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1902.


MAP OF
SOUTH WESTERN NORWAY
to illustrate
PROFESSOR HULL'S PAPER.
Scale of English Miles
0 10 20 30 40 50 60 70 80
ATLANTIC
OCEAN
5° E. of Gr. 6°
7°
8°
9°
10°
11°
58°
59°
60°
61°
62°
63°
TRONDHIEM
Dronthem
CHRISTIANIA
Drammen
Kongsberg
Skien
Frederiksværn
Christiania Fiord
Langesund
Krageroe
Osterriisoer
Tvedestrand
Arendal
Grimstad
Lillesand
CHRISTIANSAND
Mandal
The Naze
or Lindesnæs Lt.
Lister Land
Flekkefiord
Egersund
STAVANGER
Bukke Fiord
Karmoe
Bommel Oe
Selboe Fd.
BERGEN
Stor Sartor Oe
Sogne Fiord
Sulen I.
Bremangerland
Stadtland
Aalesund
Romsdal Fiord
Molde
Christiansund
Smolen
Hitteren
Hardanger Fd.
Skagstöls Tind
Stromstad
Fredrikshald
Hamar
Lillehammer
Stanford's Geogl. Estabt. London

ORDINARY MEETING.*

CAPTAIN HEATH, IN THE CHAIR.

The Minutes of the last Meeting were read and confirmed, and the following election took place :—

ASSOCIATE :—Ivo F. C. Carr Gregg, Esq.

The following paper was then read by the author :—

THE PHYSICAL HISTORY OF THE NORWEGIAN FJORDS. By Professor EDWARD HULL, M.A., LL.D., F.R.S., F.G.S. (Secretary). (With Map.)

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* Monday, February 17th, 1902.

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INTRODUCTORY.

THE Fjords of Western Norway occupy an exceptional, perhaps unique, position amongst the physical features of Europe. These arms of the sea entering from the western coast penetrate for long distances into the very heart of the lofty snowcapped plateau of the Norwegian promontory, and while descending to great depths below the surface of the waters along their central portions, are often bounded by cliffs and walls of rock whose upper margins are sometimes decked by snowfields or glaciers, and which rise to levels above the surface almost as great as that of the floor below the same horizontal plane.

In no other country in Europe have we examples on so magnificent a scale of such profound channels invaded by the waters of the ocean; bounded by such stupendous walls of rock, overlooked by perennial snowfields and ultimately merging into valleys, such as that of the Romsdal, lined by walls, generally precipitous, often vertical, and rising several thousand feet till culminating in some stupendous "horn" or peak; or else forming the margin of that vast snowfield which covers as with a white sheet the surface of

the great central table-land. This central snowfield, visible from the sea at a distance of one hundred miles, sends down into the adjoining valleys glaciers, such as that of the Jostedalsbrae Glacier, unsurpassed in magnitude by any in Europe, and which in the northern part of the peninsula are almost bathed by the waters of the sea itself. Nor can we fail, when coasting along these great waterways, to notice from time to time the evidences both of former submersion to depths of several hundred feet below the present level, as also of recent elevation of the land. That the fjords were at a former period the channels of glaciers, on a vastly greater scale than those of the present day, is also shown by the polished and striated surfaces of the rocks down to the water's edge; first recognized by that enthusiastic glacialist, the late Professor James Forbes.* Here the *roches moutonnées* indicate the direction of the ice-movement, generally seawards; and the occurrence of moraines and perched blocks in various positions show where there have been pauses in the retreat of the ice into higher levels. On the other hand, the flat surfaces of terraces, lining the sides of the valleys, especially in protected spots, may constantly be noticed, occasionally affording a footing for dwellings and land for cultivation. That these terraces ("strand linien") are ancient sea-beaches cannot be doubted, and they show the extent to which the whole of Norway was submerged at a period preceding the present, amounting, according to Professor Reusch, to over 600 feet in the Christiania and Trondhjem region, but in other regions to a less extent.

2. *Depths of the Fjords below the surface of the Sea.*

But the subject which most strongly excites our interest and wonder is the profound depths to which these fjords (or gulfs) descend below the surface of the waters, reaching in the case of the Sogne Fjord to nearly 4,000 feet (665 fathoms) as shown by the soundings on the Admiralty Charts. If these gulfs were, as must be believed, the channels of former glaciers and filled with ice down to their very floors, and much above the present water-level as shown by the unsubmerged ice-worn rocks, the thickness of the ice would appear to have reached at least 5,000 to 6,000 feet in the

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* *Norway and its Glaciers* (Edinburgh, 1853).

central portions of these profound sea-lochs which at the present day carry the ocean waters to the very roots of the central tableland; the source and origin of the glacier ice.

3. *Age of the rocks bounding the Fjords.*

Throughout their course the fjords and connected valleys are found only traversing rocks of the highest geological antiquity known under the name of Archæan and Silurian; consisting of granite, gneiss, hornblendic and micaceous schists, quartzite and dolomite, generally presenting a rude, though decided, stratification. Nowhere are these valleys and fjords bounded by walls of Mesozoic or Secondary age, and it is only on the eastern side of the Scandinavian promontory that they penetrate strata of even Silurian age; as for example in the Christiania Fjord. Geologists and petrologists are well acquainted with the structure and composition of the Archæan rocks, the oldest of the world; but of their mode and conditions of formation, notwithstanding all that has been written on the subject, we are in comparatively profound ignorance, beyond the general inference that they were deposited under physical conditions differing widely from those in which the Palæozoic and later deposits were formed, and in which we find remains of animal and vegetable life. Needless to say, no organic forms have been found in these Archæan rocks; and between the period of their formation and that of the Silurian strata, a long lapse of geological time probably intervened.*

PART II.

1. *Original condition and formation of the Fjords.*

Having thus passed in rapid review the features and structure of the region of south-western Scandinavia in which the most important of the fjords occur, I now pass on to the next and more immediate part of my subject, namely: the physical history of these inland sea-lochs themselves; and from this history it will be clearly shown, if my views are correct, that the fjords are primarily the outcome of

* There have just been issued the sheets of the International Geological Map of Europe; *Carte géologique internationale de l'Europe*, feuilles 11, 17, and 18 (Berlin, 1902), on which the geological structure of the region now being described is admirably shown.

rain and river erosion, continued through long ages of geological history; modified somewhat by glacial action in later times, and to a less degree by changes in the relations of land and sea; in a word, that they are simply partially submerged river-valleys.* To many, this statement will appear merely a truism; and my apology for enunciating it here is, that from personal conversation on the subject, I find a great variety, not to say confusion, of thought and opinion on this subject which it is desirable to help in clearing up.

