GLACIAL ACTION IN TASMANIA.

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Through the courtesy of the secretary I have been allowed to read Mr. Moore's paper on "The discovery of glaciation in Tasmania" read at the April meeting of the Royal Society, at which I was unfortunately unable to be present, and have thus been enabled to prepare a few notes upon it. Having myself come upon evidences of ice action in February last in the neighbourhood of Mount Pelion, and being at that time ignorant of Mr. Moore's discovery four months earlier, I had intended in any case to submit to the Society a few observations on the subject of glaciation, and in continuing the discussion on this important and interesting subject I shall make a few remarks upon Mr. Moore's paper, and then pass on to what I saw myself and to a few observations on more general aspects of the matter.

It is by no means a new discovery, as Mr. Moore appears to think, that there have been glaciers among our western highlands, for Mr. R. M. Johnston, and, if I am not mistaken, the late Mr. Sprent also, noticed the existence of large erratic blocks in the valley of the Macintosh River, and inferred from these that they must have been brought down by ice, and Messrs. Dunn and Moore's and my own later finding of striated boulders, smoothed surfaces, *roches-moutonnées*, and moraine drifts, only confirms the correctness of the views of these earlier observers. Mr. Moore is therefore in error in ascribing to Mr. Dunn the honour of being the discoverer of evidences of glacial action in Tasmania, though perhaps he was the first to bring forward indisputable proofs.

The country described by Mr. Moore round Mounts Sedgwick and Tyndall and Lake Dora is very similar to that round Mount Pelion. The conglomerates which he speaks of as Devonian are of much interest, and the results of further examination of them and fossil evidence as to their age will no doubt add an important chapter to our knowledge of the geology of the colony. In my journey from Barn Bluff to Zeehan I noticed conglomerates of, I take it, three distinct ages: 1. A coarse conglomerate composed mainly of thoroughly waterworn pebbles of micaceous schists and quartzite lying in horizontal layers unconformably on the upturned edges of ancient schists and quartzites, and constituting the lowest beds of the permo-carboniferous coal mea-

sures; (2) a very similar coarse pebble conglomerate lying on the edges of older strata towards the south end of Mount Murchison. This one, I think, is older than the coal measures, and may be the Devonian conglomerate of Mr. Moore, but fossil evidence is not yet available to decide its age. And 3. A somewhat similar conglomerate conformably bedded with the quartzites and schists and intercalated in layers in them. This differs from the two former ones in being much more jointed, the joint planes passing fairly through the component pebbles, and in being also so thoroughly cemented together that when the rock is broken the pebbles do not break out from their setting but right across their substance. The conglomerates of Mount Owen, Mount Zeehan, and parts of Mount Reid are of this third class, conformably bedded with slate and sandstone. I am not yet prepared to say that the quartzites and schists of the Upper Forth, and westward thence to Mount Murchison, are of the same age as the sandstones and slates of Mount Zeehan, though the included conglomerates among the quartzites are very similar to those among the sandstones of Mount Owen, but I have not seen any signs of uncomformability up to the present, and the difference of lithological character may be due simply to the first named being nearer the axis of the mountain-making movement or crumpling. Nevertheless it seems rather more probable that the quartzites are older altogether than the Zeehan fossiliferous strata. The general strike of both formations, supposing them to be different, being the same, about N.N.W., and both lying inclined at high angles, it is likely to be a matter of difficulty to establish the fact of difference of age by stratigraphical evidence alone, and the paucity of fossils debars us from getting good palæontological proof.

Mr. Moore mentions that Mount Sedgwick is capped with diabase greenstone, as is also Mount Dundas; to these we may add Barn Bluff, Mount Pelion, Mount Ossa, the Ducane Range, the Eldon Range, East Mount Pelion, and the Oakley Range, as all showing the same feature. It seems manifest to me that the great greenstone plateau in the centre of the island, the northern edge of which forms the Western Tiers, once extended westward so as to include all these peaks, and it is probable that ice action had a great deal to do with carving out the deep valleys that now separate them. I do not mean to say that ice has been the only considerable agent in cutting out the valleys, for these highlands do not appear to have ever been under water since the eruption of the greenstones in mesozoic times, and great subaerial erosion must have taken place before the coming of the ice sheets, which, as we shall see later on, probably did not exist till a comparatively recent time, later tertiary or even pleistocene.

