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1902.

ORDINARY GENERAL MEETING.*

MARTIN L. ROUSE, ESQ., B.L., IN THE CHAIR.

The Minutes of the last Meeting were read and confirmed, and the following election was announced :—

MEMBER :—Herr Ole Theodor Olsen, F.R.G.S.

The following paper was read by the author :—

THE PHYSICAL HISTORY OF THE FJORDS OF NEW ZEALAND. By J. MALCOLM MACLAREN, Esq., B.Sc., F.G.S.

Introductory.—The fjord basins—locally termed the West Coast Sounds—of New Zealand are situated on the western coast of the Province of Otago, in the South Island. They lie approximately on the meridian of 167° E. Long., between the parallels of 44° and 46° S. Lat., and run with a general east to west direction, penetrating from ten to twenty miles into the mountains by narrow and tortuous channels, which vary in width from a few hundred yards to a mile and a half. They are some fourteen in number, the best known being Milford Sound in the north and Dusky Sound and Preservation Inlet in the south. Access to the majority can be had only from the sea, the steep mountain ranges, and the dense vegetation thereon, forming an almost impenetrable barrier to those approaching from the central Otago plain or from the Lake District. It is these ranges that furnish the *Notornis Mantelli*, or takahe, the rarest of all existing birds, with a habitat so secure that, since 1840, only five specimens have been obtained.

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* Held Monday, March 3rd, 1902.

At Preservation and Chalky Inlets—the most southerly of the group—the shores of the sounds slope gently from the rounded mountain ridges to the sea level, but in all the others to the north, the fjord walls are steep and precipitous, and continue so for many fathoms below the surface. In Milford Sound, some of these cliffs rise perpendicularly to a height of 1,500 feet above sea level.

2. *Mountain ranges.*—Except in the neighbourhood of Milford Sound and immediately to the south, the mountain ranges at the heads of the sounds are neither high nor broad. In the south the highest peak is about 5,500 feet above sea level, and only eight or nine miles separates the headwaters of Doubtful Sound and one of the arms of Lake Manapouri, on the eastern slope of the main range. About Milford Sound, however, the watershed is much broader and the mountains much higher; here assuming a distinctly Alpine character, and culminating in Mount Earnslaw, 9,165 feet high. For this reason, therefore, it is only in the north that rivers of any important size flow into the heads of the sounds. These are the Arthur and the Cleddau, falling together into Freshwater Basin at the head of Milford Sound, and the Hollyford River, running into Lake McKerrow (or Kakapo), which, though now a freshwater lake, is really the fjord continuation of Martin's Bay. These three rivers are fed from the snowfields and glaciers of the Balloon Mountains and the Bryneira Range, both of which rise well above the snow line. As Pembroke Peak (6,710 feet), near Milford Sound, is permanently snow clad, the snow line in these latitudes may be set down at about 6,500 feet above sea level. As might be inferred from the height of the watershed and the shortness of their courses, the streams falling into the sounds are really mountain torrents, with considerable erosive power. In the southern sounds comparatively small streams have eroded deep ravines back almost to their sources.

3. *Cascades.*—In some places, and especially is this the case at Milford Sound, the fjord has truncated the lateral valleys, the waters of the latter pouring forth as cascades on the placid waters of the sound. Of this character are the Stirling and the Bowen Falls, in Milford Sound, the latter with 540 feet of sheer drop. In the mountains at the head of Milford Sound are the famous Sutherland Falls, which in a drop of nearly 2,000 feet (1,904) touch the cliff face but three times.

Wherever possible, the shores and mountain slopes of the New Zealand sounds are covered by an extremely dense and luxuriant impenetrable forest growth, the prevailing sombre hues of which add not a little to the grandeur of the fjord scenery. During December, however, the hillsides burst into a blaze with the crimson flower of the rata (*Metrosideros robusta et al. sp.*) the "Christmas tree" of the colonists, which forms in places a not inconsiderable portion of the forest growth. The luxuriance of the vegetation is due to the extreme humidity of these regions, the average annual rainfall being certainly not less than 125 inches. The forest, at 3,500 feet, gives way to grassy uplands, and these again, at a further 3,000 feet, to the perennial snow-fields.

4. *Depths of the Fjords.*—Probably the most remarkable point of resemblance to the Norwegian fjords is that which is apparent on mapping the isobathic contours of the New Zealand Sounds. Like the former, they are, without exception, much shallower at their mouths than in the interior. In no case is the depth at the entrance more than 76 fathoms, and the average depth there may be stated at about 35 fathoms. The maximum interior depth yet obtained is 288 fathoms, in Breaksea Sound. A reference to the following table will show these points clearly.

