Evidences of Former Glaciation in the Southern Hemisphere (Australia, New Zealand, and Tasmania) Subsequent to the Deposition of Rocks of Miocene Age.

New Zealand.—One of the most accomplished geological observers, Prof. T. D. Hutton, in commenting "On the Supposed Glacial Epoch in Australia" (Proc. Roy. Soc. of N.S. Wales, pp. 338, 339, 1885), states that "In New Zealand there are, as is well known, ice marks dating from the present day to some period when the glaciers were at their greatest extent, and for many years New Zealand geologists have been accustomed to call this latter time the *glacier* epoch of New Zealand, in order to distinguish it from a *glacial* epoch, which term implies a considerable reduction of temperature." The term *glacier* he considers does not imply any hypothesis as to the cause. He affirms also that all New Zealand geologists are of opinion that the *glacier* epoch there was long anterior to the glacial epoch of Europe and North America. In combating erroneous views of Dr. von Lendenfeld as to the date of the former glacier epoch, he states that "The islands in the Sounds are not *moutonnées*, and although some of the smaller ones are rounded, they show no signs of lee and strike sides, The precipices on either side of the Sounds are also in general quite rough, and I noticed only two localities (both previously observed by Dr. Hector) where there was any appearance of polishing: one was in Milford Sound on the south side of the entrance to the "Narrows,' the other near Deas Cove, in Thompson Sound. I saw neither grooves nor striæ; but Dr. Hector noticed them in Thompson Sound, and in the Cleddau Valley." He, however, continues:—"All this is very different from any glaciated district in Scotland, Wales, or Ireland, where nearly every rock tells the same tale, and, judging from published accounts, it is very different from the fiords of Norway, the rocks of which are much the same as those of the West Coast Sounds of New Zealand. Yet that these Sounds have at one time been occupied by ice is proved by the huge granite boulders lying on the sandstones and mudstones at Kisbee Bay in Preservation Inlet." He refers these evidences of glaciation and great glacier epoch as belonging to a very ancient date, long anterior to the glacial epoch of Europe and North America. There is apparently nowhere in New Zealand any evidence of such intense glaciation as that which spread over the lower levels of Scotland, Ireland, and Wales, as we have no mention of anything corresponding to the "till" of the great northern ice sheet.

The absence of such evidence in a region whose mountains rise to a height of over 12,000 feet,* and whose southern borders extend to 47° 10' south latitude, is full of significance when we come to consider the various theories advanced to account for the occurrence of the great glacial epoch in the Northern Hemisphere, and especially so when we come to examine the proofs of a true glacial epoch in the more northerly limits of the Australian mainland.

Australia.—In the Australian mainland there are no high mountains as in New Zealand. The highest peak in the eastern cordillera occurs in the southern and eastern Australian Alps in about 37°, corresponding to the position of Mount Etna in north latitude—Mount Kosciusko and Mount Townsend, the two highest peaks attain here an elevation of 7,171 and 7,256 feet respectively. The whole of the mainland lies within 11° and 39° south latitude, broadly corresponding to the position of Northern Africa or Syria and Arabia in northern latitudes. As moreover the greater portion of Australia is low-lying, it can be no more expected that we should find any traces of intense glacial action within its borders in past times, than that we should look for evidences of the extension of the great ice sheet of Northern Europe in the lowlands of the lower northern latitudes of Syria and Arabia.

Apparent Absence of Glacial Deposits corresponding to the "Till" of Scotland.—Setting aside for the present the origin of certain erratic boulders and other marks of glaciation which are found in beds of conglomerate in New South Wales, Victoria, and Tasmania, in rocks corresponding to the close of the Permo-Carboniferous age, and which undoubtedly appear to have been transported to their present position by means of floating ice—no satisfactory evidence of glacial action has yet been discovered in Australia corresponding to the till, boulder clay, *moraine-profonde or grund-moraine* of the great ice age of Northern Europe and North America. Indeed it would be a matter of the greatest surprise, even to the most ardent disciples of ice-cap extension, in Europe and America, if such evidences should appear; for neither the advocates of the effects upon climate of the extremes of eccentricity of the earth's orbit combined with the precession of the equinoxes, the advocates of changes in the distribution of land and water, nor the advocates of a combination of astronomical and geographical causes, have ever attempted to show that influences could possibly induce such an extreme lowering of temperature as would cause the northern polar ice cap to creep and extend beyond the north latitude of 39°, which point corresponds in south latitude nearly with the

*Mount Cook 12,349 feet.

most southerly limits of the low-lying Australian Continent. In Western Europe, during the great ice age, there is no evidence of the great ice sheet extending further south than 51° north latitude. When we consider that the most southerly point of Australia corresponds with Lisbon in north latitude, or 12° to the south of Ireland, we may more readily comprehend the improbability of an extension of the southern polar cap to any part of the Australian Continent under similar conditions to those of the European ice age.

Evidences of comparatively recent Glaciation on the Australian Mainland, as Recorded by Various Observers.—Subsequent to the earlier observations of Selwyn, Daintree, and others in respect of ancient glacial phenomena in rocks of Permo-Carboniferous age, it would appear that Professor Tate, in the year 1877, was the next observer who drew particular attention to the existence of glacial phenomena on the mainland of Australia of a comparatively recent date. In a paper of a later date, read before the Australasian Association for the Advancement of Science (Proc. 1887, pp. 231, 232), entitled "Glacial Phenomena in South Australia," he again describes the nature of the evidence upon which he bases his conclusion as to their glacial origin. He describes the glaciated surface as well developed on the coast cliffs at Hallet's Cove, south of Holdfast Bay, in St. Vincent Gulf. That is, therefore, in 35° south lat.; and, as the surface plane of the track inferred to have been polished by the ice is now only 40 feet above the level of the adjacent sea, it is more than probable that the track was marked prior to the final stage of the known upheaval of the floor of the old tertiary sea, whose remains in the vicinity, and as cliffs along the Great Australian Bight, form the most characteristic feature of the South Australian coast line. Professor Tate states that "The path of the glacier (?) is traceable for a distance of two miles along the top of the scarped cliffs, at about forty feet above the sea level; on the north it is cut off from the cliff by encroachment of the sea, from this point the glaciated surface is continuous in a southerly direction for a distance of one mile to Black Point, the north headland of Hallet's Cove. On the line of the glacier there now intervenes the long but narrow bay of Hallet's Cove, but on the south headland the track is picked up on about the same trend, though apparently at a little higher level. Here again the glacier (?) path is soon cut out by removal of the cliff. On the north side of the cove the glaciated surface is beautifully displayed; the edges of nearly vertical strata are sheared off, and when of quartzite the surface shows a high polish, and when of mudstones, conspicuous grooved and striæ. Some moraine *debris*, including stones that have been beneath the glacier (?) occur

here. On the south side moraine matter is very abundant, and includes many boulders, some occurring as *blocks perches*."

"The common rocks of the moraine *debris* are granites, gneiss, hornblende schists, and others, which do not occur in situations nearer than the Gorge at Normanville, about 46 miles to the south. In all, 17 distinct varieties of rock, chiefly metamorphic and foreign to the immediate neighbourhood, have been collected along the path of the glacier. The proximity of the miocene escarpments suggest the possibility of the pre-miocene (post-miocene?) age of the glacier." . . . "It is highly probable that the glacier cut its way through the incoherent miocene formation, and that some of the miocene shingle furnished some portion of the moraine *debris*."

Professor Tate selects particular examples of the *debris* for illustrating their glacial character, viz, slab of quartzite having a highly polished surface and faintly striated; chip of mudstone having a smooth surface, strongly striated and grooved; ice-worn pebble polished and striated on its upper and lower faces, found partly embedded in soil resting on glaciated surface. Professor Tate also draws attention to some forgotten early observations of Mr. Selwyn in relation to glacial phenomena in South Australia, discovered, by him, further south in the bed of the Inman, Cape Jarvis Peninsula, consisting of smooth striated and grooved rock surfaces, of which Mr. Selwyn wrote:—"The direction of the grooves and scratches is east and west in parallel lines, and though they follow the course of the stream I do not think that they could have been produced by the action of water forcing pebbles and boulders detached from the drift along the stream." The rounded surfaces of mica slate on the south flank of Kaiserstuhl and Crafer's on the Adelaide chain referred to by Professor Tate are less satisfactory, and are only suggestive, and their value as collateral supports depends entirely upon the character and derivation of the ice which caused the phenomena near the present sea level at Black Point, Holdfast Bay. Professor Tate's own conclusions as to the cause of these undoubted glacial phenomena are threefold, viz., either—

1. The prevalence of a very much colder climate.
2. That the land stood at a much greater altitude (say 10,000 feet), or the mountains (presumably the Adelaide chain, whose few high peaks at present do not much exceed 2,000 feet, R.M.J.) may have had a more plateau-like form, and therefore need not have been so high, and consequently collected more snow.
3. A combination of both of the preceding conditions (1 and 2).

There is another condition, however, which Dr. von Lendenfeld* and others favoured, which also embraces Professor Tate's first condition—much colder climate —as a contributing cause, viz., the grinding action of partly stranded sheets of the Antarctic drift ice, whose extreme northerly limits, even in the present mild epoch, ascend almost into the same degree of south latitude in the vicinity of the Cape of Good Hope. But Professor Hutton points out that the existence of granite in the south polar region has not yet been discovered. All the land at present known is volcanic. It is suggested, however, that Tasmania and New Zealand could furnish such materials, but it is improbable that the well-known glaciers of the western highlands of Tasmania descended to sea level.

It is almost certain, however, that at the last great period of eccentricity of the earth's orbit with winter in aphelion, the limit of Antarctic drift ice would touch the southern extremity of the Australian mainland when Tasmania would stand well within it. It is not improbable, therefore, that in the extreme of winter portions of the drift ice might for a time be stranded on the precipitous shores of Tasmania and New Zealand, or even on the south-western shores of Western Australia, long enough to receive from overhanging cliff or pebbly beach *debris* which, on breaking away in the extremely hot and short summer, might find its way northward, to be again partly stranded on projecting points of the Australian mainland in St. Vincent Gulf, and there to leave in its trail the channelled traces of its course and part of its *debris* picked up on the coasts further south. To my mind this is the only reasonable interpretation which would sufficiently account for all the *verified data* so clearly brought forward to our notice by my distinguished friend, Professor Tate.

The curved form of the encroachment of the sea in the Great Australian Bight also favours the idea that the well-known Antarctic drift current might have operated more powerfully in the last glacial epoch in contributing to the waste action which has determined its present deep bay-like indentation.

It is evident that Professor Tate, who invariably uses the word *glacier*, inclines to the view that the *debris* on the shore of Black Point has been carried down by an inland glacier descending from local mountain tablelands—now only reaching a height of about 2,300 feet—which he assumes, without satisfactory evidence, to have stood 10,000 feet higher since the close of the miocene period, and he further objects to the floating ice theory, because he thinks it involves the necessity of assuming the *submergence* of southern parts

* Proc. Linn. Soc., N.S.W., 1886.

of the South Australian province by as much as 1,000 feet, and of this submergence he rightly adds, "That the known facts do not warrant such assumption." But is there any necessity that the advocates of the hypothesis of "floating ice" as the agent of abrasion and transport should assume any *depression* whatever? On the contrary, it seems to me that an *elevation* of, say, 70 to 100 feet of the old sea-bed at the time of glaciation would answer all the conditions which the phenomena of glaciation and present elevation (40 feet above present sea level) demands; and this would allow a depth of from five to ten fathoms of sea over the channel along whose course the glacial phenomena have been traced. It would, in the latitude of St. Vincent Gulf (35° S. latitude), require an elevation of the whole land to a height of 12,000 to 14,000 feet, with a subsequent final depression of about from 11,600 to 13,600 feet to account reasonably for the present level of the glacial phenomena at Black Point, and for the present altitude of the higher members of the old tertiary marine beds; and this double assumption is of a far more serious character, and is far less warranted by known facts than the submergence of 1,000 feet, for which, also, there is not the slightest necessity for assuming, unless it be also insisted upon that the very doubtful appearances of glaciated surface on the heights of the Adelaide range are also to be explained as having been caused by the same agency which produced the glacial phenomena. Notwithstanding my very high appreciation of the judgment of Professor Tate, better evidence than has yet been produced will be required before such a conclusion can be satisfactorily established.

Until such evidence is produced, I shall be inclined to favour the hypothesis of "partly stranded polar drift ice," carrying *debris* in summer from neighbouring southern shores, not necessarily polar, where the ice drift may have been stranded for some time during the long severe winter. The period when such action took place is likely to have been at a time when the eccentricity of the earth's orbit combined with winter in aphelion attained its greatest limit subsequent to the deposition of the rocks of miocene age. According to Dr. Croll's published tables showing the varying amounts of eccentricity for three million years back, it would appear that the periods of high eccentricity have been exceedingly numerous in that time, and one or two of them far higher than that which is supposed to have been the principal cause of the great glacial epoch of Europe and North America in the pleistocene period.