2. *First and earliest stage of formation.* (*Continental Period.*)

It is admitted by Scandinavian geologists that in Pre-silurian times the Peninsula formed a part of an extensive continent composed of Archæan rocks, and extending from northern Russia westwards into the British Isles. It was in its general form an undulating plateau, and under these conditions it would be subject to meteoric influences including those of rainfall and river-erosion. To this epoch we may probably refer the incipient formation of the larger valleys which naturally drained towards the ocean of the period, presumably lying somewhere in the position of the Atlantic. This period is too remote and too vague to allow of our doing more than alluding to it in a very cursory manner, so that we pass on to the next stage, which was one of subsidence.

3. *Second stage.* (*Silurian and Cambrian or Primordial.*)

At the close of the continental period just described, there appears to have been a gradual subsidence under the waters of the sea of a portion of the Scandinavian area towards the south, so as to allow of the deposition of the Cambrian or Primordial and Silurian strata, containing the earliest forms of marine life. These strata of Cambro-Silurian age have been so altered and folded in some places that it is difficult to distinguish them from the pre-Cambrian or Archæan formations. Probably only very small portions of the existing peninsula were unsubmerged during this stage, and the valleys of the continental period were but little extended.

* I am pleased to observe that this is the view of Lord Avebury, recently recorded in his work. He calls them "drowned river-valleys." *The Scenery of England*, p. 101 (1901).

4. *Third stage.* (*Re-elevation.*)

At the close of the Silurian epoch there was a re-elevation of the area, and this included not only the Archæan, but the Silurian tracts forming the Scandinavian peninsula and the adjoining regions both of land and sea. The almost complete absence of formations between the Cambro-Silurian and the Post-Tertiary, induces us to conclude that throughout this vast period of geological time,* this northern portion of Europe remained in the condition of unsubmerged land.† But it was none the less watered by rains, rivers, and probably snowfalls; and, therefore, the valleys were being constantly deepened by the streams descending from the tablelands, and, as we must suppose, finding an outlet in the primæval Arctic Ocean across the floor of the present North Sea. It is in this way we can account for the great depth and size of the valleys at the present day, though cut out of rocks of extreme hardness such as are those of which the Archæan system is composed. It is impossible to view the lofty cliffs of the Romsdal, the Gudvangen, the Sandven, and other valleys, rising from 2,000 to 4,000 feet on either hand, without being impressed with the fact that the erosion of such channels must have taken an enormous lapse of geological time for the streams to accomplish, even after allowance has been made for the effects of glacial action at a later period. Nowhere is the process of erosion more clearly exhibited than in some of these valleys where huge slabs and blocks, breaking off along joint planes, are continually widening the sides of the valleys, while the torrential action accompanied by magnificent cascades is cutting back and deepening the channels. These natural operations are grandly displayed at the profound gorge of Stalheim,‡ which

* Embracing the Devonian, Carboniferous, Permian, Triassic, Jurassic, Cretaceous, and Tertiary periods.

† According to Dr. Reusch, Devonian beds occur amongst the islands north of Bergen; but are quite exceptional.

‡ Thus vividly described in Stanford's *Guide to Norway*, page 39: "On the left is the vast mass of the Jordalsnut rising 3,600 feet sheer out of the valley; on the right, the Kalda Fjeld and the Axeln rise in terrific precipices, down which in summer avalanches of stone frequently fall, and often sweep away the road. Close by, on the right hand and on the left, are two very beautiful waterfalls; that on the left is the Sevlefos, a fall which, though not one of the most famous in Norway, is certainly one of the most lovely to be found in any country; the dark rocks forming a wonderful background for the white masses of foam; and on the right the Stalheimfos." The quotation is slightly curtailed.

comes suddenly into view as the traveller approaches from the Vossvangen Valley, and which is calculated to impress him with a feeling, not only of admiration, but of awe; a feeling shared in by Professor James Forbes when viewing the Sogne Fjord into which the Vossvangen immediately descends.

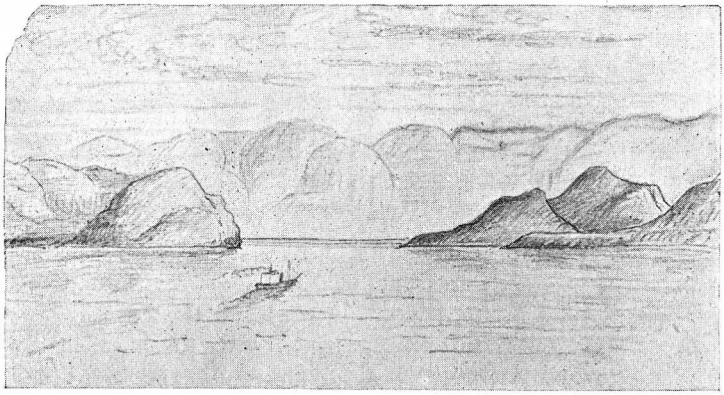

FIG. 1.—ENTRANCE TO THE HARDANGER FJORD.

5. *Unequal depths of the Fjords.*

The scenes described above belong to the land; but not less profound must be our astonishment when we come to consider the great depths to which some of the larger fjords descend below the surface of the sea. These depths, however, are very unequal; for, while that of the Sogne Fjord reaches to almost 4,000 feet (665 fathoms) the Hardanger Fjord a few miles further south, only descends to 2,750 feet (425 fathoms), the Volden Fjord to 2,298 feet (383 fathoms), and the Nord Fjord to 1,800 feet (300 fathoms); these two latter lying some distance to the north of the Sogne. Now, as the Sogne Fjord is by much the largest of the Norwegian sea-lochs, and drains a larger tract of mountain land, there would seem to be a clear connection between the size of these sea-lochs and their depths, as would be expected under the view that they have been formed by the erosive action whether of rivers, or of ice, or of both. But I must here refer for a moment to the Admiralty charts, from which we derive our knowledge of the depths of the fjords themselves.