Sound.	Approximate Length.	Average Width.	Greatest depth at Mouth.	Maximum Inland Depth Recorded.	Average Depth along Channel.
	Miles.	Miles.	Fms.	Fms.	Fms.
1. Martin's Bay Lke. McKerrow	12	·75	Alluvial flat 15 feet above sea level	96	65
2. Milford	12	·5	24	214	120
3. Bligh	12	·5	44	75	65
4. George	12	·75	46	106	95
5. Caswell	11	·75	31	151	120
6. Charles	9	·5	36	113	80
7. Nancy	9	·5	32	126	100
8. Thomson ..	22	1·0	76	250	120
9. Doubtful ..	19	1·25	52 / 24*	120	100
10. Daggs	8	·5	25	91	75
11. Breaksea ..	20	1·0	35	288	160
12. Dusky	24	2·5	30	145	100
13. Chalky	16	1·5	20	136	120
14. Preservation ..	22	·5–2·0	14	90	55

* Entrance to Smith Sound.

Lake McKerrow or Kakapo, though now a freshwater lake 15 feet above sea level, and separated from Martin's Bay by an alluvial flat three miles wide, is included in the above table for the reason already mentioned.

After passing the bar at the entrance, the floors of the fjords run approximately level to near the head of the sound, when they rise either into a cliff face or into a very small alluvial flat, the former termination being perhaps more general.

Origin of the New Zealand Fjords.—On the origin of these sounds there is little room, I think, for speculation. They obviously are submerged river-valleys, and, as will be seen from a reference to the map, show all the characteristics of valleys so formed. Their arms, originally tributary streams, generally join the main sound at a natural angle, and the sounds themselves, while preserving the general direction, yet show minor deflections; both features characteristic of mountain valleys. Further, the change from the main sound into the arm is not marked by any appreciable change in depth, and consequently in the level of the old valley floor. While at a date subsequent to their erosion and anterior to their submersion, they were undoubtedly occupied by glaciers, few traces indeed of glaciation are still preserved. The islands in the sounds, though they show no rugged contours, at the same time show no appearance of *Stoss-* and *Lee-seiten*, nor do the smaller rocks furnish any positive evidence. Still, the fjord walls in a few places, notably at the Narrows, Milford Sound, and in Deas Cove, Thompson Sound, show evidence of polishing and striation by glacier action.* With regard to the latter place, Sir James Hector remarks (*loc. cit.*): "The rock here is a granitic gneiss, the hard surface of which has faithfully preserved the grooves and polished surfaces caused by ancient glaciers." The terminal moraines in the Cleddau Valley and elsewhere also furnish evidence of the former existence of glaciers, as also do the granite erratics, 15 to 20 feet thick, found at the mouth of Preservation Inlet among slates,† and which must have been brought down the sound by ice. Possibly the scarcity of glacial markings may be due to the land, now above sea level, being covered in the Glacier

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* Hector : *Geological Exploration of the West Coast*, p. 453.

† Hutton and Ulrich : *Geology of Otago*, p. 68.

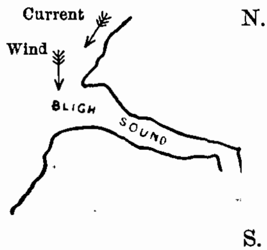
Period by snow-fields, while the old glacier beds are still submerged. The dense vegetation also prevents other than a cursory search for the signs of past glaciation.

5. *The effects of Glacier Erosion.*—The glaciers which occupied these valleys possibly, and indeed probably, augmented their depths. Nevertheless, for the New Zealand sounds, I have never been able to accept the glacier rock-basin theory, mainly because their cross sections do not coincide with my idea of those of a typical glacier excavated rock basin, which, I think, demands sloping instead of perpendicular sides; and also, because the singular isobathic contours may be explained much more simply than by calling to our aid such doubtful phenomena, in this case, at least, as glacier excavated rock basins. It is quite possible that some portion of some of the bars at the fjord mouths may be vestiges of terminal moraines, but if so, their presence at that point is probably accidental, and is in nowise essential to the formation of such bars as do occur. An ample explanation is derived from a consideration of the prevailing currents and winds on this coast. Along the western shore of the South Island there sets to the S.S.W. a current which runs at the rate of one to one-and-a-half knots per hour—and a current which is considerably accelerated when the prevailing N.W. wind is blowing. The two combined are sufficient to cause a southerly drift of shingle and gravel along the shore. It is from this cause that all the harbours on the west coast of New Zealand are bar harbours, and where breakwaters have been built and artificial harbours made, the result soon shows a struggle between nature and man for the mastery.