Now most of the Australian geologists incline to believe that the period of greatest glacial action in Australasia

occurred long anterior to that known as the glacial period of Europe. And it is not without significance as bearing upon this question, and also upon the disputed question as to whether the extreme effects of glaciation could, at any time, have been produced by astronomical causes alone *(i.e.*, without the concurrence of favouring geographical causes), to find that the highest eccentricity occurred, according to Croll, 850,000 years ago, at which time the difference between the sun's distance at *aphelion* and *perihelion* was thirteen and a half millions of miles, whereas during the last glacial period of Europe and North America in the Northern Hemisphere, the maximum difference was ten and a half millions of miles only—that is three million miles or 22·22 per cent. less. As from the nature of the distribution of land and water in the Southern Hemisphere, it is probable that geographical causes would not play so important a part in barring the introduction of warm equatorial currents from the hemisphere specially affected; it is also probable that the alteration in climate in the Southern Hemisphere would be almost purely the result of *astronomical causes alone.* If we admit this, we should seek for the cause of the milder *glacier* period of Australasia since the cretaceous age, at that point of time when the eccentricity of the earth's orbit was at its highest, and that was about 850,000 years ago, or fully 550,000 years anterior to the time of the great glacial epoch of Europe in the pleistocene age. This happily corresponds very closely with estimates as to the period which closes the miocene age, at which time there is evidence that the glacier period of Australasia began to mark its effects on our rocks and upon the organic life associated with them.

Evidence of Glacial Action in the Elevated Valleys of the Australian Alps.—In the year 1885 Dr. von Lendenfeld (Proc. Lin. Soc. of N. S. Wales, pp. 44-53) in a paper, entitled "The Glacial Period in Australia," gives an account of glacial phenomena discovered by him in the ascent of Mount Kosciusko, the highest elevation of the Australian Alps (7,200 feet), situated in about south lat. 36° 40' long. 148° east, near the south-eastern border of N. S. Wales. On the southern slope it is drained by the head waters of the Snowy River, while its northern slope is drained by the head waters of the River Murray. The marks of glaciation discovered by Dr. Lendenfeld occur principally in the Wilkinson Valley, at elevations nowhere below 5,800 feet above sea level. These consist entirely of smoothed and rounded surfaces, whose grooves and scratches are supposed to have been removed by weathering, but yielding, as Dr. Lendenfeld states, to an eye experienced in reading the signs of glacier action indubitable proof of having been originally polished and rounded

by ice. He states that "One of these instances, on a spur high above a tributary to the Snowy River, was so remarkable that my assistant (*sic*), who had never seen any roches-moutonnées in his life before, was immediately much struck by its appearance. There, there is one rock polished off with a surface of about 3 acres, and about 25 other much smaller ones around it, all polished down to exactly the same surface, divided from one another, however, by depressions of varying depth." He also states that on a spur descending from the Abbot Range *roches-moutonnées* similar in character are very numerous. He did not observe any signs corresponding to perched blocks, moraine stuff, nor *actual* traces of striated or grooved surfaces anywhere, although he conjectures, as regards the possibility of glacial action being traced at levels below 5,800 feet, beneath which he was unable to find further signs, he states:—"I have looked carefully around on my way up and down the mountain, but I was not able to detect any glacial action below 5,800 feet." He, however, is of opinion that in the Snowy valley a glacier might be expected to have descended for some distance from the mountains, and thought it likely that moraines may eventually be found there; but he also adds that it is only in this valley where moraines may be expected, "because it is the only one which comes down from an extensive plateau on which a glacier was formed."

Dr. von Lendenfeld refers the age during which such glacial action occurred to the period which marked the more intense form of glaciation in New Zealand. Mr. Jas. Stirling has also written two or three most interesting papers, in which he gives us the results of careful observations made by him on several occasions among the Australian Alps.

Mr. Stirling corroborates Dr. von Lendenfeld in attributing the polished rock surfaces on Mount Kosciusko to comparatively recent glacial action. He also states that, in his opinion, the observed widespread dispersion of the boulder deposits, the rounded contours of the crystalline rocks, and the undulatory outlines of the foot-hills in many valleys, all bespeak agencies distinct from ordinary fluviatile action, and point very distinctly to glacier action. He further cites additional evidence of glaciation as follows:—"Erratics in the Mitta Mitta and the Kiewa Valleys; huge blocks weighing many tons; smooth surfaces on the Cobberas Mountains and Mount Bogong; moraines at the base of the latter on the Mountain Creek Valley; eroded lake basins, Dry Hill, Hermongee Swamp; Omeo Lake basin; Morainic Lake, Mount Wellington, etc.; but he carefully observes, in conclusion, that "although the fact of a glacier action can . . . be satisfac-

torily established in the Australian Alps, yet further evidence is desirable as to the synchronism of the glacier period in Australia with that of the glacial epoch in the Northern Hemisphere."

So far as the higher levels of the alpine regions of Australia are concerned, the observations of Dr. von Lendenfeld, Mr. Stirling, and other observers leave us in little doubt as to the genuineness of the evidences of glacial action, and of their occurrence at a comparatively recent date; although there is no proof of the date of the occurrence as being coincidental with the glacial period of Northern Europe. Nor is there here any evidence which compel us to infer such refrigeration of climate as would in such a low latitude (36° 40') cause glaciers to descend below the 2,000 feet level above the sea. It is true that certain conglomerates bearing the marks of ice action have recently been discovered in Victoria by Messrs. Graham, Officer, and Lewis Balfour as low as 750 feet above sea level, but these undoubtedly striated boulders, apart from other objections, are so similar in character and so intimately associated in regions of recent igneous disturbance with the well-known glaciated conglomerates of Permo-Carboniferous age, which will be referred to hereafter, that I cannot at present see my way clear to accept the conclusions of Messrs. Officer and Balfour, who recognise some of the deposits as a true boulder "till," or *moraine-profonde*, formed by severe glacial action during "eocene times," and inferred by them to be quite distinct from the earlier glacial deposits associated with them of Permo-Carboniferous age, and from the ice erratics and moraines of the Australian Alps, which they ascribe to a mild glacial period during the pleistocene age. I freely admit that the appearance of some of the deposits so lucidly and ably described by Messrs. Officer and Balfour, especially the deposits on the Korkuperrimal (fig. 3) seem to justify the conclusions arrived at by them; but, what about the similarity of the striated and polished blocks and stones so huddled together in dislocations or fractures of the underlying sandstone to the adjacent and almost contiguous to the ice-borne conglomerates of permo-carboniferous age; the "pell-mell accumulation" of angular and rounded block; the broken and disintegrated clays or shales; the "angular blocks of sandstone in every conceivable position"; the underlying "broken and shattered sandstones"; and the association with the more recently erupted basaltic sheet?

Do not these cumulative evidences, taken together with the latitude and low altitude, rather tend to prove that the rocks, including the older glacial conglomerates immediately underlying the basaltic sheet, have been broken up, dislocated, and

jumbled together by the eruptive forces which more recently ejected the overlying basalt?

Surely this seems to be the more reasonable inference in accounting for the so-called boulder "till." Why, in the pell-mell ruin of the older sandstones, shales, and Permo-Carboniferous conglomerates should we omit to look for the broken remains of the latter conglomerates as well as for the broken remains of the similarly disturbed sandstones and shales? And if the supposed "till" does not contain the fragmentary remains of the admittedly associated older conglomerates of Permo-Carboniferous age, in respect of which we have already ample evidence, as being composed of such polished and striated blocks as are found in the "till,"—What have become of them? The causes which broke up and huddled the older sandstones and shales must have also broken up and jumbled afresh the older associated conglomerates; and it appears to me unreasonable, to suggest the intense glaciation involved in a glacial "till" theory for the origin of the later conglomeration, while the remains of the older and similar conglomerates—so intimately associated over a wide area with the sandstones and shales—have not been satisfactorily accounted for.

Apart from these objections, even the most ardent advocates of the powerful dynamic agency of moving ice are now beginning to recognise that, while influenced by gravitation on steep slopes, the abrading power of ice may have a wonderful grinding action; but they are far from satisfied in regard to its power to tear up, dislocate, and fracture the underlying harder rocks over which it glides, at least not to any great extent. The dislocations and fractures of the underlying rocks at Korkuperrimal, on the evidence given, do not appear to me to be the work of ice.

It is not improbable also, as regards some of the examples, that on abruptly sloping sides of creeks, the gravitating value of older conglomerates, which may have been suddenly thrust up by recent dislocations, may now partly overlie the original deposits of undisturbed older conglomerate at a lower level in their immediate vicinity. Such occurrences are common in Tasmania, where the stratified rocks of Permo-Carboniferous and Mesozoic are frequently faulted and disturbed by the forces which ejected the more recent diabasic greenstones which ramify everywhere throughout these rocks in Eastern Tasmania.

In any case, a preconception in favour of a particular hypothesis is apt to play the same tricks with the scientific imagination as it does with the imagination of unscientific sentimentalists; and in no part of a careful observer's duty is it more imperative that he should guard himself by careful

measurement of the "personal equation of error," whether due to enthusiasm or preconception, than in cases where the imagination is apt to read or project hidden foregone causal conclusions or anticipations into those facts of evidence, which, taken by themselves, are readily adaptable to any one of many possible interpretations. There is no field of geological observation where there is more avidity shown in drawing hasty inferences, and forming generalisations from imperfect data, than in that section which concerns itself with the occurrence, dynamical effects, and hypotheses of causation, in respect of former glacial action. In no field is there such assurance expressed, based upon partial or imperfect data, and in the face of the widest divergence of opinion in the interpretation of the same facts. Where sympathies are too strongly enlisted on behalf of a glacial or any other theory, they are apt to disarm the true critical faculty of the observer. He is apt to infer, too readily, that all rounded bosses and smoothed rock surfaces in the vicinity of old shingle beds are veritable *roches-moutonnées*, and that all shingle beds are *moraines*; and under this preconception he is sometimes not critical enough to distinguish the difference between the unequal wearing away of the laminations of polished stones derived from schistose rocks and the veritable *striæ* of ice action.

He is apt to magnify one of the elements which, with other links, are necessary to form the complete chain of proof—as itself the *only* element which may constitute *proof* in favour of a conclusion. As evidence of this partiality, we sometimes hear of the discovery of a single *striated stone* put forward as constituting the only *real proof* of the occurrence of former glacial action. Yet the occurrence of huge perched blocks or erratics, many tons in weight, of a rock foreign to the immediate neighbourhood, resting on a recent accumulation of a well-known rock—loam, clay, gravel, or peat—although now devoid of either polished surfaces, scratches, or grooves, may, of itself, afford more unmistakable evidence in proof of ice action of a certain age, that any number of polished, striated and grooved stones, taken from a tumbled drum of waterworn stones and clay; for the present accumulation in which the striated stones occur may not have been formed by ice action, although some of its contents may have been *derived*, immediately, from former moraine stuff; and even should the striated and polished blocks be now found in a veritable *moraine*, they do not form absolute proof that the ice markings, or at least all of them, were actually caused by the glacier which formed the moraine in which they are now found; for in many of the Scotch fiords or sea-loch basins—if we accept the theory of an inter-glacial period—we must

be prepared to find that the older moraines, in the path of the descent of the more recent glacier, would partly be dispersed, while some of its contents might be picked up, and eventually form part of the latter moraines of such districts. Thus, in respect of undoubted ice striated blocks, we must in some cases be prepared to find them as not indicating with certainty the mode of origin of the deposit in which they are now found; but, like certain fossiliferous rocks, they may have been *derived* from an older formation.

An enthusiast is also apt to attribute *all* lake basins as due to the action of glaciers, and is tempted to confound the *debris* of rocks adjacent to steep slopes of mountain due to gravitation, with superficially similar remains left in such a situation (lateral moraines) by the retreat of an ancient glacier. Of course, a typical geological sceptic may, from prejudice, err as widely in the opposite direction, and remain stubbornly unconvinced in the face of the most conclusive evidence. But, in the latter case, although the individual may injure himself, his very stubbornness may benefit geological science in causing search to be made for still more perfect evidence, and in causing the evidences already in our possession to be submitted to still more careful sifting and weighing. I have been led to make these remarks, certainly not as a reflection upon the judgment or conclusions drawn by any of the very able observers commented upon in this review, but rather as my humble apology for venturing to criticise, generally, the opinions of men of better general qualification than myself, in respect of doubtful matters where independent judgment may, without either humiliation or presumption, arrive at very different interpretations with respect to the same facts. These remarks, moreover, apply as strongly to myself in respect of the contributions, for which I am responsible, regarding the evidences in favour of glaciation in Tasmania at two widely separated periods in the history of our rocks.

Evidence of Recent Glacial Action in Tasmania.

Mr. Charles Gould, formerly the Government Geologist of Tasmania, was the first person who appears to have drawn attention to the abundant evidence of glacial action in the alpine valleys of Western Tasmania. His geological observations in these regions about 40 years ago, amid great hardships and privations, extended over a period long enough to enable him to work up the topography and to map the characteristic rocks of a very large portion of what has been, until recently, a comparatively unknown and almost inaccessible region. He has left no special memoir on the evidences of glaciation, but it was through verbal communica-

tion to a personal friend of my own,* and one of his early associates, that I first, about 20 years ago, became aware of his discovery of many evidences of glaciation in Tasmania, especially in the valleys of the western highlands, which trend westward from the great elevated plateau of 4,000 to 5,000 feet level, which occupies an area of some 400 square miles in the centre of our heart-shaped island. On its northern and western sides this elevated plateau rests upon a less elevated but still more extended plateau, whose undulations preserve a general level of from 2,000 to 3,000 feet above the sea. The extreme western and southern part of the island presents a wild and broken array of lofty mountain ranges and isolated peaks, with deeply cut ravines and valleys, but whose bases rest generally upon lower levels than the western portion of the massive central plateau. Although Tasmania does not possess any mountains of great altitude, its mountainous character may be best realised when we consider that within its limited extent (26,215 square miles) there are 20 names of mountains over 4,000 feet in height, and as many as 50 named mountains whose heights exceed 2,500 feet.

The large inland plateau which maintains a general altitude of about 4,000 feet, rising at times to over 5,000 feet, is worthy of special attention when regarding the conditions necessary for the development of a sufficiently large permanent snowfield, which would suffice to feed glaciers flowing from its marginal slopes, during a period of extremely low temperature; for great height or extremely low temperature, *per se,* does not constitute all the necessary conditions for the development of glaciers.