6. *The Admiralty charts.*

These splendid charts, published by our own Admiralty from Norwegian surveys, and on a large scale, are well supplied with soundings, both over the area of the Atlantic Ocean as well as that of the inland channels and arms of the sea to their highest reaches. Making use of these soundings (which are all in fathoms) I have contoured the depths of the larger fjords, including those of the Hardanger, the Sogne, the Nord, the Volden and the Stor, with their branches. This process enables us to obtain almost at a glance a clear idea of the form of the submerged portions of these great arms of the sea; with the general result that we find that upon entering from the outer coast and islands with comparatively shallow floors, they rapidly descend to great depths below the surface, which they retain for considerable distances, only becoming shallower as they approach the upper limits where they pass into the valleys descending from the interior mountain plateau. This form of floor is especially characteristic in the case of the Sogne Fjord; and it will be noted on examining the charts, that the position of maximum depth is just where the fjord is bounded on either hand by mountain masses of great extent and elevation; where, if covered by snow and ice (as was once the case) of prodigious magnitude glacial erosion would be most powerful and effective. I may here at once state that the phenomena observable in Norway as elsewhere, support, as it seems to me in a convincing manner, the views of the late Sir Andrew Ramsay, and of Professor James Geikie on the effect of glaciation amongst the highlands of Scotland, Wales, and other countries including Norway, where glaciers existed in past times.*

PART III.

1. *Cause of the rapid shallowing of the Fjords seawards.*

According to the Scandinavian geologists, the cause of the rapid shallowing of the great sea-lochs on approaching their

* Ramsay: "On the Glacial origin of lakes," *Quart. Journ. Geol. Soc.* Geikie: *The Great Ice Age.* 2nd Edit. It was during a visit to the Earl of Ducie, F.R.S., that I first had an opportunity of studying the Admiralty charts of Norway, contoured with iso-bathic lines by Mr. Etheridge, F.R.S.

outlet in the North Sea, is the piling up of enormous masses of moraine matter by the former glaciers which descended these valleys.* This piling process was doubtless due to the presence of the remarkable chain of islands which follows the coast from Stavanger (latitude 59°) to the Trondhjem Fjord. That these islands are only unsubmerged portions of an extensive tract of Continental land is clear to anyone who has sailed along their shores; and the intensely glaciated character of their rock surfaces down to the water's edge is equally striking. In the former conditions of high elevation during the "Great Ice Age," the obstacle presented by these uprising ridges and bosses to the movement of the glaciers descending from the interior mountains would naturally result in the piling up of huge terminal moraines in the hollows now existing as navigable channels between the islands and the mainland.

This, however, does not fully solve the problem presented to us by the Norwegian Fjords. If we accept the view that they were originally river-valleys and as such must have been eroded under sub-aerial conditions, their descent or slope must have been continually seawards, as is the case with all river-valleys; and even giving due allowance for the deepening process by glacier action and the piling up process by moraine matter, we should naturally expect to find a continuation of the valleys themselves beyond the chain of islands across the floor of the North Sea and thus ultimately opening out along the margin of the Arctic Ocean. Strange to say, however, no such evidence is afforded by the soundings over the North Sea floor beyond slight indications in a few cases, and for short distances.† In fact, the 100 fathom contour runs along the coast for many miles with very little variation from a rectilinear course. We are therefore confronted with the problem how to account for the disappearance of these old river-valleys from the floor of the North Sea.

After much consideration the only answer to this problem seems to be that the channels do actually exist, thus connect-

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* The entrance to the Fjords seldom exceeds 100 fathoms, and is generally less.

† Such as are presented by the Selbiorn's Fjord, Lat. 59° 56′, and the Bredsund Dybet, Lat. 62° 30′. If we allow in the case of the Sogne Fjord 1,000 feet for the additional depth of the channel due to glacial erosion, and this is probably in excess of the actual amount, we have still a channel 3,000 feet in depth to be accounted for.

ing the fjords with the Arctic Ocean, but do not appear on the charts owing to the fact that they have been filled up with various sedimentary deposits, while the floor has been reduced to a general level by the action of the tidal and other currents. As I have shown in the case of the sub-oceanic valleys which lie off the coasts of the British Isles and Western Europe this process of "levelling up" has repeated illustrations due to similar causes. The submerged valleys of the "English River Channel," of the Loire, and of other streams for several miles beyond the margin of the land are often concealed, owing to filling up by sediment, and it is only as we get far out to sea that they become clearly indicated by the soundings, and descend to great depths below the general surface of the Continental platform. Of this platform the North Sea is a part and continuation, and that its surface is deeply overspread by loose material derived from the waste of the adjoining coast and islands, as also by glacial mud, gravel and boulders, there can be no doubt; though to what extent the older solid rocks are thus concealed we have no means of judging. This view is supported by the evidence of former submergence as well

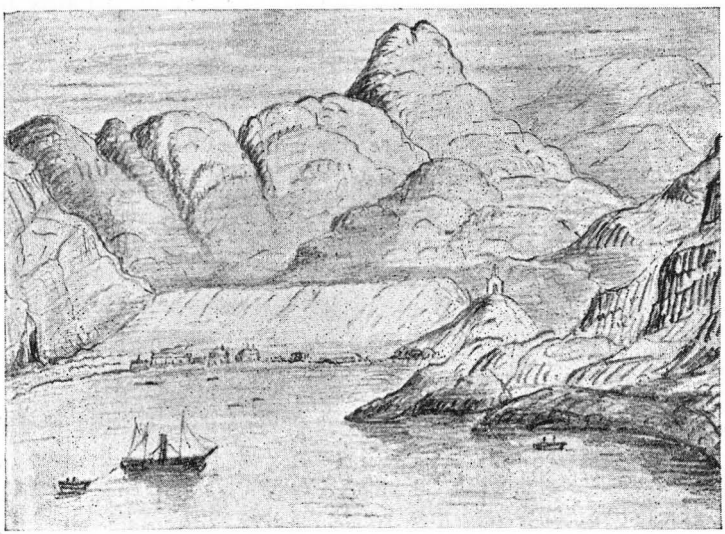

FIG. 2.—TERRACE AT MERAK. HEAD OF GEIRANGER FJORD.

as of glacial erosion to which we have already referred; and I shall now consider this evidence a little further.