The shape of many of the valleys, and the contour of the hillsides suggest, however, that the present configuration of the surface is largely due to glacial erosion, and it is probable that during the ice period the valleys, already partly worn out by running waters, were immensely deepened and enlarged by the accumulation in them of glaciers.

At the head of the Forth Valley it is very evident that the diabase greenstone is a horizontal sheet overlying the quartzites and permo-carboniferous strata, for on every hillside forming the amphitheatre at the head of the valley the same features present themselves; first, highly inclined quartzites in all the deep gullies at the base of the mountains, the lying on these horizontal coal measures, sandstones, and mudstones; then at about the same level on every peak we find the columnar greenstone resting on the coal measures. On East Mount Pelion and Barn Bluff the residual mass of greenstone left on the top of the sedimentary strata is very small, and the undisturbed coal measures are visible all round the peaks. Mr. Moore mentions the occurrence of coal-measure fossils in the moraine at Mount Sedgwick, and it will no doubt prove that the sedimentary strata there too underlie the greenstone capping. I cannot think it at all probable that Mr. Moore is correct in referring the conglomerate containing fossils to the action of floating ice; it seems much more likely that it is a moraine drift derived from the lower beds of the carboniferous formation, which, further north near Barn Bluff and Cradle Mountain, consist mainly of conglomerates. These would supply the stones of granite, slate, porphyry, etc., which Mr. Moore has noticed, and also the fossils, and I have little doubt that when he comes to examine the country more thoroughly he will find these beds *in situ* under the greenstone capping. It is hardly conceivable that if the conglomerate was deposited by floating ice in permo-carboniferous times, which is what Mr. Moore's words seem to imply, that it should happen that the only proof of such ice action should be found in a region where there has been evidently severe glaciation at a much later date. Before accepting such a theory we should first have to eliminate all possibility of the conglomerate having been formed at the later period. Round Mount Pelion there is direct proof that the glaciation took place long after the permo-carboniferous period and after the diabase greenstone had covered the strata of the latter, and Mr. Moore's observations of striated greenstone blocks on Mount Sedgwick show the same thing.

The first place in which I came upon plain proof of ice action was near East Mount Pelion, between a branch of the River Forth flowing from that mountain and from Lake Eyre, and another small feeder running in a deeper gully at

the foot of the Oakleigh Range. Between these branches of the Forth there is a ridge rising to a height of perhaps 150 feet above the level of Lake Eyre, and highest at the north end. The whole of this ridge is a succession of *roches-moutonnées* of the most typical shapes, with long rounded stopes towards the south, and short steep ones towards the north, the direction of motion of the glacier having been northward down the valley of the Forth. Between the hummocks are numerous small ponds and tarns, with their bottoms much deeper than their outlets. Some of these are grown over with swampy vegetation, and form minute peat mosses, but many still show their rocky beds. Towards the south end of the ridge the country rock is mostly schist, and though the general shapes of the *roches-moutonnées* are well marked and characteristic, striations on the rock surface have been obliterated by the weathering of the exposed surfaces, but further north, where the rock is a very dense and hard quartzite, the planed surfaces are wonderfully clear, and it is difficult to find a place where a stone showing the smoothed surface can be knocked out of them, so little disintegration of the rock has taken place. Owing to the extreme hardness of the quartzite the surfaces are not as a rule striated, but polished smooth, often almost as smooth as glass. All over the ridge numerous erratic blocks of greenstone are scattered, and as this part of the ground is separated by valleys from the slopes of the surrounding hills running up to the greenstone cappings, and there is no possibility of their having been carried uphill by running waters, it is plain that these have been transported to their present situatians by ice. It serves to give some idea of the antiquity of the ice action that these greenstone erratics are very little decomposed, being as sound and unweathered as the stones lying on the tops of Mount Wellington and Ben Lomond. When we consider that the greenstone is a felspathic rock, and weathers rather easily (the stones of it in the neogene tertiary drifts round Launceston, for example, being generally pretty thoroughly decomposed), we see that the date of the glaciation must not be referred to the very distant past, but is more likely to be pleistocene. The splendid state of preservation of the ice-worn surfaces also favours the view that they are not very ancient, for even a quartzite must suffer considerable disintegration if exposed to rain and frost, such as every winter brings in this high-lying part of the country, at an altitude of between 2,000 and 3,000 feet. The evidences of glacial action seen by Mr. Moore also appear from the description to indicate a comparatively recent date.