We must also conjoin with either of these conditions breadth of area of the névé or snow catchment, and a great local precipitation of water vapour. The necessary combinations of these requisite conditions are not dreamt of by many who too readily invoke glacial action within the Tertiary or Pleistocene period in regions where it is difficult to realise the full combination of the essential conditions necessary for its production.

The following description, already given by me in a former publication,† may help to afford the necessary information to those who may wish to know whether, in the event of a greatly lowered temperature, due to astronomical or other causes, the great inland plateau of Tasmania possesses all the other requisite conditions for the generation of glaciers:—

"The great central greenstone plateau of the Lake Country

* The Hon. Jas. Reid Scott, formerly Chief Secretary of Tasmania.

†Geology of Tasmania, p. 101.

(42° South lat.*), in its northern part especially, preserves a general rugged or undulating level of about 4,000 feet altitude, and its higher bosses and peaks and its valleys do not vary much more than 1,000 feet above or below this uniform level. From the Picton to Gad's Hill, a distance northerly of over a hundred miles, its westerly limit may be roughly traced, forming a bold and widely undulating margin relative to the western country, whose immediate general upland surface ranges between 2,000 and 3,000 feet above sea level. This margin is markedly broken by the elevated outlying spur forming the Eldon Range, near Lake St. Clair. From Gad's Hill in a south easterly direction to the Table Mountain; a distance of not less than 90 miles, its similarly indented margin presents a still bolder character as it approaches and contrasts with the lower fertile plains and valleys of the Meander and South Esk, which seldom exceed an altitude of from 600 to 700 feet above sea level.

"At the great northern and southern water divide, in the neighbourhood of the Table Mountain, it suddenly recedes and contracts, forming a large bight in the direction of the Upper Derwent tributares, notably the rivers Nive and Ouse, from which its level tends to fall, and its marginal boundaries, though frequently rising into high mountain ridges towards Mount Wellington, no longer maintains the uniform boldness of outline which characterises its northern aspect. . . Nearly everywhere along and against this plateau and the greenstone crests of Mount Dromedary, Mount Nicholas, Eldon Range, Mount Gell, Grass Tree Hill, Constitution Hill, and most of the elevated south-eastern dividing ranges, the various members of the Carboniferous (Permo-Carboniferous) and Mesozoic rocks are seen to repose invariably in a horizontal position, or, at most, with a very slight dip towards or away from them."

From this description it will be apparent that, given a period of extremely low temperature, the great elevated plateau of Tasmania possesses, in a special manner, a great width of space at a high level for the formation of an extensive snowfield. It is also significant that in its present western margin, in the vicinity of the mountain valleys, where evidences of former glacial action are so abundantly manifest, there is now even the greatest amount of rainfall. This is shown by the records at the stations at Corinna, Strahan, and Waratah, on the western aspect, as contrasted with the records of Great Lake, Ross, Oatlands, and Bothwell, towards its eastern limits, as in the following table:—

*A height of 5,000 feet in this latitude would have an inland temperature of that of nearly 6,500 feet altitude in the region of the Australian Alps.

WESTERN RAINFALL (1890).

Station.	Altitude feet.	Annual rainfall (inches).	Maximum month.
Corinna ...	15 ...	69·50 ...	October
Strahan ...	20 ...	51·39 ...	October
Waratah ...	2,000 ...	76·45 ...	October
Mean ...	...	65·78	

EASTERN RAINFALL.

Great Lake ...	3,822 ...	34·64 ...	June
Ross ...	580 ...	19·95 ...	June
Oatlands ...	1,337 ...	23,48 ...	June
Bothwell ...	2,000 (?) ...	23·63 ...	June
Mean ...	...	25·42	

So far as we can judge from existing meteorological conditions, which show that precipitation on the western portion of the plateau is nearly three times the amount of that in its eastern portion, it is obvious that if astronomical causes produced a lowered temperature in the Southern Hemisphere during the last period of maximum eccentricity, combined with winter in aphelion, the greatest precipitation of snow would take place near to the western margin of our great mountain plateau, and would there, probably, collect in sufficient mass to outweigh the short, hot summer melting, and to supply its western alpine valleys with numerous ice streams or glaciers; and while, therefore, supplying *prima facie* evidence of favourable conditions for the development of glaciers on the west, it is also suggestive as an explanation of the apparent total absence of evidence of glaciation on its eastern slopes, where the summer melting might exceed the amount of precipitation. In any case, it adds greater force to conclusions drawn from the positive evidences of glaciation observed by various persons in the alpine valleys of our western highlands, a brief account of which may now be given in chronological order.

EVIDENCES OF GLACIATION IN THE ALPINE VALLEYS OF WESTERN HIGHLANDS OF TASMANIA.

I have already alluded to Mr. Charles Gould's observations, made about 40 years ago, of abundant evidence of the usual dynamic effects of ancient glaciers in the principal alpine valleys of the western highlands of Tasmania, although it is to be regretted that this most accomplished observer, so

far as I know, has left no special memoir of his extended observations on this subject.

In the year 1874, in company with the late Honorable J. A. Scott, W. C. Piguenit, Lieut. Burgess, and two other persons, I spent six weeks (all of the party laden with knapsacks weighing from 60 to 70 lbs.) in exploring the whole of the south-western region of the western highlands lying between the mouth of the Huon and Macquarie Harbour, and in making collections and observations on the geology and botany of this region. In the year 1879 I formed one of a similar party in exploring the northern region of the western highlands, including Gad's Hill, Middlesex Plains, Vale of Belvoir, Valentine's Peak, Mount Bischoff, head waters of the Mackintosh Valley, and other tributaries of the Pieman and Arthur.

In the year 1887, in company with my friend, the late C. P. Sprent, Deputy Surveyor-General, and five others, I traversed, on foot, and examined the whole of the region lying near to the route across the island by way of the Ouse, Bronte, Lake St. Clair, Mount King William I., Mount Arrowsmith, Collingwood Valley, King River, Mount Lyell, Queen River, Macquarie Harbour, thence northward across the Hentys, Mounty Heemskirk, Corinna, Whyte and Hazlewood Rivers, Magnet Range, and Mount Bischoff, to Emu Bay on the North-West Coast. I had the opportunity at this time to visit many of the lakes, including Lake Dixon, and to spend three days in examining more particularly the rock formations on Mounts Owen, Lyell, and Sedgwick.

I had thus ample opportunities for observing the many evidences of former glaciation in these regions, enabling me to confirm the earlier observations of Mr. Gould, and also enabling me to record the general results of such observations in my work on the "Geology of Tasmania," begun in the year 1884, and published in the year 1888. I only gave my general conclusions in this work, although my notes contained particulars regarding the abundant occurrence of moraines, *roches-moutonnées*, scooped tarns and lakes innumerable, huge ice-born erratics, polished rock surfaces, etc., in many localities; notably in the Gorge descending from Scott's Peak in the centre of the lofty and picturesque Arthur Ranges, and along the Alpha and other tributaries of the Craycroft and Huon River; in deep gorges descending from Mount Wedge towards Lake Pedder and the Serpentine; on the neighbouring slopes of the Frankland Range; in deep upper gorges and valleys of the tributaries of the Mackintosh River leading from Granite Tor and Barn Bluff; but particularly in the romantic valley of the Lakes Dixon and Undine, at the source of the Franklin, in the immediate

vicinity of Mount Gell and Mount Hugel. The valley of Lake Dixon is, *par excellence*, the ideal of a perfect glacier valley. No one, however ignorant of glacial action, could in this neighbourhood gaze upon those beautiful scooped, or rather abraded, lakes or tarns (many with islets, as also observed by Mr. Montgomery in the region of Barn Bluff and Mount Pelion); the snow-white, polished, billowy, and cascade-like *roches moutonneés*, composed of quartzites, on the upper margin of Lake Dixon, together with the tumbled moraines and large erratic on the lower banks—at a level of about 2,000 feet—without being impressed with the idea that its singularly characteristic features must have been produced by the slow rasping flow of an ancient river of ice.

The numerous beautiful lakes, many with wooded islets, on the lap and all around the base of the steep slopes, as at Mount King William I., the beautiful Lake Augusta under Eldon Bluff, Lake Petrarch in the romantic Cuvier Valley, lakes and lakelets near Mount Hobhouse, and southward in the Valley of Rasselas, as well as the clusters of lakelets at the head of Traveller's Rest, and other sources of tributaries of the rivers Derwent, Gordon, King, and Pieman, are all eminently suggestive of being originally carved or sculptured by ice action during a former glacier epoch in Tasmania.

The abundance of conclusive evidence so impressed me, that when I referred to them in the descriptive part of "The Geology of Tasmania," I was content to summarise them merely as a general confirmation of the previous observations of Messrs. Gould and Sprent. Thus, at p. 164, in referring to the remains of our coal measures on the western crests of the Great Plateau, I state: "From information obtained from the Hon. J. A. Scott, now deceased, and from the appearance of their bold stratified cliffs, as seen by the writer from Mount Arrowsmith, it would seem that, like the coal seams at Ben Lomond, Mount Nicholas, and Fingal, the coal measures of this basin are the remains of a deposit of considerable thickness and extent, lying at the higher levels against the flanks of elevated peaks of the ancient greenstone, that is, above the marine beds which also occur there in the same relative position as the places already mentioned. It is evident that the valleys intervening between the great greenstone plateau and the neighbouring isolated greenstone peaks have been carved out of this upper deposit and the underlying (Permo-Carb.) marine beds. The work of denudation has been so vast that only fragments of this once more widely extended system, abutting against (or underlying) the greenstone, now bear evidence of their original extent. Both Mr. Gould and Charles Sprent bear testimony to the fact that *glacial action* at one time must have been an important

agent in the denudation of the immense cañons or gorges which trend away from the elevated plateau westward. Mr. Sprent informs me that for a great distance along the bed of the Mackintosh River, which suddenly cuts its way to the lower levels towards its main artery, the Pieman River, are to be found immense blocks of granite, some of which are many tons in weight. These granite blocks are truly *erratic*, as the granite is not now to be found *in situ* anywhere along the present course of the river. It is probable that the former have been derived from glaciers which descended into the lower valley from the direction of Granite Tor, whose summit still rears its head 4,500 feet above the existing sea level." At pp. 216, 219, 254, 255, 256, and 296 there are also extended references attesting the prevalence of evidence as to the local glaciation of the western Alps of Tasmania during the glacier epoch of Australia.

Mr. C. P. Sprent began his laborious explorations in the north-western highlands in the year 1875. No one had a more intimate knowledge of this wild country, for he was the pioneer who first opened out the greater part of this country to miners, by a process of track-cutting almost like tunnelling in the horizontal, bauera, and other scrubs—the terrible barriers to progress in this region. In 1876 he particularly observed the striking evidences of glacial action in the alpine regions of the west; but, although he gave me, verbally, almost graphic descriptions of these evidences, it was not until the year 1886 that he gave a brief written description* of his observations made ten years previously. At p. 58,* he thus refers to evidences of glaciation observed by him in the year 1876 in the Mackintosh Valley: "At the place where I struck the Mackintosh there are two immense cliffs standing a little back from the river, and at least 600 feet high. Looking at these cliffs from above or below stream they look like two small mountains; but from the top of the gorge they are completely lost in the dark shade of the slope. The river bed is full of immense rounded boulders of granite, although I could not ascertain that any occurs *in situ* thereabouts. The cliffs are of sandstone, and, judging from all appearance, I am of opinion that this deep gorge represents the track of an ancient glacier flowing down from the vicinity of the Cradle Mountain and Barn Bluff. *Traces of glacial action are common all over the West Coast in localities close to high mountains, but it is probable that these glaciers did not descend to the lowlands. The granite boulders of the Mackintosh are of a very large size, some at least five tons in weight, and it s impossible to account for their presence except on the glacial*

* "Recent explorations on the West Goast of Tasmania," by C. P. Sprent, (Trans. and Proc., Roy. Geo. Soc. of Austral., Vic. Br., Vol. III.—IV.

supposition." He then proceeds to state: "On the sides of the gorge there are many small boulders. In one I found a quantity of carbonate of copper. I had not sufficient time to search for striated markings on the rocks, but my impression was confirmed in later years by the *account of Mr. W. R. Bell, who described the position of the moraine of this ancient glacier. The same indications are to be found in the King River and the Franklin River.*"

It is evident, therefore, that the recent account of all the characteristic phenomena of glaciation observed in 1892 and 1893 by Messrs. Dunn and T. B. Moore* in the same region, that is in the neighbourhood of Mounts Tyndall, Sedgwick, and Murchison, and charted so clearly on Mr. T. B. Moore's accompanying maps, confirm Messrs. Gould, Sprent, and Bell's earlier observations; and although the later observers, Dunn and Moore, write as if they were unacquainted with the much earlier observations of the persons named, as well as of the descriptions to be found in my work on the Geology of Tasmania, it does not detract in the smallest degree from the valuable *additions* which they have made to our knowledge of the evidence of former glacial action in the alpine regions of Western Tasmania.

The occurrence of what appears to be the older conglomerates, so closely associated with newer drifts, and also bearing ice marks, according to Dunn and Moore, and which may possibly be local representations of the *debris* of floating or partly stranded ice sheets, so abundantly manifested in rocks of Permo-Carboniferous age, in South-Eastern Tasmania, and also in similar rocks in Victoria (Bacchus Marsh), and New South Wales, suggest doubt as to whether some of the moraine stuff, found on the flanks of western mountains, upon whose crests this older conglomerate rests, may not be confounded at times with the true moraine stuff of the more recent glacier epoch; for it is possible that recent disintegrations of the older ice-marked conglomerate, gravitating over the steep slopes, may also be largely represented, and sometimes mixed up with the more recent moraines. It is barely conceivable, however, that the older conglomerate would still preserve the finer marks of scratches, striæ, or groovings; but if the less perishable rocks were, until recently, preserved undisturbed in some peculiarly favourable matrix, it is conceivable that some traces of *original* markings might still remain unobliterated.