2. *Former submergence; Formation of Marine Terraces.*

The existence of raised beaches, or marine terraces, at intervals along the margin of the land, whether of the interior fjords, the outer margin, or the islands off the coast has long been recognized, and indicates the extent to which the Scandinavian peninsula was at one time depressed below the present level.

According to Reusch and Hansen these terraces rise to a level of about 200 metres, about 615 feet, in the Christiania and Trondhjem districts, in front of the lakes in the east country, forming large plains, but to a lower level elsewhere. During my visit I took the level of two well-marked terraces: one at the head of the Geiranger Fjord (Fig. 2), the surface of which is 250 feet above the sea-level, the other at Naes at the entrance to the Romsdal Valley, where it is extensively developed and passes into old terraces of the river itself for many miles inland; here the level was found to be about 220 feet. Sometimes two or three terraces were distinctly observable from the deck of the ship, rising in succession above each other as at Otero Island; but I was unable to determine their levels. According to the observations of local geologists these "strand-lines" or raised beaches slope distinctly from a higher level along the inner portions of the fjords to a lower level along the outer coast. This is particularly observable in the Tromsi region where there are two raised terraces.* These terraces are composed of sand and gravel mixed with reconstructed moraine matter and boulders. Their relations to the glaciated rock surfaces show that they belong to a later period than that of the great glaciation of Norway; though "the marine shells found in the clays show a transition from the cold Arctic climate prevailing during the deposition of the older clays to the mild climate of the present day." Considering, however, that the waters of the sea must have penetrated much further inland towards

* Geikie states that according to Erdmann the terraces are found at a level up to 800 feet and more above the surface of the sea. *Great Ice Age*, page 388.

the interior snowfields and glaciers, during this depression of the land, and that the effects of the previous intense cold had not altogether passed away, we may well suppose that some of the glaciers actually entered the arms of the sea, giving rise to icebergs of greater or less size, as in Greenland at the present day, and then passing down the fjords, laden with boulders, stones and mud, would have carried these materials into the North Sea, and as they melted would have deposited their burdens over its floor. Indeed we may go further and suppose that the sea was crowded with small bergs and rafts of ice at this period, which though very recent was probably of long duration. In this way we may account for the spread of glacial detritus over the floor of the North Sea, which by the aid of the currents would naturally be carried into the channels and depressions of any river-valleys eroded through the solid rocks of which the floor was originally formed. In this manner then, we may account for the filling up of the channels which we may suppose are continuous with those of the fjords under the waters of the North Sea though undiscoverable by means of the sounding line. These conditions appear to have continued until a pause in the course of subsidence occurred; after which a reverse movement set in during which the land was re-elevated and ultimately arrived at approximately the position it holds at the present day.*

PART IV.

1. *Comparison of the Scandinavian features with those of Scotland.*

Allowance being made for the difference of size between Norway and Scotland, there is a remarkable similarity between the physical features of both countries, indicating what may be termed sympathetic incidents in their physical history. Briefly stated, the following are the points on which this similarity is founded:—

a. In both cases the rocks are mainly either of Archæan, or of very ancient geological age.

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* During the re-elevation there were doubtless pauses in the movement represented by the successive terraces to which I have already referred.

b. In both, the mainland is sheltered from the outer ocean by a chain of islands.

c. In both, the mountains are penetrated by sea-lochs or channels, shallower at their outlet than further inland towards the centre.

d. In both the rocks are glaciated down to, and below the water-edge, and by the direction of the glacial striations and their form of surface show that the interior highlands were centres of dispersion for the snow and ice of the glacial period. Similar phenomena, such as moraines, perched blocks and boulders, are observable in both cases.

e. In both the presence of marine terraces and raised beaches show that after the glacial period, the land was submerged to various depths below the present level of the sea.*

f. In both there has been re-elevation and recession of glacial conditions, resulting in the case of Scotland, in the entire disappearance of the glaciers, but in the case of Norway, in their retreat into the higher valleys of the interior mountains.

2. *Special points of analogy.*

Without going very far into a description of these phenomena as they occur in Scotland, which would be foreign to the object of this paper, I will offer some observations on two of the above features, taking as my guide Professor James Geikie's admirable work, to which the reader is referred for fuller details.† It is unnecessary that I should specially refer to Nos. *a* and *b*, in the above points of comparison which can be inferred from an inspection of any geological map of Scotland or of the British Isles. I therefore pass on to the third of the above points, wherein it is stated that the Scottish mountains are penetrated by sea-lochs or channels, shallow at their entrance but deepening inland; thus showing that they are true fjords,

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* Mr. T. F. Jamieson, in his excellent paper on the Glaciation of Scotland, has shown that the parting of the ice-flow eastward and westward took place at Craig Dhu in Inverness-shire in the valley of the R. Spean. *Quart. Journ. Geo. Soc.*, vol. 18, p. 170 (1862).

† *The Great Ice Age*; also *Scenery and Geology of Scotland*, by Sir A. Geikie, p. 125.

though on a small scale as compared with those of Norway. In both cases they are true rock-basins; that is to say, they are deeper near the centre than at the outlet formed of solid rock, due to the erosive action of some agent which is neither the original river, nor the sea, and which can, therefore only have been that of glacial ice, aided by sand, stones, and boulders imbedded in its mass, and under enormous pressure, wearing down the floor of the valley during a long period of geological time. The arguments of the late Professor Sir A. C. Ramsay,* supported and illustrated as they have been by Professor James Geikie, can alone account for the numerous examples of rock-basins, both in Norway and Scotland. The latter author takes all the suggested "explanations" *seriatim*, and discusses them in detail, showing that neither the action of the sea which planes the surface down to a level, or of rivers which "cannot run upwards," nor the local foldings or faultings of the strata, nor local subsidences which he truly pronounces "incredible" in the cases of such basins as those of the innumerable lakes of Scotland, Cumberland, Wales, Scandinavia, Finland, and Switzerland can account for the phenomena.† On the other hand it is easy to show that both in Scandinavia and Scotland glacial erosion has been most effective in the central or upper portion of each rock basin or inland fjord, where the mass of the ice descending from the interior valleys may be assumed to have reached its greatest thickness and weight; while farther out towards the sea, owing to gradual melting, the thickness of the ice had diminished, and with this the erosive effects. Thus were a glacier to continue to flow for a sufficient length of time, this unequal pressure upon the underlying rock would produce some effect; there would be a great deal more wear and tear where the ice had been thick than where it had been thin, and thus a rock-basin would eventually be formed.

