr. TEALL) remarked that the Author had set forth his facts well and clearly, and the conclusion to which they inevitably pointed—namely, that the palagonite-formation was, at all events in part, contemporaneous with the Glacial Period—was of very great interest.