There is one or two facts of very great importance disclosed by Mr. T. B. Moore's charts and observations which

* "Discovery of Glaciation in the vicinity of Mount Tyndall, Tasmania." By T. B. Moore. (Roy. Soc., Tas., 1893).

deserve special attention. First, as regards the height up to which the marks of glaciation are found, Mr. Moore informs us that the surface of the conglomerates, within 25 feet of the summit of Mount Tyndall, is polished and striated, that is, at an altitude of 3,850 feet. It is evident here that the collecting ground for the snow to generate glaciers in the small remaining peak of 25 feet would not of itself adequately account for these higher polished surfaces, nor for the supply of glaciers on all sides which shed such extensive moraines as those lying all around Lakes Rolleston, Garnet, Dora, Dunn's Boss; and, similarly, the small portion of Mount Sedgwick remaining above the original névé would not, of itself, adequately account for its higher glacial markings, nor for the extensive moraines around Lake Margaret, Hamilton Moraine (enclosed by a circular belt, Basin Lake), Lake Spicer, etc. The general trend of striæ may as readily on lower levels have the arrow head of lineal direction turned the other way. Is it not conceivable that the great elevated catchment basin of the great plateau, a little further east, may have sent down, by the existing deep channels of the North and South Eldon, its far mightier glacier streams, which, obstructed partially by the slightly elevated plateau of Lake Spicer and Lake Dora, might, nevertheless, ride over them, abrading and scooping out the basins of the present lakes and lakelets in the line of their path, until they were finally stopped by impact and convergence with whatever local glaciers flowed from the crests of Mount Sedgwick and Mount Tyndall, and thereafter their united streams, producing the large accumulation of moraine stuff on the 2,182 to 2,400 feet plateau at their bases, and at their arrested or final melting points? These remarks, however, are merely suggestive, and are mainly occasioned by the difficulty of adequately accounting for the moraine stuff and the extent of the glaciers, when so small a collecting ground remains above the ancient névé or snow line on the caps of Mounts Tyndall and Sedgwick. At any rate, Mr. Moore has supplied us with most valuable evidence which help towards the solution of these and other difficulties, and his topographical charts of the leading features of this interesting neighbourhood are simply invaluable to anyone who wishes to study them. The prevalence of moraines at the 2,000 feet level, both here and Mount Pelion and Lake Dixon, indicating generally the retiring points of the principal glaciers, are very significant, and strongly support my former views as to the absence of evidence of glaciation in the lowest levels, and also as to the probability that none of our Tasmanian glaciers ever reached the sea.

The able paper by Mr. A. Montgomery, M.A., Govern-

ment Geologist, which has been read to us this evening, I had the privilege of reading beforehand. It contains a very interesting account of his recent geological observations, many of which are new and extremely interesting; but, above all, it not only greatly extends our knowledge of glacial phenomena in Tasmania, but we have also a valuable examination of all collateral evidences, which bear directly or indirectly on the possible extent of glaciation in Tasmania generally during the glacial epoch, its intensity, and its cause; and upon the whole I am gratified to find that his extended and independent inquiries lead him to a conclusion similar to my own, viz., that although refrigeration of our climate was sufficiently intense during the glacial epoch to produce streams of glaciers upon our alpine regions in the west, and possibly in other mountains further south, he is inclined to believe that the refrigeration was not so intense as to cause the ice to invade the levels of our lowlands. He seems disposed, however, to expect the initiation of snowfields and glaciers in isolated mountains further east, but I have given my reasons already why I incline to think that the smaller amount of precipitation, and possibly the milder local climate of the eastern part, may have combined to turn the balance of summer melting against winter precipitation, and so cause a pluvial epoch, at most, in Eastern Tasmania. This inference, in my opinion, would harmonise more closely with all the known facts, and particularly with the total absence of any clear signs of glacial phenomena among our pluvial terrace drifts in the lower levels of Eastern Tasmania.

Mr. Montgomery is also inclined to ascribe a greater denuding power to glaciers in the formation and deepening of mountain valleys and ravines than I am myself disposed to allow. I admit they are very important agents in intensifying the great work of denudation in mountain valleys, whose channels have already been deeply cut by flowing water; but, on the whole, the real carver of valleys and ravines, and the great waster of land surfaces is great precipitation, the more mobile gravitation, and the infinitely greater dissolving power of water in motion. Valleys originally formed by water agency determine the course which glaciers have followed, rather than that glaciers have determined and cut out the channels of valleys in which they have been known to occur. I am also of opinion that the greater denudation of the western slopes of the great greenstone plateau—which, in my work, "The Geology of Tasmania," I inferred that it extended, probably at the close of the Mesozoic age, westwards as far as the West Coast Range, which it partly embraced—was effected, and the leading features carved out, much as they are now found, long prior to our glacier

epoch, and this denudation must have been in constant and intense operation ever since the upheaval of the plateau. Even if we allowed only a period of $2\frac{1}{2}$ millions of years to have elapsed between the upheaval of the great greenstone plateau, while allowing a waste at the average estimated rate of one foot of rock in 3,000 years, we must also allow that denudation, especially that powerful form of eating back against water courses, would have removed a quantity of matter—from its ravines especially—equivalent to *a uniform depth of* 833 *feet over its whole area*; and this estimate in such an elevation is probably far too low. The denudation, which has been effected even since the earlier glacier epoch relatively, *could not be a third of this amount*; and since the maximum stage of the glacial epoch, 210,000 years ago, probably *not a tenth* of the amount of denudation which must have been effected prior to the later glacial epoch.

The probability that our valleys would originally eat inward in cuts against the vertical faces of the elevated plateau also invalidates any inferences drawn from the latest cuts made in its watercourses far in the interior of the upland regions; for the beginnings or initial stage of a valley system at its original outer edge would give widely different results. However this may be, Mr. Montgomery's observations of recent action are valuable, although some of the inferences drawn by him may not apply as widely as he may be inclined to consider at the present moment. In the greater number of conclusions formed by him, however, I cordially concur. The evidence given by him of glacial phenomena in the vicinity of Mount Pelion and Lake Eyre are particularly full and clear, and leave not the slightest doubt as to their genuine character. His demonstration of the existence of glaciers flowing from the elevated regions of Barn Bluff and Mount Pelion (whose peaks are fully 1,000 feet higher than Mount Tyndall), of their discharge of moraine stuff, of their singularly perfect *roches-moutonnées*, and erratics at the 2,000 to 2,792 feet level near Lake Eyre, is simply complete and unassailable. His paper, as a whole, is the most comprehensive contribution which I have yet seen as regards the whole question of glaciation and its supposed cause, so far as Tasmania is concerned. I do not here refer to Mr. Montgomery's views as to the causes of the glacial epoch further than to remark that he adopts in the main the view which requires the concurrence of astronomical and favouring geographical and physical causes, a view which I myself have adopted in "The Geology of Tasmania."

The whole subject of causation is treated separately hereafter.

Evidences of Great Glacial Epochs Concurring with Great Cycles of Change in Organic Life, and also Concurrently with Exceptional Terrestrial Disturbances.

The adoption of the astronomical theory as the *sole* cause of glacial epochs throughout all time naturally excited a prejudice against it in the minds of many able geologists, because the known records of the rocks, with the exception of, perhaps, the last two great cold epochs—viz., "The glacier epoch of Australasia," at the beginning of the Pliocene (Neogene of Tasmania), and the "ice age" of Europe and North America, in Pleistocene age—there is not the feeblest evidence of glacial phenomena intercalated within the sedimentary formations, even going as far back as the close of Permo-Carboniferous times. This utter lack of correspondence with the frequent recurrences of periods of maximum eccentricity of the earth's orbit with winter in aphelion in any one hemisphere every 21,000 years, through all this time, certainly appeared to demonstrate that the astronomical theory *alone* could not adequately account for the facts.

The "*imperfection of the record*" theory of effacement which was sought by Sir Robt. Ball and others to form a buttress to it, breaks down completely when closely and widely inquired into. But perhaps the greatest blow to the "*imperfection of the record*" theory of effacement in attempting to show harmonious reasons for the total absence of glacial phenomena in the tertiary rocks generally—in Europe at least—corresponding to recurring cycles of eccentricity, is the discovery of glacial phenomena, consisting of vast beds of striated conglomerates, polished rocks, perfect *roches-moutonneés*, and huge ice-borne erratics in the rocks of *Permo-Carboniferous* age, of nearly all countries in both hemispheres; and thus even showing a greater universality of broadly contemporaneous intense glacial conditions than was exhibited during the last "ice age" of Europe and North America in the Pleistocene period. For, surely, if obliteration by denudation, carried on over a long period, was considered to be an adequate reason for the removal of all traces of glacial action in the earlier Tertiary rocks of Europe, the actual preservation, *universally* of abundant and undoubted glacial phenomena in the much more remote *Permo-Carboniferous* rocks, during such a vastly greater period of time, utterly collapses the "*imperfection of the record*" theory of effacement, as applied to the secondary and tertiary rocks.

The older glacial epoch of *Permo-Carboniferous* age, together

with the glacier epoch of Australia in the early Pliocene, and the later "ice age" of Europe and North America in Pleistocene age, are undoubtedly thus shown to be truly exceptional conditions recurring irregularly and not concurrent with the comparatively frequent cycles of the earth's eccentricity, *except at very wide intervals of time*, when, probably, the peculiar combination of astronomical, physical, and geographical causes combined to produce those extreme and exceptional conditions, corresponding to the three almost universal glacial or cold epochs, of which the rocks contain the most abundant and undoubted evidence.

Glacial Epochs Harmonising with Great Cycles of Change in the Plant Life of Australia and Tasmania.

The acceptance of the "*exceptional occurrence*" view of glacial epochs is also strongly corroborated by the great cycles of organic changes, especially as regards plant life.

Thus, about the time of the glacial epoch of *Permo-Carboniferous* age, the original flora of Australia and Tasmania consisted, mainly, of the following characteristic genera, viz., *Glossopteris*, *Gangamopteris*, *Noeggarathiopsis*, *Schizoneura*, *Lepidodendron*.

After the *Permo-Carboniferous* glacial epoch, corresponding to the ushering in of the milder Mesozoic age, the old flora of *Permo-Carboniferous* age suddenly died away completely. *Not a vestige remained!* The Mesozoic rocks then became almost suddenly characterised by the abundance of the following plant forms, viz.:—*Pecopteris*, *Neuropteris*, *Sphenopteris*, *Thinnfeldia*, *Cyclopteris*, *Tæniopteris*, *Odontopteris*, *Sagenopteris*, *Alethopteris*, *Phyllotheca*, *Annularia*, *Podozamites*, *Pterophyllum*, *Otozamites*, *Sphenozamites*, *Brachyphyllum*, *Taxites*, *Sequoites*, *Walchia*, *Cunninghamites*, *Araucarites*, *Baièra*, *Salisburia*, *Ginkgophyllum*, *Zeugophyllites*, (Poa-cordiates).

At the close of the Mesozoic age in Tasmania all its rich and varied flora in its turn disappeared, or "yielded to the great law of death;" and although for the most part no marine beds intervene between our Upper Mesozoic rocks and the immediately succeeding Lower Tertiary leaf beds, the flora of the latter were "brought to the birth and ushered upon the scene" suddenly, and appearing locally as if a new creation. But it is significant that this sudden change *is exactly isochronous* with an unparalleled eruption of igneous rocks (later greenstone) concurrent with widespread convulsions of the older strata. These greenstones even now are so widespread as to form the leading physiographical features

throughout the mountains and lowlands of the island. At the time of eruption, probably recurring at intervals over a long period, it seems as if the conditions for plant life were everywhere impossible. There is no evidence at this time of glacial phenomena,* but as Mr. J. S. Gardner has arrived at the conclusion, from the study of fossil floras and "strong negative and positive evidence," that, although there were no intense glacial effects, there were alternating warm and colder conditions produced, most probably due to astronomical causes alone, and therefore it seems probable that our great eruptive period, which destroyed our *Mesozoic* flora, may have been concurrent with a cold epoch,* due perhaps to less intense eccentricity of the earth's orbit, and thus showing a correspondence with the next great eruptive period (basalt) which, concurring with more potent astronomical and geographical conditions, during our glacier epoch at the commencement of our Neogene period (Pliocene), the whole of our rich and varied Tertiary flora was similarily suddenly and almost completely destroyed, locally at least.

These three great changes in our flora, therefore, corresponding with the exceptional glacial epochs, and also corresponding closely with the periods of great physical convulsions, go to show that there is an underlying bond of connection with exceptional concurrences, at remote intervals, of astronomical, physical, and geographical causes,† and that the combination of the three latter causes is essential to the initiation of conditions which produce glacial epochs contemporaneously in widely separated parts of the globe. The universality of glacial action towards the close of the *Permo-Carboniferous* age is testified by the following observations of their occurrence in rocks of different countries.

Evidence of Glacial Action in Rocks of the Permo-Carboniferous Age.

Tasmania.—It is fully nine years ago (1884) since I first communicated to the Royal Society of Tasmania my discovery of evidences of ice action in the rocks of Permo-Carboniferous age at Maria Island. In the year 1886 I made a further discovery of similar evidences of ice action in the shape of huge erratics and polished blocks of the harder rocks foreign to the neighbourhood, in the same formation, at One Tree Point,

* Dana recognised the close of the cretaceous period as "an epoch of cold."