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* "On the Glacial origin of lakes," *Quart. Journ. Geol. Soc.*, xviii, p. 185.

† *The Great Ice Age*, p. 294. I have been tempted thus to dwell upon Ramsay's views and Geikie's defence of them longer than I had intended, as they have been subject to contention on the part of some less competent to form an opinion.

4. *Sea-lochs and Rock-basins of Scotland.*

Amongst the most striking examples in Scotland of sea-lochs which are also rock-basins as shown by the soundings, may be mentioned Loch Broom, which at Ullapool is only 9 fathoms deep, but higher up at Lacmelm descends to 26 fathoms; Little Loch Broom at the entrance is 18 fathoms, but towards the centre descends to 57 fathoms. The inner sound of Ramsay, which reaches a depth of 138 fathoms, but which would be converted into a lake were the region elevated to the extent of 100 fathoms. More fjord-like still is L. Etive, 20 miles in length and generally less than a mile in breadth, which at its entrance at Connel Sound is very narrow, and at half-tide the water rushes over the reef of rock with the roar of a cataract; yet half way up it descends to depths of over 70 fathoms. And, lastly, we have the case of one of the largest lakes in Scotland, L. Lomond,* which at its outlet is only a few feet above the sea-level, yet under Ben Lomond, where the ice must have been of enormous thickness, it descends to 90 and 101 fathoms in depth.

It is unnecessary to quote further examples to show that the fjords (or sea-lochs) of Scotland are like those of Norway, true rock-basins, and that in both cases the origin of these remarkable hollows in the solid rock must be attributed to the action of glacial ice during the Great Ice Age.

5. *Views of Scandinavian geologists on glacial erosion.*

The effects of glacial erosion in Norway are strongly insisted on by Scandinavian geologists.† To it is attributed the formation of that remarkable channel ("the Norwegian Channel") which curves round the northern margin of the Skagerak and the southern extremity of the Scandinavian peninsula, reaching a depth of 2,500 feet, and the origin of which is indicated by the direction of the glacial groovings and striæ of the adjoining coast. To glacier erosion is also

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* Ramsay considered L. Lomond and L. Katrine as "large cases of glacier-erosion," *Quart. Journ. Geo. Soc.*, vol. xviii, p. 203. Geikie concurs in this view, *loc. cit.*, p. 295.

† *Norway*, article "Topography," by A. M. Hansan, pp. 18, 25. It is a remarkable fact first noticed by Horbye that between lat. 62° and 63½° the erosive agent moved from the comparatively lower ground of

attributed the formation of the numerous rock basins now existing as inland lakes, and the deepening of the beds of the fjords in their central portions below the level at which they must have reached when they were simply river-valleys continuously descending from their sources to their outfall in the sea or the ocean. To this agency also are referred the existence of the range of low islands and the intervening channels which lie off the western coast of Norway, and which bear the evidence of glacial erosion over their surfaces in a marked degree. Wherever we turn in Norway we are confronted with the evidence of the effects of ice movement at a former period which may be paralleled, but not surpassed, in any other country in Europe.

6. *Marine terraces or raised beaches of Scotland.*

The next point of comparison between the physical features of Norway and Scotland referred to above, is the occurrence of marine terraces, or raised beaches in both countries, indicating post-glacial submergence below the present levels.

All round the coast of Scotland, with occasional intervals along precipitous and exposed parts of the coast, there run one or more well-defined terraces, reaching to a height of 290 and even 350 feet near St. Andrews, and consisting of sandy, gravelly, or clayey material, sometimes containing shells, and sometimes bounded by cliffs perforated by caves now high and dry, while isolated sea-stacks rise above the surface of the terrace. Along the west coast of Argyllshire especially of Cantyre, two terraces are often to be observed, the higher about 40 feet, the lower about 25 feet above the high water line.* The higher terrace, which would be the older, is considered by Sir A. Geikie to date from the later part of the glacial period ; the lower, or more recent, which is the most marked of all the terraces, may have been elevated since man became an inhabitant of the island, as it has yielded in several places works of human fabrication.†

Sweden westward over the Dovrefjeld towards the North Atlantic. *Sur les Phénomènes d'érosion en Norwege*, p. 40.

* Originally described by Maclaren in his *Geology of Fife*, and by Smith of Jordanhill.

† *Scenery and Geology of Scotland*, page 320. No fewer than eighteen canoes have at different times been dug out of this terrace, some of them amongst streets and houses. *Ibid.*, p. 324.

In Argyllshire, this terrace constitutes the sites for churches and other buildings, being the only approximately level ground in that part of Scotland. In other districts it has afforded ground for many towns and villages, such as Leith, Dundee, Arbroath, Rothsay, Greenock, Ardrossan and Ayr.

But the actual submergence of Scotland since the glacial epoch is not limited by the levels of the raised beaches above described. Marine deposits of sand, gravel and clay have been recognized at much greater altitudes. Professor James Geikie places the submergence of Scotland in later or interglacial times at not less than 1,238 feet as indicated by the Kames on the Fintry Hills; but in the south-east of the country the depression did not exceed 1,050 to 1,060 feet.* I myself have seen beds of stratified sand and gravel high up amongst the hills of Kantyre. On the whole we may conclude that the depression of the land in interglacial times in Scotland was much about the same as that of Scandinavia, and it need scarcely be added that other parts of the British Isles partook, to a greater or less extent, of these terrestrial oscillations of level. In England and Ireland the interglacial and post-glacial beds are found at varying levels up to 1,300 feet above the level of the sea.

PART V.