6. *Effects of Ocean Currents.*—The drift takes place until the mouth of a fjord is reached and, in the resultant eddy, the gravel and shingle are swept into the still water of the fjord, forming a bar, the inner slope of which is regulated by the slope angle which such materials assume in water under given conditions. As the rise and fall of the tides is here very small—from 6 to 8 feet only in springs—and the entrances to the sounds are not at all constricted, no strong "rip" or current is developed to keep the mouth clear. That the above has been the main, if not indeed the sole cause, of the shape of the fjord beds at their mouths may perhaps be more readily admitted when it is stated that an examination of some of the arms of the sounds shows bathymetric features similar to those already described. For example, in South Port—a cove in Chalky Sound—we have much greater

interior depths (36 fms.) than are shown on the sand bar at its mouth (9 fms.). It would certainly appear that, weak though the tidal currents of the outer sound may have been, they were sufficient to carry sand and gravel and to deposit it in the absolutely still water at the entrance to the cove. Now had these phenomena resulted from the filling of glacier excavated basins, similar basins, in the form of lakelets and tarns, would reasonably have been expected above sea level, but so far as I know, such have not yet been discovered.

7. *Form of entrance to the Sounds.*—Another feature of the fjord mouths, illustrative of the power and prevailing direction of the winds and current, is apparent on inspection of the chart. In nearly every case the north side of the entrance has a tongue-like projection to the south or south-west, while the opposite southern side shows a concave curve of erosion, as will be clear from the accompanying sketch of the mouth of Bligh Sound.



The only fjord of any size, the mouth of which has been silted up, is Martin's Bay and its fjord continuation, Lake McKerrow or Kakapo, and it is rather remarkable that this is the only old valley which faced directly to the north-west —or to the direction of the prevailing wind. It was, moreover, the first encountered by the coast drift in its southward journey. It is clear that the sand drifted into the bay had but little chance of escape against the prevailing wind, and was piled up until it formed a bar three miles wide, effectually ponding back the inner waters of the fjord.

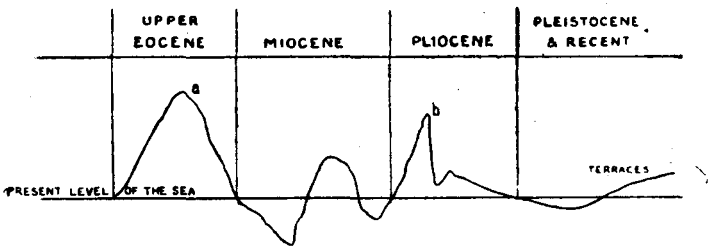
8. *Rocks lining the Sound.*—The rocks in which the sounds occur are eruptive granites and hard metamorphic gneisses, both well calculated to withstand the onslaught of nature's denuding agents for long ages. In Caswell Sound, a bed of marble, of poor quality, has been found. The restriction of the sounds to the comparatively limited area mentioned

at the outset is probably connected with the presence on the coast further to the north of comparatively soft, easily denuded rocks of Cretaceo-Tertiary and Lower Tertiary age.

9. *Form of the oceanic floor.*—So far, soundings have not been sufficiently numerous to show whether the submarine valleys are indicated by seaward channels in the ocean floor. But the probability of finding such channels is very remote, for the south-west coast of New Zealand, instead of standing on a submerged platform, as does Norway, slopes away sharply to the Thomson Basin, between New Zealand and Australia, with its average depth of 2,600 fathoms. This contradiction of the axiomatic expression of recent writers—that a deeply indented coast line stands on a submarine platform—is perhaps, after all, only apparent. For, from stratigraphical conditions in the Southern Alps, which need not, in this paper, be indicated further than to mention that the Southern Alps themselves are probably the eastern half of an anticline, the western position of which has disappeared, a great fault line, with a hade to the west, is assumed to pass down the west coast of the South Island of New Zealand. Such a fault would at once reconcile fact and theory, and would, *inter alia*, account in a measure for the extremely straight coast line shown in the sounds region.