The high narrow plateau lying between Mount Pelion and Barn Bluff shows in its every contour the former presence of

glaciers; it is a succession of low rolling hummocks of rounded outlines, and full of small lakes and tarns. From the top of Barn Bluff I counted over one hundred little lakes in sight at one time in this plateau, and there are probably several hundreds in all. Some of these little lakes are very pretty, Lake Isles in particular; but indeed the whole of the scenery of this part of the country is most beautiful.

On the slopes of Barn Bluff there are two or more lines of moraine ridges, separating flat valleys, which have been the beds of adjacent glaciers; these are mainly composed of immense loose blocks of greenstone from the cap of the peak. The discovery of loose angular blocks of cannel coal on the south-east spur from Barn Bluff has led to some of the ground being laid open by mining operations, and it is soon seen that the fragments are portion of a ground moraine. The superficial soil, to a depth of over 20 feet in parts, is composed entirely of angular fragments of the adjacent rocks of all sizes, jumbled together in the wildest confusion. In one of the pits a large sheet of cannel coal, evidently lifted as a whole from the main seam, was come upon, and proved to extend over a space some 16 feet square, or more, but when cut through it was found to be resting on loose angular fragmentary material, in which, among other things, were angular blocks of the coal itself, one piece standing on edge immediately under the large sheet. No landslip or river could carry such a sheet of coal without breaking it, but ice could easily lift it from its bed, and transport it a very considerable distance uninjured. It may be remarked that the lumps of cannel lying about the surface of the ground are nearly of as good quality as those dug up from some feet deep, so that exposure to the weather has not had much effect on the mineral. This coal, which, by the way is associated with fragments of shale carrying prints of a *Glossopteris* and a *Noeggerathiopsis*, and therefore belongs to the lower or Mersey coal measures, is a very bituminous substance, and would doubtless resist atmospheric alteration for a very long time, but I hardly think it possible for it to have been exposed or lying near the surface from, say, the miocene period till now without very perceptible oxidation; its good state of preservation, therefore, strengthens my belief that the glaciation is of pleistocene date. Another argument in favour of a comparatively modern date being ascribed to it is found in the small amount of destruction of the ground moraine by subaerial erosion, the ground having all the appearance of not having long been denuded of its ice covering, and not being cut into fresh shapes by the modern watercourses, as we should expect if it had long been exposed to their action, especially in a district where the rainfall is so heavy as round Cradle Mountain.

Going from Barn Bluff towards Granite Tor the rolling

hummocks and rounded ridges continue to be met with on the high lands, and descending suddenly and abruptly from these are huge deep ravines and valleys. It is noticeable that in many of these the streams in the bottom of the ravines are quite insignificant in size, and not at all likely to have been sufficient to eat out such huge valleys. Even where they are fairly large rivers, as in the case of the Fury, Forth, Bluff, and Sophia rivers, it may be noticed that the sides of the gorges have on the whole broad flat slopes, and present a generally even outline; they are scarred with deep little ravines, it is true, in which there are watercourses, but these from a little distance are almost invisible. This points to the likelihood of the main deep gorges having been the beds of glaciers, the erosion by running water since the retirement of the ice having been sufficient to greatly alter the contours shaped by the latter. All across from Barn Bluff to Mount Reid the solid rock seems to be immediately under the very shallow surface soil, both on the ridges and in the valleys, as if there had not been time for the formation of accumulations of superficial *debris* to any considerable extent since the times when the ice planed away all the loose stuff covering the solid rock. Throughout this district the contours of the hills are on the whole wide, broad, and flat slopes, not the sharp, jagged, broken outlines which we should expect to find in schist and quartzite country carved only by running water.