1. *General Elevation of the land of Western Europe during the Glacial period.*

The subject of this paper would be more incomplete than is necessarily the case, did I omit to point out the evidence which Norway affords of a general and great elevation of the European land-area at an epoch just preceding the Great Ice Age and the connection of this extension of the land area with the conditions which resulted in a vast extension of snow and ice consequent on the refrigeration of the climate. In a series of papers published by the Victoria Institute I have described the existence of valleys physically, or inferentially, continuous with those of existing rivers which, after traversing the Continental Platform, open out on the

* *Great Ice Age*, p. 254. Prestwich states that the shell beds extend to an elevation in Scotland of 510 feet. *Geology*, vol. ii, p. 450, the amount of submergence was very unequal in different parts of the British Isles, having been 1,300 feet in North Wales, and 400 feet in Isle of Wight as shown by the gravel terraces at St. George's Downs and above "the Needles."

floor of the ocean at depths descending to 6,000 or 7,000 feet.*

These channels were determined by the aid of the soundings on the Admiralty charts and were shown to have all the characteristics in form and structure of some of the large cañons of Western America and other countries; and their resemblance to many of the Norwegian fjords is equally striking. They were shown to be traceable at intervals from off the Atlantic Coast of the British Isles, and of Spain and Portugal to that of Africa, where the Congo valley is continued for a distance of 120 miles out under the ocean, traversing the Continental Platform and opening out on the Abyssal Ocean at a depth of 1,200 fathoms, or 7,200 feet below the surface. These submerged river-valleys were found to be referable to those of the Loire, the Gironde, the Adour, the Douro, the Mondego, and the Tagus; this last, as well as the Adour, being actually continuous with the existing river-valley; this statement also applies to the Congo and to some of the rivers entering the Mediterranean from the European side; determined by the late Professor Issel of the University of Genoa.

2. *River-Valleys necessarily Sub-aerial.*

As river-valleys can only be formed under conditions of air and land the inference is inevitable that during their formation those tracts of the Atlantic below which they extend were under sub-aerial conditions, and that their present submerged position is owing to subsequent depression. Such depression must therefore have taken place to the extent of about 6,000 feet along the whole of the eastern border of the Atlantic; or to put the point conversely, the former elevation as respects the level of the ocean must have been about 6,000 or 7,000 feet, at which depth the base-level of the Continental Platform

* "Investigations regarding the submerged terraces and river-valleys bordering the British Isles," *Trans. Vict. Inst.*, vol. xxx, p. 305. "On the Sub-Oceanic Terraces and River-Valleys of Western Europe." *Ibid.*, vol. xxxi, p. 259. "On the Sub-Oceanic River-Valleys of the West African Continent, and the Mediterranean Basin." *Ibid.*, vol. xxxii, p. 147. Also, "Des investigations récentes relatives aux Anciennes Vallées envahies par la mer des Iles Britanniques et de l'oust de l'Europe." *Comptes Rendus du Congrès Geologique International*, VIII Session, en France, 1901, p. 321.

is found where the side descends abruptly from the 200 fathom isobathic line. That Scandinavia and the North Sea partook of these great oscillations of the land is unquestionable. It is inconceivable that any portion of Western or Northern Europe could have remained approximately unmoved while the adjoining regions were undergoing such stupendous changes of level, and we are thus in a position to account for the great depth of the fjords even allowing for the effect of glacier-erosion over their floors. The fjords when river-valleys may be inferred to have entered the North Sea with channels of perhaps 2,000 feet or more, and to have crossed the floor of that sea in the direction of the Arctic Ocean, which descends very rapidly to a depth of over 1,000 fathoms; by this means alone could the rivers have been drained. But, as already stated, these channels are not now discoverable, to any important extent, by the soundings; which fact I have endeavoured to account for by supposing that they have been filled up with glacial mud, sand, gravel, and boulders carried down by floating ice from the interior highlands, and spread over the floor of the Continental (now the North Sea) Platform by the tides and currents. Similar silting of the original channels has taken place off the coast of Western Europe and the British Isles as I have shown when dealing with the sub-oceanic river-valleys of this region; but it may well be supposed that the effects would be even greater in the case of the North Sea which washes the coast of Norway and received the glaciers and icebergs which descended from its mountains. We may now conclude this necessarily brief account of these physical events by arranging them under the following stages:—

3. *General succession of events in the history of the Norwegian fjords.*

(*a*) *Earliest stage* (Pre-Silurian.) Continental conditions; land formed of Archæan rocks. Erosion of river-valleys commences.

(*b*) *Second stage.* Partial submergence during Silurian times.

(*c*) *Third stage.* Elevation of land during later Palæozoic, Mesozoic and Tertiary times; with continuous erosion of river-valleys.

(*d*) *Fourth stage.* (Glacial period.) Great upheaval of land and sea-areas accompanied by valley erosion.

Refrigeration of climate; extension of snowfields and glaciers which descended and filled the valleys and moved out over the north sea-floor; deepening of the valleys by glacier-erosion.*

(*e*) *Fifth stage.* (Interglacial.) General subsidence of land and sea; amelioration of climate; marine terraces (or "strand-lines") formed along the coast of the submerged lands and fjords, the sea filled with floating ice and bergs.

(*f*) *Sixth stage.* (Post Glacial.) Slight re-elevation of area, accompanied by recurrence of cold conditions but not to the extent of the fourth stage.

(*g*) *Seventh stage.* (Recent.) Gradual re-elevation of land and amelioration of climate to present conditions; sea-beaches formed at intervals of emergence along the coast at commencement of human occupation of the country.

DISCUSSION.

The CHAIRMAN.—Now that we have heard Professor Hull's very interesting address, I hope some of those present may make any remarks they desire.

Dr. LOGAN JACK, F.G.S.—Mr. Chairman, I have had much pleasure in listening to the able exposition of the history of the Norwegian fjords that has been given by Professor Hull to-night. The difficulty is that anything I have to say can scarcely take the form of discussion, inasmuch as I agree with every word that has fallen from Professor Hull. It appeared to me that there are, however, some things that might have been, perhaps, more fully explained for the benefit of the general audience, such as why the ice became heaped up for these great depths, and this, I think the lecturer will agree, must have been on account of the strangulation which took place at the narrowing towards the mouths of the valleys, and that strangulation was followed by immediate relief as the ice escaped from the mouths of the valleys and, consequently, the pressure no longer caused the heaping up of the ice. One could suppose that the pressure would be the greatest immediately in advance of the point where the strangulation took place; but we must consider the nature of ice as an explanation of that.

* See page 254 for opinions of Professor Brögger and Dr. Nansen on the elevation of Norway at this epoch.