10. *Geological History.*—The geological history of the southern portion of New Zealand, during the Tertiary period, is, thanks to the succession of marine and lacustrine beds in the south, and of marine beds in the north, comparatively easy to trace. The elevation which resulted in the initial formation of those river channels which are now occupied by the sounds, took place either in Lower or Upper Eocene times, according to whether we follow Professor Hutton or the officers of the New Zealand Geological Survey in the grouping of the Lower Tertiary rocks. The former insists on an unconformity, between the Waipara and Oamaru formations, representing a period of elevation at that time—equivalent probably to Lower Eocene—while the latter, broadly speaking, group the beds together as Cretaceo-Tertiary, thus throwing the unconformity into Upper Eocene time. Whatever the correct interpretation may be, it is certain, at least, that, in Lower Tertiary time, the Southern Alps received their final foldings and flexures accompanied by great upheaval, for all the beds since deposited lie more or less horizontally on their flanks and moreover are

deposited at some distance up the present valleys, thus proving the prior existence of the latter. During the Miocene period a depression of from 2,000 to 3,000 feet below the present level took place, resulting in the deposition of the Pareora beds. In Pliocene times, since no deposits referable to this age are found in the South Island, we must assume a period of elevation. It could not, however, have been of long duration, for in the North Island we find both Upper and Lower Pliocene beds—the Wanganui and Kai-iwi Series respectively. A depression in Pleistocene times is indicated by the deposits at Cape Wanbrow, Oamaru, and by the silt deposits of the Southland Plains. The major oscillations of the land surface during the Tertiary period may be graphically represented as follows:—



a.—Elevation during which present valley system originated.
b.—Elevation during Glacier Period.

11. *Elevation of land during the Pliocene Period.*—As shown in the above diagram, the elevation of the land which led to the great *Glacier* Period (not *Glacial*, for New Zealand was never in Cainozoic time, at least, overwhelmed by an ice-cap) took place during the Pliocene Age, but whether in Early or Late Pliocene there is no evidence to show. Certain it is, however, that the glaciers covered then a very greatly extended area compared with that which they now occupy. In some places their moraines have been found within a few miles of the eastern seaboard, from which the present glaciers are now distant quite ninety miles. This glacier extension, with all its attendant phenomena, including the occupation and possible erosion of the fjord beds, is amply accounted for by the assumption of a greater elevation of the land of only some 3,000 to 5,000 feet—if indeed as much be required. For even at the present time, in lat. 44° S. (or equivalent to that of Bordeaux), the Fox Glacier, on the west coast, comes to within 700 feet of the sea level. Indeed, no other theory

seems tenable. For assuming, for the nonce, a colder climate to have existed at that period, and disregarding changes of elevation, the lower temperature requisite to extend the glaciers to their former bounds would also have been sufficient to extend them to the sea, and a boulder clay or stratified morainic matter would have resulted, of which some traces would surely have been found. Again in the well-developed marine upper tertiaries of the North Island there are species of shells which have persisted through Pliocene and Pleistocene times up to the present, a persistence hardly compatible with the assumption of a period of intense cold for the neighbouring South Island.

12. *Raised Terraces of Recent Age.*—With regard to recent changes of elevation in the Sounds district, I must confess that I am unable to adduce any evidence from personal knowledge. The subject has, however, been investigated by Captain Hutton, who mentions* distinctly formed terraces at the entrance to Doubtful Inlet, the highest being about 800 feet above sea level. Professor Park, who made an examination of the coast line near Martin's Bay,† saw there terraces 100 to 300 feet above sea level. At Coal Island, Preservation Inlet, there are sea-worn caves 10 to 20 feet above sea level, and at Green Island, in the same inlet, there is a pierced rock about 100 feet in height and completely perforated at the level of a terrace, now 40 feet above sea level. All these facts point, of course, towards elevation. Sir James Hector, however, many years ago, maintained that the coast was sinking. His evidence, so far as I remember it, was mainly negative, based on the failure to find certain estuarine beds which should have been found above sea level had the coast been rising. But the failure may have been due to other causes than non-elevation, and it must not be forgotten that in the fjords themselves the dense vegetation renders the determination of ancient terraces almost impossible. In any case the evidence in favour of elevation, being positive, by far outweighs that for subsidence. That oscillation is taking place at the present time, the gently sloping shore (25° to 40°) of the west coast furnishes conclusive proof, for otherwise the thundering billows of one of the most tumultuous seas in the world

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* Hutton : *Geology of Otago*, p. 80.
† Park : *Report of Geological Survey of New Zealand.*

would long ago have worn back even these hard rocks to form a line of beetling cliffs.

[The author then exhibited a set of lantern slides to illustrate his subject.]

Discussion.

The Chairman.—I think we are greatly indebted to Mr. Maclaren for these exquisite views of the New Zealand fjords. If we had only come to see those we should have been delighted; but we have, besides, had the scientific interest that attaches to the paper itself put so ably before us.

If any gentlemen wish to join in the discussion we shall be very glad to listen to them.

Dr. Jack, F.G.S.—I have listened with very great pleasure to the lecture which has been delivered on this interesting subject. It is true that neither the description nor even the photographic slides give one any adequate idea of the marvellous beauty of these sounds; but that is no discredit to my friend, the author of the paper, for I do not think that the human language can adequately describe the beauty of those sounds. I thank God that I have seen them, but I am quite unable to describe them.