The lakes at the head of the west branch of the Murchison River, and on the divide between it and the Henty, Lakes Spicer, Dora, Beatrice, Rolleston, Julia, Selina, etc., also probably indicate the former presence of glaciers, and I think we must come to the conclusion that the whole of the deep gorges among these western mountains, now occupied by the headwaters of the Pieman, Henty, and King Rivers, have been at no very distant period of time occupied by rivers of ice. The erratic blocks noted by Mr. R. M. Johnston in the Mackintosh Valley quite bear out this conclusion. It is very likely that the ice had retired from the low-lying valleys long before it finally disappeared from the tops of the ranges, just as in the New Zealand Alps we find indications that the present glaciers once extended much lower down, and therefore the smoothed surfaces at Mount Pelion and Lake Dora may be of much later date than the erosion of the main valleys, but nevertheless it seems probable that the whole of the present shape of the country along the West Coast Range is due to ice action of comparatively recent date.

If we allow that the deep valleys at the head of the Pieman were once occupied by glaciers, we must admit that the ice came down to within 500 or 600 feet of the present sea level, for these gorges are very deep, or perhaps we should rather

say to points which are now that distance above the sea, for of course it is quite possible that there has been elevation or subsidence of the land as a whole since the ice age. Later on, however, I shall point out that there has been no subsidence of the country worth mentioning during the period when these masses of ice existed, but rather elevation, the land being probably higher now than then. Now if the ice lay so low in these valleys, what about other parts of the colony? The glaciers would not be likely to be confined to one district, but would be on the other high lands as well. Ben Lomond, Mount Wellington, and the Great Central Plateau probably also had their share of ice and perpetual snow. The great lakes on the Central Plateau are almost *prima facie* evidence of glaciation, ice being one of the most common causes of the formation of lakes. On Ben Lomond also there is a lake for which it is hard to account, except as having been formed by ice; and the peculiar flat shelf on the south side of the Butts at the foot of the talus slope, a plain some four or five miles long and two miles wide, on which most of the Ben Lomond mines are situated, is also difficult of explanation. It may perhaps have been the seat of a glacier, from which branches ran down Story's Creek, the Castle Carey Creek, and Gipp's Creek. On the slopes of Mount Nicholas the coal-bearing sandstones are overlaid by a heavy superficial covering of loose greenstone drift derived from the capping or central ridge, whichever it may prove to be, of the range. Going over this lately it seemed to me that simple landslips and rolling down of loose stones from the higher ground were not sufficient to account for the immense quantities of loose superficial rock, and one is strongly tempted to regard this as moraine stuff. More evidence is required before accepting this view, but it seems to me to have a good deal of probability. We shall probably yet have to ascribe the shape of a great many natural features of the country to glacial action, but while this is suggested as a potent cause I must admit that evidence is wanting to prove widespread glaciation in the eastern parts of the colony, and I mention the matter rather because it seems an almost necessary consequence of admitting the prevalence of ice in the western highlands that it should also have existed in the east, than on account of any direct proof.