† This conclusion is in harmony with the originally expressed opinions of Agassiz and Dana, according to Dr. Wallace's account (p. 222—"Island Life)." "Agassiz appears to have been the first to suggest that the principal epochs of life extermination were epochs of cold; and Dana thinks that two at least of such epochs may be recognised at the close of the paleozoic and of the cretaceous periods." To which we may certainly in Australasia add a third at the close of the paleogene period (miocene) concurring with the great glacier epoch of Australasia.

Bruni Island. Since that time I have obtained abundant evidence in rocks of the same age throughout South-eastern Tasmania.

Everywhere these ice-borne conglomerates and erratics are found in more or less barren layers of the *lower marine* beds, locally known as "Mudstone Rocks." In places, however, as at Beltana, near Hobart, Bedlam Walls, Blackman's Bay Heads, Variety Bay, Adventure Bay, Esperance, and Eaglehawk Neck, the dropped erratics and conglomerates are associated in dense white or yellow, close-grained mudstones, with the following organisms:—

Spirifera Darwinii	*J. Morris.*
,, Strzelecki	*de Kon.*
,, convoluta	*Phillips.*
,, glaber	*W. Martin.*
,, tasmaniensis ...	*J. Morris.*
Terebraluta sacculus	*J. de C. Sow.*
Sanguinolites Etheridgei ...	*de Kon.*
,, undatus ...	*J. D. Dana.*
Pachydomus carinatus ...	*J. Morris.*
Edmondia ovalis	*R. M. Johnston.*
Aviculo-Pecten limæformis ...	*J. Morris.*
Tellinomya Etheridgei ...	*R. M. Johnston.*
Platyschisma occula	*J. de C. Sow.*
Orthonata compressa	*J. Morris.*
Astartila cytherea	*Dana.*
Theca lanceolata	*J. Morris.*
Goniatites micromphalus ...	*J. Morris.*
,, strictus	*Dana.*

Also, among other forms, a stray fragment bearing a clear impression of the well-known fern, *Gangamopteris spathulata*, M'Coy.

The erratics generally are found in the middle or lower horizons, and are nowhere associated with the fine laminated zones almost wholly made up of the remains of the common lace-like Fenestellæ. There can be, therefore, no possible doubt as to the age of the rocks in which the ice-borne conglomerates and erratics occur.

For the most part the polished or angular pebbles, boulders, or angular blocks, occur singly, embedded in what must have been, at the time of deposition, an exceedingly soft, fine homogeneous mud, showing in these beds scarce a trace of lamination. In some places, however, they occur in thin lenticular patches as an irregular conglomerate bed. The rocks are either polished or angular pebbles, or blocks grading from small pebbles to blocks over a ton in weight, principally composed of various kinds of granite, gneiss, quartzites, mica-schists, slates, quartz-rock, all being rocks

foreign to the localities in which they are found. The larger erratics, composed of granite or quartzite, generally occur singly, and appear as if they had been quietly dropped upon the soft muddy floor from floating ice. The polished sides of many of them plainly indicate ice action, and certainly the huge single granite and quartzite blocks found at Beltana, One Tree Point, Bruni, Bedlam Walls, and Maria Island, weighing respectively from half a ton to over a ton, could not have been transported to their present position in the original soft muddy bottom of the ancient and comparatively shallow sea floor, except by the agency of floating ice. Although here no favourable conditions occur for tracing fine markings of striæ or groovings, the cumulative evidence, otherwise, is certainly conclusive in referring the transport of these conglomerate and huge erratics to ice agency.

The mudstone beds in which the erratics occur are now everywhere cross-jointed in the most curious fashion.

At Eaglehawk Neck, at a place famously known to the curious sight-seer as the "Tesselated Pavement," the wonderful regularity of the cross-jointing is marvellously perfect. It is curious to observe that, whether the jointing be perfect or irregular, they cut through small, hard, polished pebbles or quartz blocks as though they formed a perfectly homogeneous substance with the now hardened mudstone matrix. In the large granite erratic, over half a ton weight, on the shore at Beltana, several joints, some fine as a hair, others coarse, continuous with those of the mudstone, meet and intersect in the solid grey granite and divide it as completely as in similar cross jointings in the now homogeneous, hard, and siliceous mud rock itself. This feature of the cross-jointing is constant everywhere in the planes in which the erratics occur.

It is possible that some of the thick conglomerate beds occurring in the vicinity of Mount Tyndall, Mount Lyell, and Mount Owen, in which marks of ice action are reported to have been recently discovered by Messrs. Dunn and Moore, may yet prove to belong to the same horizon.

Australia.—What is known among Australian geologists as the "glacial conglomerates" of Victoria, and occurring at Bacchus Marsh, Wild Duck, and in other places in Victoria, are the best evidences in Australasia of glacial action on a large scale in rocks deposited towards the close of the *Permo-Carboniferous* age. It is now about 27 years ago since these ice-borne conglomerates were first referred to this mode of origin by Sir R. Daintree, whose view of their mode of origin was soon after confirmed by Dr. A. R. C. Selwyn. R. D. Oldham, in the year 1886, further confirmed the conclusions of Daintree and Selwyn, and correlated the deposits with similar glacial phenomena occurring in the Newcastle beds, New

South Wales, and with the Talchir and Salt Range ice-borne conglomerates of India, whose position is known to be of Permo-Carboniferous age. Other observers, notably Mr. J. E. Dunn, F.G.S., have conclusively shown by the abundant proofs of glacial action that the conglomerates of this region have been transported thither by floating ice, as in the case of the conglomerates and erratics of a similar horizon in New South Wales and Tasmania.

Mr. Dunn states that the conglomerate is spread over a wide area on both sides of the dividing range, and particularly at Bacchus Marsh, Wooragee, Wahgunyah, Rutherglen, The Springs, El Dorado, Tarrawinga, Badaginnie, Wild Duck Creek, Carisbrook, and the Gordons. Its thickness is stated to be over 100 feet at Bacchus Marsh and in a shaft at Wooragee.

It contains granites in great variety, gneiss, schist, quartz rock, etc., the great mass being derived, as in Tasmania, from schistose and other ancient rocks. The material, Mr. Dunn states, "ranges in size from the finest silt up to great blocks several feet across, and weighing in some cases *probably from* 20 *to* 30 *tons*.

"From the well rounded, almost polished pebble boulder to the rough angular fragment of rock that has been torn from its parent mass, and not subsequently abraded, all are represented in these conglomerates." Elsewhere Mr. Dunn states that "Not only are the pebbles, etc., scored and scratched, but great numbers are rubbed on one or more sides (facetted)." From the occurrence of the same genus of ferns (either *Glossopteris* or *Gangamopteris*) occurring in similar ice-borne conglomerates in the Dwyka's or Ecca beds of South Africa and in New South Wales, Mr. Dunn believes them to be of the same age, *i.e.*, *Permo-Carboniferous*.

Other Countries.—Similar evidence of glacial action in the corresponding *Permian* of England has long been made known to geologists by Mr. Ramsay.

Thus in England; Talchir and Salt Range, India; Dwyka conglomerates, South Africa; Bacchus Marsh conglomerates, Victoria; and in similar conglomerates in New South Wales and Tasmania, we have abundant evidence in rocks of the same *Permo-Carboniferous* age in widely separated regions of both hemispheres, that a general refrigeration of climate occurred near to the close of the *Permo-Carboniferous* age, indicating *that a general refrigeration of climate of great intensity existed, probably due to exceptional combination of astronomical, physical, and geographical causes, as in the glacier and glacial epochs of Pliocene and Pleistocene ages respectively; and we may, therefore, safely term the older period in which such phenomena has occurred—the ancient glacial epoch of Permo-Carboniferous age.*

The Causes of Glacial Epochs.

Mr. Scarles V. Wood, jun., enumerates no less than seven different causes which have been advanced, more or less strenuously at various times by different persons, to account for the marked changes in climate of which the record of the rocks bear unmistakable evidence. These are—

1. A decrease in the original heat of the planet.
2. Changes in the obliquity of the ecliptic.
3. Changes in the position of the earth's axis of rotation.
4. A variation in the amount of heat radiated from the Sun.
5. A variation in the temperature of space.
6. The combined effect of the precession of the equinoxes and of the eccentricity of the earth's orbit.
7. Changes in the distribution of land and water. To these we must add another, or rather the combination of the last two, as ably put forward by Dr. Wallace in his "Island Life," viz. :
8. A particular distribution of geographical and physical conditions operating concurrently with high eccentricity of the earth's orbit with winter in aphelion.

As regards the first five supposed causes, I follow Dr. Wallace in rejecting them on the grounds that they are either inadequate, taken singly or in combination, to explain the whole of the known phenomena associated with glacial epochs, or there is no geological evidence which reveal their occurrence.

There remain, therefore, only two, taken singly with the third, which demand their causal concurrence.

Before entering upon a discussion as to the efficiency or otherwise of the principal hypotheses which would at least explain the observed dynamic effects of former glaciation, and which, after all, are the only phenomena that require special explanation from a geologist's point of view, it is necessary to mark strongly the distinction between (1) a period of abnormally *low temperature* in a given region, and (2) glacial action, *per se*, in the same region. In ordinary discussions on probable causes of glaciation the two ideas are mixed up, or appear to signify the same thing, and consequently not a little of the antagonism between some of the advocates of the *geographical theory* and the *astronomical theory* respectively is due to the lack of precision with which they grasp the essential differences which exist between them.

The mere lowering of temperature throughout the various zones of isotherms of any one hemisphere during a period of extreme eccentricity with winter in aphelion, as first demon-

strated by the late Dr. Croll, and as lately confirmed and amplified in some particulars by Sir. Robert Ball and others, would no doubt cause the limits of the polar ice cap to extend considerably towards the lower latitudes. But this result would not of itself involve the dynamic effects of glaciation without (1) the agency of highlands, and (2) without sufficient precipitation of moisture to turn the balance in each separate locality against the loss by melting during the short but excessive heat of summer. Inasmuch also as the now depressed isochional of the névé or snow line, the result of the astronomical cause, would still continue to rise in height towards the Equator, there would (3) still be a point or isothermal line towards the Equator, beyond which the lowered temperature, from astronomical causes, would be inadequate to produce the freezing of water vapour near to the earth's surface, even in cases where the latter attained to a considerable height, yet falling short of its still more elevated snow line isochional.

On the other hand, the evidences of former glaciation in any one place are only direct proof that the particular area affected was formerly subjected to conditions involving a temperature at or below 32° F., but they do not directly determine whether the area so affected was mainly influenced by (1) a general change in the regional temperature of that place, due to astronomical causes; or (2) by geographical and physical causes which, subsequent to the glacial action, of which evidence remains, may have operated in lowering the mountain cap below the influence of normal temperature of the existing snow line isochional, above which it may have formerly reared; or (3) by alteration in the distribution of land and water in the same region, and thereby altering the thermal currents of air and ocean, whereby the isotherm of a former climate, as in Labrador, may have been changed—with or without the conjunction of astronomical causes—to an isotherm like that of Ireland. Notwithstanding all such qualifications which arise in the mind when dealing with the milder and detached examples of former glaciations which occur on the border line of latitudes lying almost beyond the scope of the astronomical cause to produce intense meteorological changes—as on lowlands in lower latitudes—it is almost conclusive that it would require a general astronomical cause, in combination with the geographical, to account for that intense form of glacial action which repeated itself after a small geological interval of time in Northern Europe, and in North America, during the pleistocene period. How far any one of these causes would fail to account for all the known evidence of glacial phenomena in the younger rocks of both hemispheres is best realised when we consider the matter more closely.

The Objections which Suggest Themselves when Attempting to Explain the Phenomena of Glaciation in both Hemispheres by reference to the Astronomical Theory taken by Itself.

As my object is to go straight to the root of the difficulty of explaining the intense form of glaciation over Northern Europe and North America during the pleistocene period by reference to the astronomical theory *alone*, I will at once grant that the necessary amount of precipitation and vapour, the thermal currents of air and ocean, the elevation of the land, the distance of inland regions from vapour-producing sources, and the difference in latitude, would result in producing all those variable effects upon isotherms and amount of snowfall within the same latitude as they are known to do at present; although we must anticipate greater intensity of effect, and a greater extension of the isotherm of frost at sea level, together with a general lowering of the snow level or névé.

Thus, though it must still be contended that geographical and physical causes would continue to operate in producing some such variations in isotherms, and in the variableness of the distribution of snow, even in the same latitude, or even in different faces of great physical barriers such as lofty mountain chains, it is still quite conceivable that the astronomical cause alone might adequately account for the glacial epoch of Europe and North America, as well as for the milder effects of glaciation exhibited in the rocks of Australia.

The real difficulty to the acceptance of the adequacy of the astronomical theory, *taken by itself*, is as much due to its lack of consistency with astronomical facts as it is to its inadequacy to explain the facts of geology, and in the latter case—not so much as regards positive evidence in respect of glacial effects actually *preserved in our rocks*, as for its inadequacy to explain the *absence of glacial effects* at numerous points within the tertiary period corresponding with the cycles of extreme eccentricity* of the earth's orbit combined with winter in aphelion; many of which were as great, and, at two cycles, enormously greater than in the pleistocene period, where alone correspondence appears to occur. To be consistent with itself, therefore, it must demand that similar effects of glaciation in both hemispheres in the same latitude, or nearly so, should be produced at intervals, and in intensity corresponding with the recurrence of

* This is on the assumption that Dr. Croll's calculations of periods of eccentricity calculated for the last 3 millions are relatively correct, if not absolutely so; and that there were many cycles within the cainozoic age alone, two of which were enormously greater than the last, which is supposed to correspond with the glacial epoch of pleistocene age.

astronomical periods of extreme eccentricity with winter in aphelion, alternately every 10,500 years in each hemisphere. *There is not, however, the slightest evidence of glacial epochs, such as that of the pleiostecene period in Europe and North America*, occurring within the tertiary period, corresponding to the recurrence of cycles of extreme eccentricity. Indeed, the double or repeated recurrence of a glacial epoch within the pleistocene period in the Northern Hemisphere, and probably the glacier epoch towards the close of the tertiary period in Australasia, appear to be peculiarly exceptional occurrences within the whole range of the Cainozoic period.