I observe that Mr. Maclaren is sceptical about these sounds themselves being rock-basins—that is, having a rock-bound outlet; but I must say that I lean very much towards the theory that they are rock-basins, and evidence against it can, it seems to me, be only of a negative character. It is true that at the mouths of these outlets there are found accumulations, which in all probability are due to the heaping up of matter by the currents. They were possibly moraine deposits in the first instance; but even if there were no moraine deposits there would be quite enough material along the coast to form bars in such localities. But, at the same time, the evidence that there is no barrier of rock beneath those accumulations of drift is not clear. The fact is that nothing but borings could actually prove whether or not there is a rock barrier. I believe in all probability such barriers do exist as are found at the mouths of the rock-basins at the foot of the Alps. Mr. Maclaren justly pointed out that ice accumulations would imply, as a general rule, sloping valleys rather than precipitous valleys with overhanging glaciers. There is no doubt in my mind that very extensive glaciers would produce valleys with soft slopes, and such valleys were probably produced at the period of the greatest extension of the ice; but supposing that to have been followed by a considerable period of less extension of the ice, *i.e.*, the ice sheet filling a less wide valley, then I see no reason why the attenuated ice-sheet should not go on grinding out a narrower rock-basin. I have seen modern glaciers overhung, in some places, by precipitous cliffs. So I do not think the evidence that glaciers are not even now scoring out valleys and making depressions which are bounded at their furthest extent by a rock barrier is quite conclusive. I do not for a moment deny the oscillation of level. That is abundantly proved by the evidence that Mr. Maclaren brought before us. The paper is one which gives rise to much ground for thought on our part, and I am much indebted, personally, to Mr. Maclaren for having brought the subject before us.

The CHAIRMAN.—To what Dr. Jack has just said I should like to add that from my little observation in Norway I have noticed that the fjords in some cases have exceedingly precipitous sides—as precipitous as they possibly could be, rising for several thousand feet, and sinking, as we were informed on my trip, 80 fathoms close to the shore.

We were told by Professor Hull, in his recent lecture, that these fjords show markings of glacial action near to the present level of the water, and he infers from their depths that they were true glacial beds after they had been river-channels. It seems to me that the record of depths in this table is not complete for drawing an inference. If you only give the depth at the mouth and then give the average depth afterwards, it is not evident whether the maximum depth coincides with the narrowing of the valleys at certain points. If the valleys became very narrow, then the heaped up ice caused by its pressure and erosive action a deepening of the valley. The ice, being throttled, would hollow out a greater depth. Of course water does that too if flowing rapidly. I understand the lecturer to say that in New Zealand glacial markings are not found low down close to the water in these lands. Is that so?

Mr. MACLAREN.—Yes; the few that have been observed have been found near sea-level.

Mr. ROUSE.—Then in that case it seems to me that they stand on the same footing as the Norwegian fjords, except for this drift, which may itself lie on the top of a moraine. There is nothing here to militate against it—in fact, one would rather infer that it was so from the immense contrast there is between some of the depths at the mouths and the greatest depths recorded.

If no other gentleman would like to take part in the discussion, I will call on Mr. Maclaren to reply. I have only to express our hearty thanks to Mr. Maclaren for his exceedingly interesting paper and his most exquisite photographic views of the New Zealand fjords.

Mr. MACLAREN.—I would only like to say with reference to the remarks of Dr. Jack and the Chairman that we have very little data to go upon, and I have put at your disposal all that we have. You must remember that in the West Coast Sounds region there are only a few people living, and it is reached only in the summer time by excursion steamers, and no scientific investigation has been made of the isobathic contours of the fjords. All I have to go upon are the few soundings that have been made by the Admiralty.

With reference to Dr. Jack's remark about the possibility of the shallowing of the mouth being due to moraine matter, I quite admit that; but it seems to me that the evidence is in favour of a coast-drift as I suggest. With regard to the character of the fjord walls; those precipices, no doubt, may owe their steepness to the action of glaciers, just, as Dr. Jack remarked, is the case with the glacier valleys in the Southern Alps, to which he referred. As I have already said, the fjords were undoubtedly occupied for a time by glaciers, which must have had some effect on the sides of the valleys.

The Meeting then adjourned.

POSTSCRIPT.

A letter was received from the Secretary, Professor Hull, stating his great regret that, owing to illness, he was unable to be present to hear Mr. Maclaren's paper on a subject in which he was much interested, and he desired to join in thanking the author for this communication.