At the head of the Ring River on the western slope of Mount Reid there has been discovered a "deep lead" which presents some features suggestive of ice action. The upper part of the filling of the old river valley forming the lead for upwards of 100 feet, and perhaps more, consists of very thin layers of fine sandy clay, perfectly horizontally bedded, the sediments having been plainly laid down in very still water. These clays are exactly like the glacial clays now

being deposited in South Canterbury, New Zealand, in lakes fed with turbid water issuing from beneath glaciers. While the clays have been laid down in still water, it is equally clear that the coarse gravel and boulders in the bottom of the lead have been deposited in the bed of a running stream, and it is therefore evident that the valley of a once turbulent watercourse has been somehow converted into a deep and still lake. The stream appears to have run to the northward, in quite a different direction to the present Ring River, and the valley of the latter must have been eroded since the older river system was covered up and obliterated, for it cuts through the above clayey layers to some depth. Seeing that there are grounds for considering the valley of the Mackintosh to have been scoured out by glacial action, it seems reasonable to suppose that the old Ring River became dammed by the advancing ice and its valley converted into a lake, which became rapidly filled with glacial sediments. The ice-sheets still advancing probably performed much of the work of erosion of the present Ring River Valley. Lower down this, it may be mentioned, we have further proof in the finding of gravel terraces 200 feet above the present stream, that an older river system has been almost entirely obliterated. The clays of the Deep Lead, so far as yet known, are very free from fossils which would give evidence as to its age, but as work proceeds it is probable that some leaves will be found which will help us to fix their date.

It has always been regarded by mining men as an uncommon feature in connection with the Mount Bischoff tin deposits that there was little or no trace of tin ore in the rivers and creeks heading from the rich gravels on the Mount, it being usual under such circumstances for the ore to be found for miles down the streams draining from the lodes or older gravel deposits. As the plateau round Waratah is high enough to have been well above the probable snow-line at the time of the glaciation of the country further inland, it seems possible that the deep gorges of the North Valley and Arthur Rivers may have been glacier beds, a supposition which their depth and shape give some colour to. If these valleys were cut out by ice the stanniferous gravels would have no opportunity of being sluiced over and over again in the streams, so as to distribute the ore along their courses for long distances, but would be swept clean away with other rock *debris*. Should evidence be by and bye obtained to bear out this explanation, it would have further interest as giving a clue to the time of glaciation, for the Waratah plateau consists of basalt of tertiary age, overlying tertiary leaf beds, and the Waratah valley up to the railway station has been cut through these basalts. The basaltic outbursts appear throughout this colony to have been

between the palæogene and neogene periods, or probably pleiocene; and this would make the glacial action either pleiocene or post-pleiocene. Not having direct proof of glaciation at Mount Bischoff, this argument is not convincing, but taken in conjunction with the fact next to be mentioned, it has weight. On Gads Hill, and at various points along the top of the Oakley Range, the same tertiary basalt is found as a superficial covering, and an escarpment of it forms the western edge of the plateaux on the top of the Oakley Range and overlooking the River Forth. The valley of the Forth has plainly been scooped out since the basalt was poured out, and as we have seen, at the head of this valley, the proofs of the presence of glaciers are very well marked. Consequently the pleiocene or later age of the glaciation must be regarded as demonstrated. It may here be remarked that, according to Dr. von Lenderfeld, the evidences of glacial action in the Australian Alps point to its having taken place at quite a recent date, and with this corroboration I think that it is most likely that our glaciers existed as late as the pleistocene period. As above stated, the excellent preservation of the rock surfaces, the slight decomposition of the greenstone erratics, and the small amount of erosion of the ground moraine at Barn Bluff, all go to show a very recent date, geologically speaking.

The importance of being able to limit the probable period of existence of the glaciers to neogene and recent periods becomes apparent when we come to consider the questions of the cause and extent of the glaciation of the country, and as to whether our cold period had any connection with the glacial period of the Northern Hemisphere. First let us glance at the causes of glaciation: It might be due to greater elevation of the land, to geographical changes resulting in a redistribution of sea and land, diversion of ocean currents, and so on, or it might be due to astronomical, causes as so lucidly explained by Sir Robert Ball in his recently-published little book on "The Cause of an Ice Age." Having limited the period of existence of the glaciers to the time between the outpouring of the basalts and the present day, we can examine the evidence of our later tertiary deposits to find if there is any indication of the country having subsided from a higher elevation to a lower one. We find that all round the island, in the Launceston tertiary basin, in that of the Derwent, at Macquarie Harbour, and at Oyster Bay, there are palacogene lacustrine deposits laid down in hollows, the bottoms of which are often much below present sea level, and which are in the Launceston Basin as much as 1,000 feet in thickness. They have doubtless been formed during a period of continuous subsidence extending throughout the palæogene period. After the