Ice is not a solid mass of iron, but is, to some extent, plastic, or at all events it follows the conditions of plasticity; and it is, sometimes, behind a barrier that the greatest heaping up will necessarily take place, and the impetus which could drive forward the enormous masses of ice is a thing that is difficult to understand under any conditions. A mass of ice 6,000 feet thick would require something very considerably thicker to drive it, and to drive it into those narrow valleys; but no doubt the fact that it has done so is proof that the ice had enormous force from behind (*vis a tergo*) and was capable of giving an impetus to those masses of ice that penetrated the valleys in the form of glaciers.

I have nothing further to remark, except that the outlets are the principal points of interest, and Professor Hull has shown very clearly how the moraines, aided by the ocean currents, have formed the marine terraces to which he has referred, so that they may have a foundation of rock; and yet they have been heaped up, and their height added to, by the moraines left by the glaciers themselves and the further accumulations of detritus banked up by the ocean currents.

[Mr. Martin Rouse having called attention to one of the diagrams, Professor Hull further explained the same.]

Mr. MARTIN ROUSE.—How are the islands represented there?

Professor HULL.—They are not represented there at all. *This* is the cause of the channel passing between the islands. [*Explaining.*]

Mr. MARTIN ROUSE.—Is there generally an opening in that case?

Professor HULL.—Oh, yes; it is generally quite open. [*Describing.*]

Mr. MARTIN ROUSE.—The Bay of Bergen: is that in the nature of a fjord?

Professor HULL.—Bergen is the place that I could not recall to my mind just now, when I digressed from my paper, and said that the snowfield of the interior could be seen from a point before you get into the harbour of Bergen, at a distance of 100 miles. It is called a fjord; but I do not know that the Bergen bay, or harbour, is properly called a fjord. It is one of the channels.

Mr. MARTIN ROUSE.—You say that fjords have their own winding channels out between islands?

Professor HULL.—Yes; they get out one way or another.

The CHAIRMAN.—We are much obliged to Professor Hull for his

interesting address. The only remark that I would like to make is with reference to the depths at the mouths of the fjords and, probably, the bays that Mr. Rouse has referred to. It seems to me to be analogous to the deposit of bars at the mouths of rivers.

When you get volumes of fresh water coming down and bringing deposit, directly it comes into contact with the salt water it is deposited, more or less; and you see the same thing in all rivers, to a more or less extent, at the present time. Why we see no moraine is, I think, as Professor Hull says, that the old channel at the mouth is bound to be obliterated. In the St. George's Channel and the English Channel you have a submerged channel because the tides run in the direction of the old channels and so keep them free.

I am sure you will allow me to convey your thanks to Professor Hull for his very interesting address. [Applause.]

Professor HULL.—I am much obliged for the manner in which you have received my paper, and am specially gratified that so experienced a geologist as Dr. Logan Jack is able to concur in my views regarding the physical history of the Norwegian fjords.

The Meeting then terminated.

COMMUNICATIONS RECEIVED.

The following communication from the Rev. Dr. Walker will be read with interest:—

COMPARISON OF THE ICELANDIC FEATURES WITH THOSE OF NORWAY.

(*Cf.* Part IV, p. 136, of paper.)

Why is no parallel drawn between the physical features of Iceland and Norway, which in several particulars present such a remarkable similarity?

1. Both countries alike possess a "Snaefell," a mountain covered with snow; in other words, Iceland itself has no fewer than three Snaefells: (1) Snaefell Jokull, whose glittering cone I have seen 70 miles away to the north-north-west when standing on the shore at Reykjavik in the innermost recess of the Faxafjordr; (2) East Snaefell, as situate in the east of the island; and there is also a third Snaefell elsewhere.

As a rule a "fell" denotes among Icelanders a mountain of inferior elevation to a "jokull," which signifies a mountain per-

petually covered with snow. Hekla is spoken of as only a "fell." Snaefell in the south-west is, as above stated, a "jokull," though only somewhat over 4,000 feet in altitude, whereas East Snaefell, if I recollect rightly, reaches to a height of over 4,000 feet.

2. (p. 135) *Formation of Marine Terraces.*—There is, I believe, such a marine terrace on the north coast of Iceland, a few miles to the east of Hasavik, which place I have visited, but not the terrace. It is, I think, mentioned in Henderson's *Iceland* (2 vols.). That a missionary visited the island in or about 1818 on behalf of the B. and F. Bible Society and reports the occurrence in said marine terrace of a stratum of the well-known shells, *Cyprina Islandica*, of smaller size than those now occurring in such abundance in a living state at Isafjordr in the north-west.* I have little or rather no doubt that Professor Hull would at once discover many other such terraces alike in the interior fjords, the archipelago of islands, skerries, etc., that stud the sea to the west of Iceland, and the barriers of rocks that break the force of the tide to the south of the island. My own pursuit of entomology, and very imperfect knowledge, left me little leisure or capability for such matters.

3. (p. 133 of paper) *Deepening Process by Glacier Action and the Piling-up Process by Moraine Matter.*—I have on more than one occasion witnessed this "piling up of the moraine." Take the masses of moraine widely and thickly strewn on the banks of the Glára (pronounced *Glera*) as an example, close to where that river debouches into the Eyjafjordr (just north of Oddeyii itself, a suburb of and rather less than a mile north of Akureyri) and on the western bank of that fjordr. This river, which I visited on July 10th, 1890, is reduced to a mere thread in the summer season in the centre of the fields of moraine that it brings down when in flood. Iceland has been described as a land in which both frost and fire have done their worst, and correspondingly the moraine in question does not only consist of the ordinary stones rounded alike by glacier friction above and by the action of the watercourse lower down, but of obsidian pebbles which also owe their formation of vitrified lava to intense heat. The "deepening process by glacier

* Spelt Eyjafjördr on Thoroddsen's Geological Map which shows numerous raised beaches along the shores of the northern inlets and fjords.—ED.

action" may also be illustrated by the Glárafoss, the foss of the Glára, a mile or more above the mouth of the river, only reached after a painful and heavy trudge over the said beds of moraine, which crunch under the feet, and where the river thunders down a narrow and steep chasm. Yet a few hundred yards farther on and the stream is hemmed in here in the middle of July by a regular penthouse of drift snow, and I have no doubt issues from a glacier, and deepens its course in its constant and forceful cascade.