Both Dr. Croll and Sir Robert Ball clearly perceived the difficulty presented by the lack of evidence of earlier glaciation in our rocks corresponding to former recurrences of cycles of maximum eccentricity. The latter dismisses this serious difficulty far too curtly, by allusions to the alleged imperfection of the records of the rocks, and to the perishable nature of boulder clays, rendering them peculiarly liable to be washed away; and, as regards moraines, erratics, etc., he adds, "The advent of one ice sheet ploughs away the traces of preceding ice sheets." But surely some definite traces ought to be found intercalated among the many well-preserved beds of the equally perishable sediments of the tertiary formations within the region covered or affected by the last great spread of ice during the pleistocene age. References to the rate and amount of denudation by atmospheric and other causes, based upon the amount of sediments held in suspension, and solutions derived from the waste of the land in rivers flowing into the ocean, may be fairly correct, but surely this waste is not composed entirely of the latest formed deposits. The destruction ever going on in our rocks does not operate so intensely upon the latest layers formed as upon particular areas whose slopes and troughs favour the rapidly erosive action of the great destroyer, *water in motion*; and this action operates in vertical cuts and gashes through the envelopes of whatever strata may be underneath, rather than in sweeping away all trace of the most recently formed layers, many of which must occur in such situations where they were covered and permanently protected by the newer sediments in course of formation, and, perhaps, largely derived from the immediate waste of the very oldest rocks.

Why, therefore, should we not expect fairly complete vertical fragments of ancient boulder clays, moraine stuff, erratic drifts and in the tertiary formations at least, as commonly as we do of contemporaneous clays, deposited gravels, lignites and sediments, equally perishable stuff, otherwise derived? This is not the only difficulty which bars the way to the acceptance of the astronomical theory taken by itself in adequately accounting for the glacial epoch of Northern

Europe and North America during the pleistocene age. For if the general belief of Australasian geologists be correct that the great *glacier epoch* of Southern Australia, Tasmania, and New Zealand occurred prior to the pleistocene age of Europe, and probably at a point of time contemporaneous with the pliocene of Europe, the astronomical theory alone would be an inadequate explanation of the whole facts. It is generally believed, however, that during the pleistocene period Australasia had experienced a pluvial epoch almost the parallel of corresponding northern latitudes—North Africa and Syria—during the glacial epoch. Thus, in a very able address recently delivered by Professor Jas. Geikie, D.C.L., LL.D., F.R.S., as President of the Geological Society of Edinburgh, he states:—*

"But while the conditions in Northern and Central Europe were markedly glacial, further south only more or less isolated snow-capped mountains and local glaciers appeared—such, for example, as those of the Sierra Nevada, the Apennines, Corsica, the Atlas, the Lebanon, etc. In connection with these facts we may note also the Azores were reached by floating ice; and I need only refer in a word to the evidence of cold, wet conditions as furnished by the plant and animal remains of Southern Europe. *Again, in North Africa and Syria, we find in now dessicated regions widespread fluviatile accumulations, which, in the opinion of a number of competent observers, are indicative of rainy conditions contemporaneous with the glacial period of Europe.*"

I have marked the latter portion with italics for the purpose of drawing particular attention to the fact that the geographical position of Australia, at least, in southern latitudes corresponds exactly with the position of North Africa and Syria, in northern latitude. If, therefore, the causes which produced the great glacial epoch in Northern Europe did not extend *glacial* effects into Syria and North Africa, why should some Australian geologists expect intense *glacial* effects in Australia, seeing that corresponding latitudes in the Northern Hemisphere only experienced mild glacial effects on high mountain slopes, and only *an increased rainfall* on lower levels. If the opinion of our most competent geological observers in Australia be correct, an increased pluvial action in Australia, Tasmania, and New Zealand are the only contemporaneous effects observed during the pleistocene period, as in corresponding latitudes in Syria and North Africa; and thus far there is harmony with the astronomical theory. But if, in the opinion of the same observers, the isolated snow-capped mountains and local glaciers of Southern

* "Supposed Causes of the Glacial Period:" Professor Jas. Geikie, D.C.L., LL.D., F.R.S. (Trans. Edin. Geol. Soc., p. 212.)

Australia and Tasmania, and the more intense glacier period of New Zealand, indicating a still more marked refrigeration of climate, occurred anterior to this, namely, in the pliocene period, it would prove that geographical and physical causes *must be added* to the astronomical before we can adequately account for the special refrigeration of Northern and Central Europe at a later epoch.

From independent reasoning, based mainly on the absence of evidence of glaciation in the earlier tertiary rocks o Europe, corresponding to former cycles of even greater intensity of the eccentricity of the earth's orbit than occurred during the pleistocene period, Dr. Wallace and Mr. Searles V. Wood, jun., arrive at an exactly similar conclusion, viz., the necessity of the concurrence of geographical and astronomical causes.

There is one remarkable point connected with the supposed earlier occurrence of the *glacier period* of Australasia, which, if confirmed, will be a strong argument in favour of the potency of the astronomical theory, considered at any rate as a constant and necessary major element or great co-efficient in the causation of great glacial or glacier epochs. In the extended calculation of the cycles of eccentricity of the earth's orbit, Dr. Croll places the highest limit reached in three million years at a point of time nearly 850,000 years ago, or about 550,000 years anterior to the last great cycle, extending from 80,000 to 250,000 years ago, which is supposed to correspond with the glacial and inter-glacial epochs of Europe and North America. Now, as already stated by me:—* "Although it be admitted that the primary cause of the glacial epoch in the Northern Hemisphere in the pleistocene period may be due to the high phase of eccentricity of the earth's orbit in combination with winter in aphelion—the effect of precession—it does not necessarily follow that the extreme effects of glaciation have been produced in both hemispheres, or in different epochs by the recurrence of such astronomical causes *alone*. It is admitted that warm ocean currents have such an important bearing upon the question that, if they were not debarred to a great extent from the hemisphere specially affected by the astronomical causes referred to, glaciation of an extraordinary character would not be appreciable. Now the preponderance and the nature of the distribution of the land in the Northern Hemisphere render the latter more liable to the obstruction or diversion of the warm equatorial ocean currents produced by geographical changes, while, with the smaller extent of elevated land and its insular position,

* Geol. of Tasmania, p. 255.

the Southern Hemisphere would be comparatively unaffected."

Now from these considerations it is important to observe that, as regards Australasia, the influence of geographical barriers may be said to be *nil*, and that to this region, whatever great general climatic changes may have taken place, can be referred with greater certainty to astronomical causes *alone*. But if we admit this, we must also allow that the major astronomical cause must produce the major effect. Seeing, therefore, that Dr. Croll has calculated the amount of eccentricity of the earth's orbit 850,000 years ago to be 28·57 per cent. greater than during the last cycle which is supposed to correspond with the glacial epoch of the Northern Hemisphere, ought we not to expect to find in Australasia, where alone the purely astronomical effect would be most clearly revealed, the most marked extreme of climate? If we reason correctly we must answer in the affirmative, whatever may be our preconceptions, which are ever too prone to take side glances at consequences before making a reply. We must therefore, in Australasia at least, expect to find, probably near to the close of the tertiary period (according to the very moderate estimate of geological time by Dr. Wallace), evidences of a greater intensity of refrigeration of climate than during the period corresponding to the glacial epoch of the Northern Hemisphere, whose intensity there is mainly due to *combined causes*. The evidences of our rocks by which the most competent geologists of Australasia were originally led to place our glacier epoch in the pliocene period, and a great pluvial epoch in the pleistocene period, are remarkable as a confirmation of the potency of the astronomical cause in itself to produce at periods of *maximum eccentricity* great climatic changes, corresponding in effect to the degree of eccentricity at the respective periods.

Of course it is taken for granted that the astronomical cause, even although operating in a broadly contemporaneous manner in both hemispheres in any one epoch, must nevertheless, in its minor phases of variation every 10,500 years due to precession, place the scene of greatest severity in either hemisphere consecutively and not contemporaneously.

It is admitted that a glacial epoch is broad enough to contain many of such *consecutive* alternations.

The Weight of Negative Evidence.

The weight of negative evidence against the astronomical theory by itself, as regards the absence of glacial deposits in other tertiary formations, is ably summarised by Dr. Wallace in the following terms:—"But when we proceed to examine the tertiary deposits of other parts of Europe, and especially

of our own country, for evidence of this kind, not only is such evidence completely wanting, but the facts are of so definite a character as to satisfy most geologists that it can never have existed; and the same may be said of temperate North America and of the Arctic regions generally."

Mr. Searles V. Wood, junr., who wrote a remarkably able paper on "The Climate Controversy," is quoted by Dr. Wallace in support of this conclusion, as follows :—

"Now the Eocene formation is complete in England, and is exposed in continuous sections along the north coast of the Isle of Wight from its base to its junction with the Oligocene (or Lower Miocene according to some) and along the northern coast of Kent from its base to the lower Bagshot Sand. It has been intersected by railway and other cuttings in all directions and at all horizons, and pierced by wells innumerable; while from its strata in England, France, and Belgium the most extensive collections of organic remains have been made of any formation yet explored, and from nearly all its horizons, for at one place or another nearly every horizon may be said to have yielded fossils of some kind. These fossils, however, whether they be the remains of a flora, such as that of Sheppey, or of a vertebral fauna, containing the crocodile and alligator, such as is yielded by beds indicative of terrestrial conditions, or of a molluscan assemblage, such as is present in marine or flurio-marine beds of the formation, are of unmistakably *tropical or sub-tropical character throughout; and no trace whatever has appeared of the intercalation of a glacial period, much less of successive intercalations indicative of more than one period of* 10,500 *years glaciation.* Nor can it be urged that the glacial epochs of the Eocene in England were intervals of dry land, and so have left no evidence of their existence behind them, because a large part of the continuous sequence of Eocene deposits in this country consists of alternations of fluriatile, fluvio-marine, and purely marine strata; so that it seems impossible, that, during the accumulation of the Eocene formation in England, a glacial period could have occurred without its evidences being abundantly apparent. The Oligocene of Northern Germany and Belgium and the Miocene of these countries and of France, have also afforded a rich molluscan fauna, which, like that of the Eocene, has as yet presented no indication of the intrusion of anything to interfere with its uniformly sub-tropical character."*

Dr. Wallace, in confirmation, goes on to say †:—"When we consider that this enormous series of deposits, many thousand feet in thickness, consists wholly of alternation of clays, sands, marls, shales, or limestones, with a few beds of pebbles

* *Geol. Magazine*, 1876, p. 392: Island Life, pp, 173-174.

† Island Life, pp. 174, 175.

or conglomerate, not one of the whole series containing irregular blocks of foreign material, boulders, or gravel, such as we have seen to be the essential characteristic of a glacial epoch; and when we find that this 'very same general character pervades all the extensive tertiary deposits of temperate North America, we shall, I think, be forced to the conclusion that no general glacial epoch could have occurred during their formation.'" And Dr. Wallace further anticipates Sir Robt. Ball's argument, which relies solely upon the "imperfection of the geological record," by the concluding part of his observations, where he states: "It must be remembered that the 'imperfection of the geological record' will not help us here, because the series of tertiary deposits is unusually complete, and we must suppose some destructive agency to have selected all the intercalated glacial beds, and to have so completely made away with them that not a fragment remains, while preserving all, or almost all, the *interglacial* beds; and to have acted thus capriciously, not in one limited area only, but over the whole Northern Hemisphere, with the local exceptions on the flanks of great mountain ranges already referred to." On the whole, therefore, it seems to be conclusively demonstrated that a concurrence of favourable geographical conditions with astronomical causes is essential to the initiation of glacial conditions even in existing temperate zones, and that changes of eccentricity, however great, have no potency in themselves to produce glaciation of an intense form on the lower levels of existing temperate latitudes, because warm air and ocean currents have so preponderating an influence, that, if they were not diverted and barred by physical and geographical conditions from the regions affected, glaciation on lowlands of existing temperate latitudes would be impossible. These conclusions are in no way disturbed by the more recent calculations by Sir Robt. Ball in regard to the exact proportion of *direct* heat received by any one hemisphere during the long winter and short summer of a period of great eccentricity of winter in aphelion in the respective hemispheres; for he himself acknowledges that the heat influence affecting either hemisphere under the most extreme conditions are not confined to the direct sun rays. At page 126 ("The Cause of an Ice Age") Sir Robt. Ball states, "There are two causes by which the severity of a glaciation is somewhat modified. There is, first, the actual storage of some of the copious heat of summer in the glaciated hemisphere itself, to be doled out again during winter; there is, secondly, the *the contribution of heat from the opposite hemisphere, which may be conveyed via air or via water across the equator into glaciated regions.*" Hence it follows that his calculations—proving that within the same hemisphere the heat received direct from the sun amounts to

63 per cent. in summer and only 37 per cent. in winter—do not help us to gauge the actual heat received in the winter of the glaciated hemisphere, as he has not formed any estimate of the known indirect sources of heat which would be received by air and ocean currents from the genial hemisphere, but the value of which we may have, now, some means of conceiving from the study of two regions in nearly the same northern latitudes, viz., Labrador and Ireland.