basaltic eruptions which closed the latter, the land appears to have risen again gradually, and the palæogene sediments have been deeply cut into. The terraced gravels of the Ringarooma Valley and North-eastern Tasmania generally, show that the elevation has been practically continuous, though on the islands in Bass Straits there are proofs of minor oscillations of level, hence we must conclude that the general elevation of the country is now higher than it has been since the early part of the palæogene period. It has not risen quite so high as previous to the great subsidence, for we find deep leads at Beaconsfield and George's Bay running considerably below sea level (270 feet at Beaconsfield), and the old channel of the Ringarooma River at Derby is more than 90 feet lower than the present one. No elevation of the country sufficient to cause its glaciation has therefore occurred since the beginning, probably, of the miocene period.

The second great cause of accumulation of ice is found in geographical changes leading to a redistribution of sea and land, alteration of ocean currents, and change in the direction of prevalent winds. The most important change which would be likely to affect Tasmania in this respect would be the opening of Bass Strait, and the severance of this island from the Continent. The biological proof is conclusive that there was practically unbroken land connection between us and the mainland up to early in the pleiocene period, and if the glaciation had taken place before the severance, it would be easy to suppose that the opening of the strait had led to an amelioration of climate, but as it appears to have been later than this, it is hard to conceive any reason for formation of glaciers which would not exist now as well. In the neogene and recent period, too, we have no evidence of changes in the Australian Continent which could have any effect upon our climate, and consequently we have to abandon this explanation also.

It is therefore probable that the refrigeration of the climate of Tasmania, which led to the gathering of glaciers on its high mountains, was due to the causes insisted upon by Dr. Croll and Sir Robert Ball. It is most likely true that these causes are not, of themselves, sufficient to account for a period of extreme glaciation such as was experienced in the Northern Hemisphere in the glacial period without the concurrence of geographical changes favourable to its production, but nevertheless the astronomical and physical argument is so strong that we must concede that it would account for a very considerable refrigeration.

In discussing the subject of the climate of this colony during the neogene period, Mr. R. M. Johnston considers that there is no evidence of glacial action in the lower lying lands, and regards the glaciers as having been of small

extent. While inclined to believe that the ice covering has been more extensive than he is disposed to allow, in the main I agree with his view, and do not think that the whole country could have been ice bound. Many of our indigenous animals existed in the colony before the probable date of the glaciation, and if the latter had been extreme would have been killed out altogether, in which case, if I am right in referring the cold period to a time subsequent to the severance of Tasmania from the Australian Continent, there would have been no chance of a fresh stock having been obtained from the mainland after the climate again became milder.

Outside of this colony evidences of glacial action have been found in the Australian Alps and on the beach near Adelaide. The latter occurrence, first described by Professor Tate, has been questioned, but is confirmed by Mr. R. L. Jack, who visited the place in 1891. The glaciation marks in the Australian Alps seem to be very similar to those in our highlands, but the Adelaide occurrence is not so easy of explanation, apparently indicating a large glacier at sea level at a period later than miocene. Mr. Jack ("Geology of Queensland," p. 619), in referring to this, also quotes from the "Challenger" reports to show that Kerguelen Land, too, has been at no ancient date completely covered by heavy ice, and points out that if the Antarctic ice-cap were extended to cover Kerguelen Land, there would be no improbability of its also reaching the shores of Australia.

The whole subject is most interesting, and has numerous aspects on which more light is required, and fresh proofs of the extent and date of the glacial action all over the Southern Hemisphere will be eagerly looked forward to.