4. (p. 137) *Perched Blocks and Boulders.*—I noticed such a huge perched boulder of a different formation from that of the surrounding rocks in the Krisuvik desert in the south of Iceland. Its lodgment there is no doubt due to prehistoric glacial action, but on my inquiry of the under-guide as to how it came there, his reply was, "Gretlir's work." All such matters are set down to the surpassing strength of the national hero of Iceland.

5. (p. 137) *In the case of Scotland, in the entire disappearance of Glaciers.*—But the case of Iceland is far more analogous to that of Norway. Here the glaciers have not disappeared but have retreated into the higher valleys of the interior mountains. The snow mountains in the north of Iceland are farther inland and cannot be beheld from the coasting steamer like those in the south. Glacial action in the south is doing that, if I am not mistaken, now, which glacial action in the north did in a prehistoric age. Stand on the shore of Heimaerg (Home Island) the only inhabited one of the whole group of the Westmann Islands, and gaze northwards to the south coast of Iceland, and a perfect panorama of snow peaks will be beheld in succession, those of the Eyjafjadla jokull, the Myrdals jokull, and the Oraefa jokull, with their glittering pinnacles of ice spiring aloft into the cloudless arctic skies—inland, though not seemingly so, because the intervening lands between the base of said mountains and the coast only present a dead level.

6. There is great philosophical significance in the term that the Icelander applies to his snow mountains in several cases and to some of his islands. Alone, stationary and immovable, whereas glaciers slip down, fjords are carved out, rivers wear down the rocks, Askja (the name for a bandbox in Iceland, or any circular-

* Or Vestmannaeyjar on Thoroddsen's map.

receptacle) nearly split its crater to pieces in the east of the island in the last century by the quantity of scoriæ and other ejectamenta that it threw up. But *Dranga* in Iceland means something deeply and firmly fixed, and so we have *Dranga* jokull that dominates the fjords in the north-west; *Drangey*, the name of the island scene of Gretlir's abode when outlawed, at the upper end of the Skaga-fjordr; *Drangr* and *Einarsdrangr* among the Westmann Islands. And now that one is on the subject of the *everlasting hills*, one may compare *Mount Pagus* in the rear of Smyrna and πήγνυμι, to fix or fasten; the Greeks conceived the very same idea, and our own "*peg*."

7. I could multiply these instances, but forbear; and only regret in conclusion, having myself visited South-West Norway and South Italy, and speaking with a personal knowledge of Western Asia, Northern Africa, and the greater part of Western Europe, that the one island which is *par excellence* the paradise of the geologist, and which certainly far exceeds South Italy in the variety and extent of area of its volcanic phenomena, and is to my mind at least equal to Norway in respect of fjords, illustrations of erosion, and of glacial action, should not have the personal travel, the great and accurate knowledge, and last, not least, the distinguished ability of a Hull or a Logan Lobley brought to bear upon it.

POSTSCRIPT.

Since the above was in type, the great work of Professor W. C. Brögger, LL.D., *Om de senglaciale og postglaciale nivåforandringer i Kristianiafeltet** has reached my hands through the courtesy of its distinguished author. It has been brought out with special advantage to those to whom Norse is an unknown tongue by the addition of a "Summary of the Contents" in English. The various changes of level of the land from the commencement to the close of the Glacial period; the advance and retreat of the glaciers at successive stages; the submergence of the land during the formation of the marine terraces; and the changes of climate during these oscillations are here ably described and illustrated. To those who, like the writer, have

* Norges geologiske undersegelse. No. 31.

endeavoured to prove the great changes of level of the Glacial period, the views of Professor Brögger are most satisfactory, as he shows that "the sea-bottom, during the time of the greatest ice sheet of Europe, must have been uplifted at least 2,600 metres (8,528 feet), higher than it is at present (p. 683), which even exceeds the amount of elevation deduced by the writer from the depth of the sub-oceanic river valleys, at the commencement of the Glacial period. On the other hand the extent of the submergence undergone by the land in the Kristiania region is determined to have been 215–216 metres (about 710 feet), at the period when the highest of the terraces was in course of formation; and at Mjosen it was even somewhat more, or about 768 feet. E. H.

COMMUNICATION FROM CAVALIERE W. P. JERVIS, F.G.S.

Thus it is only this week that I have read with the liveliest interest your welcome studies. Since I have closely followed your several papers on the enormous changes of level throughout a considerable part of the Atlantic, I was prepared to learn much more with the like interest, and feel very pleased that you continue to examine a question which, though in consonance with all the teachings of science, has been so little understood by geologists—in fact, I believe, as I already expressed it, that it is high time for us to investigate the former conditions of that part of our globe which is now covered by the ocean.

It is to the future teachings of this important study, and to which I suggested the name of Thallassology, in view of the vastness of the subject, that I believe that geology will be incalculably indebted, in order to gain a clearer insight into the history of the globe.

Several points in your paper struck me as most important explanations of difficulties which I was unable before to understand.

I had not an idea that the raised beaches in Norway were of a nature analogous to those of the British Isles, and indicating so clearly, by sub-Arctic fauna along with glacial detritus, an emersion subsequent to the Ice Age, but before the rigidity of the climate

had passed away entirely, though so evidently not to be confounded with the former upheaval.

Until I read your explanation of the shallowness of the fjords, in many instances in their lower course, I was under the impression that it was due to a great extent to glacial boulders and detritus which did not reach the sea; but you so plainly show the manner in which the ice attained to prodigious thickness in the upper portion of the fjords as to have eroded to a far greater extent than further down, that no difficulty remains in one's mind, and the entire obliteration of the submerged channels beyond the present outlets of so many fjords into the North Sea (so far, at least, as my Norwegian soundings show) seems to be attributable to icebergs breaking off from the respective fjords at a remote period, but in a very insignificant degree, in proportion, to the action of the marine currents to which I had fancied that they owed their being filled in.

Such is the apparent uniformity of breadth and depth of the great channel skirting Norway in the North Sea, that it seems to me improbable that icebergs should have been carried out to sea westwards to such a vast extent as to have covered the floor of the North Sea to any great thickness with boulders or detritus; but we shall never know further on this subject.

Concurring with what Dr. Walker observed in his communication, I should greatly wish to find you now extend your investigations to Iceland, but more especially to Greenland and South Finland.

BOBBIO PELLICE, TURIN.

25th July, 1902.