The former being in a glaciated condition owing to the influence of the Arctic cold current of water; the latter in a genial condition owing chiefly to the influence of the warm Gulf Stream, whose heat has been mainly derived from south equatorial regions.* While I cannot but admire the masterly and lucid manner in which Sir Robert Ball explains the astronomical theory, and supports the main conclusions of Dr. Croll, I am still disposed to think that in limiting his observation, too closely, to the *direct* sources of heat and their exact measurement, as regards the glaciated hemisphere, he has not sufficiently reflected upon the powerful modifying influences of the indirect supplies received from the genial hemisphere, nor of the possible changes which might occur in geographical conditions, which might greatly multiply or diminish the nominal amount of heat transmitted by the opening of new equatorial channels of communication, or by barring former channels. Nay more, according to Herschel's astronomical theory, as modified by Sir Robt. Ball, and its expected influence upon climate during a period of great eccentricity with the winter in aphelion, in the Southern Hemisphere, as at present, —it is stated: "In the northern we should have a short but very *mild* winter, with a very long but *very cool* summer, *i.e.*, an approach to perpetual spring," but from Mr. Robt. H. Scott's recent work on Meteorology, we find from existing conditions † "*the opposite is the case, owing to the unequal distribution of land and water*," ‡ and also owing to the fact "that in the summer in the Northern Hemisphere *the sun's rays fall on the greatest possible land area*." Here we have a complete reversal of the supposed influence of the astronomical cause, proving that the geographical conditions, which Sir Robt. Ball almost ignores as a *necessary* concurring cause in the initiation of a glacial epoch, has a *preponderating effect* in the determination of existing climates; and although Sir Robt. Ball only admits, to a certain extent, the modifying influence of geographical conditions § and feels the result "a little

* Dr. Croll estimated that the quantity of heat transferred by the Gulf stream from equatorial regions was not less than one-fifth of the entire heat possessed by the North Atlantic.

† Elementary Meteorology, R. G Scott, p. 231

‡ Ibid, p. 230.

§ The Cause of an Ice Age, p. 134.

disappointing" in view of the astronomical theory put forward, he nevertheless has practically* to admit that a glacial epoch *cannot take place* without the concurrence of two great causes, viz., a period of great eccentricity of the earth's orbit, with winter in aphelion, conjoined with specially favouring geographical conditions.

Improbability of finding Evidence of Intense Glaciation in any Portion of Australasian Lowlands among Rocks of the same Age with the Glacial Epoch of North and Central Europe and North America.

There are some enthusiasts who are so infatuated by the supposed omnipotence of the astronomical theory when regarded as the sole cause of glacial epochs, that they are somehow imbued with the idea that the same cause or causes which produced the Till or "*Grund Moraine*" of the northern glacial epoch in the lowlands of Scotland, Wales, and Ireland, between north lat. 51° to 59°, and covered these countries with a continuous ice sheet, may also be expected to have produced similarly intense results of glaciation in south lat. 36° to 38° in the lowlands of Australia, in a region corresponding to North Africa and the middle of the Mediterranean Sea in the Northern Hemisphere.

Now, while it is granted that the actual facts of observation may be faithfully recorded by persons holding such extravagant notions, it may be doubted whether they are able to draw inferences from the less perfect portion of supposed glacial evidence without being coloured to some extent by the extravagance of their ideas concerning the potency of causal influences.

If we are to be guided by the true scientific method in the investigation of the potency of causes relating to climate and glaciation, we must surely proceed in a reasonable manner by deducing the unknown from the known, the past from the present.

Now the potency of the causes which produced the glacial epoch in northern and central Europe have been fairly gauged by very able observers; and they have not only closely determined the limits of the spread of the northern ice sheet in a southerly direction, but, by a careful chain of observation of the upper and lower limits of ice action on elevated slopes of mountains in a series of latitudinal points, they have arrived at a fairly approximate idea of the altitude of the glacial epoch névé or snow line; and from such materials have given

* Ibid. 134, 159, 160.

us broadly satisfactory isochionals for various latitudes, embracing at least the whole of the region subjected to glaciation, excepting of course the local glaciation of mountains ascending beyond the névé in higher temperate and tropical countries.

It is also necessary to understand clearly the position which Australia, Tasmania, and New Zealand occupy in southern latitudes, as compared with the position of countries in Europe, in northern latitudes, over which it is known intense glaciation extended during the Great Glacial Epoch.

For this purpose I have placed in parallel columns the names of a few well-known places nearly in the same line of isotherm or latitude, and therefore approximately the respective equivalents of each other in north and south latitude.

APPROXIMATE EQUIVALENTS.

Estimate height of snow line (feet). Present Time. *Northern Hemisphere.*	Glacial Epoch. *Northern Hemisphere.*	*Southern Latitudes.*	*Northern Latitudes.*
		1. Southern limit of N. Zealand.	Mouth of River Loire, France
		2. Southern limit of Tasmania.	Venice, Bayonne.
		3. Southern limit of Australia.	Lisbon, Valencia.
9,520	6,520	4. Mount Cook, New Zealand.	Pyrenees, Rotondo, Balkans Apennines.
9,520	6,520	5. Mount Olympus, Cradle Mount, Tasmania.	Cape St. Vincent, Sicily, Athens.
11,187	8,187	6. Bacchus Marsh, Victoria.	Sierra Nevada.
11,480	8,480	7. Mount Kosciusko.	Tangiers, N. Africa, Malta,
		8. Mount Lofty Range, Adelaide.	Cyprus, Mount Atlas, N. Africa, Morocco.
		9. Australia.	North Africa, Syria.

The importance of this contrast is great, because it brings forcibly before our minds that the position of Australia corresponds, not with the glaciated area of North and Central Europe, but with those more genial southerly regions of North Africa and Syria, lying beyond the scope of the intense glacial influence of the glacial epoch; and it reminds us also, although we may be prepared to agree with Sir Robt. Ball, that we might find evidence of corresponding glacial intensity to the northen ice age of Europe in the Southern Hemisphere, that Australasia in any part—perhaps with the exception of Stewart Island lying at the southern extremity of New Zealand—*does not come within that portion of the Southern Hemisphere which corresponds with the specially glaciated region of Northern and Central Europe and North America.* If we reason from the known to the unknown, therefore, we have good *a posteriori* grounds for doubting the value of evidence which locates the effects of intense glacial action, during the

glacial epoch of Europe, in any part of the lowlands of even the most southerly region of the Australian mainland, at least. These conclusions are in perfect harmony with the most recent investigations of the extent and comparative intensity of the glaciation of Europe in the last ice age. Perhaps there is no one entitled to speak with greater authority on such a matter as Prof. James Geikie, D.C.L., LL.D., F.R.S., the accomplished author of "The Great Ice Age." In his last presidential address* to the members of the Geological Society of Edinburgh—from which I am proud to have received the honour of being elected as one of the honorary foreign corresponding members—he deals with the whole of the "Supposed Causes of the Glacial Period" with a master mind. In referring to the extent of knowledge now possessed by us in measuring the limits and intensity of glaciation of the "Ice Age," he states† :—"So greatly has our knowledge of the Glaciation of Europe increased during recent years, that the height of the snow line of the glacial period has been determined by MM. Simony, Partsch, Penck, and Höfer. Their method is simple enough. They first ascertain the lowest parts of a glaciated region from which independent glaciers have flowed. This gives the maximum height of the snow line.

"Next they determine the lowest point reached by such glaciers. It is obvious that the snow line would occur higher up than that, but at a lower level than the actual sources of the glaciers, and thus the minimum height of the former snow line is approximately ascertained.

"The lowest level from which independent glaciers formerly flowed, and the terminal point reached by the highest lying glaciers having been duly ascertained, it is possible to determine with sufficient accuracy the mean height of the old snow line. The required data are best obtained, as one might have expected, in the Pyrenees and amongst the mountains of MIDDLE and SOUTHERN Europe.

"*In those regions the snow line would seem to have been some* 3,000 *feet or so lower than now!* From such data Professor Penck has constructed a map showing the isochional lines of the glacial period. These lines are, I need hardly say, only approximations, but they are sufficiently near the truth to bring out the contrast between the ice age and the present. Thus the isochional of 1,000 metres which at present lies above Northern Scandinavia was pushed south to the latitude of Southern France and North Italy; while the isochional of 2,000 metres (now overlying the extreme North of France

* Trans. Edinburgh Geol. Soc., Vol. VI., Part 3, pp. 209, 230.

† Ibid., p. 211.

and North Germany) passed in glacial times over the northern part of the Mediterranean. . . . It is interesting to note that while in the Tabra (North Carpathians) the snow line was depressed in glacial times to the extent of 2,700 feet only, in the Alps it descended some 4,000 feet or more below its present level. With the snow line of that great chain at such an elevation it is obvious that *only a few of the higher points of the Apennines could rise into the regions of the névé. This is the reason* why moraines are met with in only the *higher valleys of that range.*"

Professor Jas Geikie elsewhere remarks :—"Isochional lines are not isotherms. Their height and direction are determined not only by temperature, but by the amount and distribution of the snowfall.* Nevertheless, the position of the snow line in Europe during the ice age enables us to form a rough estimate of the temperature. At present, in middle Europe, the temperature falls† 1° F. for every 300 feet of ascent. Hence, if we take the average depression of the snow line in glacial times at 3,000 feet, that would correspond approximately to a lowering of the temperature by 10·2°. This may not appear to be much, but, as Penck points out, were the mean annual temperature to be lowered to that extent, it would bring the climate of Northern Norway down to Southern Germany, and the climate of Sweden to Austria and Moravia, while that of the Alps would be met with over the basin of the Mediterranean."

" Let it be noted further that this lowering of the temperature, this displacement of climatic zones, was experienced over the whole continent, extending on the one hand south into Africa, and on the other east into Asia. *But while the conditions in Northern and Central Europe were markedly glacial, further south only more or less isolated snow-capped mountains and local glaciers appeared, such, for example, as those of Sierra Nevada, the Apennines, Corsica, the Atlas, the Lebanon, etc.*"

It is of particular interest to note the portion of Professor Geikie's remarks, which have been italicised, as it is just this milder form of glaciation which we can reasonably expect in the southernmost part of Australasia, including Tasmania and New Zealand, whose position is almost the exact equivalent of the regions bordering the Mediterranean referred to by him; and also, that even within this southern region of Australia, it is only in the vicinity of mountains whose crests are likely

* The better known term "*isochryme*" only implies equality in extremes of *cold* (R. M. J.).

† From independent calculations based, by the writer, on Mr. R. H. Scott's tables of existing mean temperatures for various latitudes, together with limits of existing snow line over both hemispheres, it would require only a fall of 1deg. F. for every 400 feet of ascent. (R. M. J.)

to have ascended into the névé at the time of a glacial epoch that we can reasonably hope to find good evidence of former glaciation due to local glaciers, and there *only in the higher valleys*. As this region, however, corresponds to the southern extremity of Europe and the northerly extremity of Africa, it is probable that during a period of lowered temperature there would be a greatly increased rainfall, with a great increase in the dynamic effects of existing rivers and watercourses, both in highlands and lowlands.

Such was the condition of similar latitudes during the ice age of Europe, according to Prof. James Geikie; for in the same address, from which I have so largely quoted, he states,* "that in the extreme south of Europe, and in North Africa and West Asia, increased rain precipitation accompanied lowering of temperature; from which it may be inferred that precipitation in glacial times was greater generally than it is now."

Now it is important to observe that in New South Wales, South Australia, Victoria, New Zealand, and Tasmania we have abundant evidence, in the extensive, irregular, coarse, shingly terrace-drifts formed in the main valleys frequently overlying our older tertiary basalts, of conditions which indicate, clearly, that during the period extending throughout the Neogene (Pliocene) and Pleistocene ages there was a greatly increased rainfall; and so generally throughout these colonies are these characteristics manifested during this period that Australian geologists have long been in the habit of referring to it as the "pluvial epoch" of Australasia. The representative geologists in Australasia are almost unanimous in placing the beginning of our glacier and pluvial epochs as far back as the commencement of the Pliocene age, and it would appear that this refrigerated pluvial epoch was either continuous or recurred again and again, well up to the close of the Pleistocene period; and only the later terrace drifts, therefore, may be said to be the isochrones of the glacial drifts of the ice age of the Northern Hemisphere.

I have referred to the evidence of lowered temperature, local alpine glaciation, and greatly increased rainfall of the pluvial epoch very frequently in my larger work on "The Geology of Tasmania."

Thus, in commenting upon the climate of the Neogene period (Pliocene), I stated (p. 219), "Mr. Wilkinson is of opinion that the great drift deposits left at different levels upon the sides of the valleys as they were deepened towards the close of the Neogene period indicate a much greater rainfall than at present, and this greater rainfall is inferred to be due to the greater extent of glaciation of portions of the

* Loc cit., p. 214

Northern and Southern Hemispheres. Whatever grounds there may be for this view, it is clear, from the absence of huge ice-borne erratics, and other evidences *on the lower levels*, we are not justified in assuming a very serious and general refrigeration of the climate in the Australasian regions."

"That a considerable change of climate, however, had its beginning at this time is most probable, as evidenced by the sudden disappearance of the characteristic flora of the older, or *Paleogene*, epoch; and especially by the striking contrast which its unstratified, irregular drift deposits (almost barren of all traces of life) present, as compared with the more regularly stratified members, replete with life remains, of the Paleogone epoch." Again, in discussing the causes of colder climate, pp. 254-257, I stated, "It is clear that the conditions under which the successive, irregular, coarse, shingly terrace drifts had been formed in the main valleys were very different from those under which the Paleogene formations were deposited, and it is also probable, as suggested in respect of equivalent formations in New South Wales by Mr. S. Wilkinson, and in South Australia by Professor Tate, that the mode of deposition and other circumstances indicate a greater rainfall than at present. The paucity of life in the formations by itself, while depriving us of the aid of palæontology in the classification of the rocks and in inferring local climatic conditions, only affords negative evidence in support of a growing refrigeration of climate. Whether this supposed change in the direction of a colder climate became sufficiently intense within the period to produce the local ice sheets and glaciers, of which there is evidence in valleys of the western highlands of Tasmania, notably along the deeply cut ravines of the Mackintosh River, it is difficult to determine. It is quite conceivable, however, that simultaneously with the rising of the floor of the old Paleogene sea the adjacent land partook of a corresponding elevation"—(and to this we may now add the conception of maximum eccentricity of the earth's orbit, whose occurrence is placed about 550,000 years before the glacial epoch by Dr. Croll, which time would approximate closely to the early part of our Neogene period or beginning of our pluvial epoch)—" and we may therefore expect to find, as a direct consequence, a considerable change of temperature over the area so affected."

It is important also to observe, here, that Prof. Hutton is of opinion that the former greater extension of the New Zealand glaciers occurred during the interval between the Pareora system and the marine beds of the Wanganui system, *i.e.*, at a period isochronous with our Neogene pluvial drifts and terraces.

The difficulty of explaining these facts by reference to a cause which only came into operation at a much later period, *i.e.*, in the Pleistocene glacial epoch, and which forms the greatest stumbling block to the acceptance of the potency of the astronomical theory as being *alone* sufficient to account for such a refrigeration of climate as that which produced the intense glacial epoch of Europe, is next discussed by me in the same place at considerable length—pp. 255, 256—and the following conclusions were arrived at:—"Accordingly from the very much smaller proportion of elevated land in the Southern Hemisphere, and from the improbability of the equatorial ocean currents having been appreciably excluded at any time, owing to the absence of connected land barriers, it is reasonable to infer that the combined effects of astronomical and geological causes, similar to those which brought about the glacial epoch in Europe and North America (but *especially to the favourable latitudinal position*)—are not likely to have *operated intensely* in Australasia.

"That this seems to be the more reasonable view as regards Australia is borne out by local evidences.

"In the first place the Neogene epoch of Australasia corresponds with the Pliocene epoch of Europe, and, consequently, whatever the local climatic conditions may have been, they cannot in all respects be referred to causes which entered into combination in a succeeding epoch in the Northern Hemisphere.

"In the second place, while admitting the evidence of former glaciation in local alpine regions, there is no satisfactory proof that the erratics found in such regions belong to the period in which our raised terrace drifts were formed; and neither in these nor in the later deposits of the extensive lower levels do we find any clear signs of ice action, such as are exhibited so widely in Europe and America, in the shape of moraines, boulder drift, striated blocks, perched blocks, and other huge ice-borne erratics, etc. On the contrary, the prevailing terrace drifts in Tasmania are formed from materials derived from the adjacent or underlying rocks; and with the exception of huge boulders at the base, or on the slopes of mountain ranges, clearly traceable to gravitation, there is not the slightest trace of rock masses which would necessitate the agency of ice as a means of transport,* if we except also those evidences (*i.e.*, of glacial action) in alpine regions in the western highlands, which are more probably local effects due mainly to a much greater elevation of the land in former times (and I am now able to add, perhaps, also the influence of the greater limit of the eccentricity of

* These remarks do not apply to the ice-borne erratics found in rocks of Permo-Carboniferous age, of which there is the most abundant evidence throughout the older mudstones of this age in Tasmania, Victoria, and New South Wales.

the earth's orbit with winter in aphelion occurring, according to Dr. Croll, 550,000 years prior to the glacial epoch of the Northern Hemisphere)." I then conclude with the observation (p. 256):—"The author is personally familiar with the various evidences of glaciation in Scotland at the higher and lower levels, and his knowledge of Tasmania is sufficiently wide to enable him to state with confidence that corresponding evidences *in the latter place* (*i.e.*, obviously the *lower levels*) are entirely wanting within the tertiary and later periods."

In the recent paper already referred to, prepared by Messrs. Officer and Balfour, of Victoria, the authors erroneously convert my statement as to the absence of evidence of *intense glaciation* into an assertion "*that there is no evidence there* (Tasmania) *to show that a glacial period has ever taken place.*" I make no such statement. I was the first person not to observe, but to publish evidence clearly proving ice action in the alpine regions of our western highlands, but the absence in lower levels of any evidence of ice action confirms my opinion as to the absence of *intense glacial action* during our glacier and pluvial epochs. In this view, regarding the absence of evidence of glaciation on the lower levels of Tasmania, I am gratified to have the support of our able Government Geologist, Mr. Montgomery, for in his paper just read ("Glacial Action in Tasmania"), in referring to this very question, he states: "In the main I agree with his view," that is, with the view which I had inclined to take as expressed in page 256 "Geol. of Tasmania."

Mr. Montgomery's most valuable contribution to our knowledge of ice action, together with similarly valuable papers of Messrs. Dunn and Moore, now enable us to fix the limits of the upper and lower indications of positive ice action on the shoulders and slopes of our western highlands with a close approximation to the truth, at least sufficiently so to give us a fairly good base for determining the isochional of the névé or snow line of our western highlands, during the two great glacier periods already referred to. But first it is necessary to consider how far denudation may have reduced the height of our mountain tops. If we even allow in such situations a rate of denudation of three times that of the average rate, which is estimated to be nearly one foot in 3,000 years (that gives one foot per 1,000 years), we can only allow a lowering of altitude by about 850 feet since the beginning of the Pliocene period, at which time it is probable the refrigeration, due to the maximum of eccentricity in the earth's orbit 850,000 years ago, might probably have caused the earlier glaciation of our western alpine region, which, even now, has a very extended surface (Great Greenstone Plateau) with a mean altitude of 4,000 feet. This allowance for denudation would bring the mean altitude of the same

mountain plateau up to about 5,000 feet, and the same cause would also incline us to extend its elevated area further west, so as to embrace at least Mounts Tyndall, Geikie, Murchison, Read, Jukes, Owen, and Lyell. This would give us a very extended elevated catchment platform for the collection and piling up of a permanent snowfield sufficient to form an adequate supply for feeding the numerous glaciers which are known to have descended from its western slopes.

If we also assume for the lat. 42° south that the snow cap would at least be 1,000 feet thick, we should then have reached a surface level of 6,000 feet. The question now is a crucial one. Would a height of 5,000 feet in this latitude ascend into the *isochional* or plane of the permanent freezing point, supposing that the general lowering of the temperature produced by the astronomical cause during the last glacial epoch of Europe also produced exactly corresponding effects under similar conditions as to latitude, etc., in Tasmania and neighbouring Australasian colonies? Let us see. In the corresponding latitudes of the Pyrenees, the névé was only lowered 3,000 feet during the maximum effect of glacial action in the recent European ice age. As the névé at the present time, there, is placed at about 9,520 feet altitude, it is obvious that during the glacial period of Europe the névé of the Pyrenees must have stood at a height of about 6,520 feet. This would indicate that the mean height of even our *restored* western plateau would fall below the névé by about 1,520 feet, and under such conditions *there could have been no snow cap, and hence no glaciers produced by the same general cause which produced the ice age of Europe in the pleistocene period.* It must also be borne in mind that the Southern Hemisphere at present has its winter in aphelion, and that the existing level of the isochional or névé is far below the altitude of the névé in corresponding latitudes in the Northern Hemisphere; and, therefore, in my opinion, it would not be correct to measure the fall of 3,000 feet in relation to calculated height of existing névé in the Southern Hemisphere, for the limit of 3,000 feet fall is calculated in relation to existing isotherms in the Northern Hemisphere. But suppose the mean of existing difference of the level at the névé in both hemispheres be taken for the same latitude it would still leave our restored western plateau about 1,225 feet below the estimated local névé or snow level at the time of the glacial epoch in Europe. This bears out the evidence of Australasian geologists that our glacier and pluvial epoch *was not brought about* by the same cause which produced the glacial epoch of Europe and North America in the pleistocene period. Let us now see whether, by the same method of reasoning, a more favourable argument can be advanced on behalf of the earlier cycle of *maximum* eccen-

tricity of about 550,000 years earlier in the Pliocene age and contemporaneous with our older pluvial terrace drifts on lower levels. It may be remembered that the eccentricity of the earth's orbit at this maximum period of cyclic eccentricity is calculated to have been 28·57 per cent. greater than the cycle of eccentricity which occurred during the last ice age of Europe. If we reason that the effect on temperature should be in proportion to the intensities of eccentricity, we must assume that the lowering of the névé or snow line in the earlier maximum cycle would be as much as 3,857 feet, and this, with the restored level of our western mountain plateau, which would have been wasted for 850,000 years, would place the mean level of its upper surface at a height of about 400 *feet above* the névé or snow line, and thus produce the necessary *initial* conditions for the formation of a snowfield which might eventually accumulate snow and ice whose surface might be as high as 1,400 feet above the snow line, and would then, by the assumed balance of precipitation over melting, be able to send glaciers down its western slopes, possibly within 1,000 feet, or, in favourable valleys, perhaps to 600 or 700 feet above sea level. According to personal observation, and to the testimony of Messrs. Montgomery, Moore, Sprent, Jones, Dunn, and others, the same calculations would indicate corresponding results for Mount Kosciusko and other peaks over 6,300 feet in the southern Alps of Australia.

Thus, if we take 11,000 feet as the isochional or névé for the latitude of Mount Kosciusko we have the following result:—

		ALT.
Existing isochional of Mount Kosciusko (say)		11,000ft.
Less 3,857 feet, due to lowering of temperature during period of max. eccentricity of earth's orbit with winter in aphelion, 850,000 years ago, say in Pliocene period ...		3,857ft.
Isochional of older glacier period of Australia in latitude 36°... ...		7,143ft.
Present height of Mount Kosciusko	7,200ft.	
Add waste by denudation in 850,000 years	850ft.	
		8,050ft.
Difference showing height above névé		907ft.

The above calculation would also justify us in looking for alpine glaciers on the slopes of the lofty Bogong Range, in the direction of Beechworth, adjoining, and almost a continuation of, the Australian Alps. Mount Bogong itself 6,508 feet high, and the highest mountain in Victoria, may be said to be the south-westerly continuation of the Australian Alps, which rises into the lofty peak of Mount Kosciusko, the most elevated mountain in Australia. The careful observations of Messrs. Stirling and Dunn regarding the abundant evidence of glaciation in these Alps of Victoria are strongly fortified by the calculations given, proving that without any material alteration of present levels the elevated table lands and peaks of this region would ascend above the névé or isochional of the earlier Pliocene period, and so form the initial condition for producing a permanent snowfield, with its attendant glaciers, in the Kiewa, Mitta Mitta, and other mountain valleys; in which places the two observers named have given ample evidence in the discovered moraines, huge erratics, roches-moutonnees, striated blocks, etc.

That the evidence of glaciation on these Alps are more probably isochronous with the earlier cold pluvial epoch* which produced our older terrace drifts on lower levels of the Australian mainland and Tasmania is favoured by the same mode of determining the isochional of the névé for the period corresponding with the later glacial epochs of the Northern Hemisphere, thus :—

		ALT.
Existing isochional of snow line about		11,000ft.
Less depression of névé due to extremity of orbit at last glacial epoch in Northern Hemisphere. Max. effect estimated to be about 210,000 years ago...		3,000ft.
Estimated height of névé or snow field at the time of the last glacial epoch		8,000ft.
Present height of Mount Bogong, highest point of Victorian Alps...	6,508ft.	
Add waste by denudation in 210,000 years (say)	210	
		6,718ft.
Falling short of the névé or snow line of the last glacial epoch by about 1,282 feet		1,282ft.

* It is of importance to note here that Dr. Croll, impressed with the much greater eccentricity of the earth's orbit corresponding with this period, was fully convinced that a glacial epoch must have occurred at this time.

Surely the acceptance of the earlier epoch showing not only harmony with the causes which produced our earlier pluvial terrace drifts, but also satisfying all physical conditions for the initiation of glaciation, is a more reasonable conclusion to arrive at than to refer the glacial evidences to the later epoch, which would not satisfy physical conditions essential to the initiation of glacial action without involving the double assumption of an elevation and subsequent depression of 1,282 feet, for which there is no evidence whatever.

As regards the very doubtful evidence of intense glacial action in the shape of "boulder till" discovered by Messrs. Officer and Balfour in the lowlands of Korkuperrimal, situated nearly 200 miles to the east of mountains where alone in Victoria a permanent snowfield capable of yielding glaciers could be formed, it is evident that the potency of neither of the two great epochs of cycles of maximum eccentricity could be adequate to produce such intense effects, even if the lowlands of Victoria stood 5,000 feet above their present level.

As there is no proof of any kind to indicate such elevation and final depression at any time corresponding to these glacial epochs, *i.e.*, subsequent to the deposition of their Miocene leaf beds, it is probable that a mistake has been made in the inferences drawn from the facts. The certainty, moreover, that an elevation, not depression, of considerable extent has taken place since the upper Eocene or Miocene period is evidenced unmistakably by the Tertiary marine beds over a great portion of the lower levels of the Victorian territory on both slopes of the great dividing range. The supposed glaciation of the Korkuperrimal region is therefore quite anomalistic.

Sufficient illustration has now been given with respect to evidences bearing upon causes of glaciation, in Australia and Tasmania at least, to justify me in adopting for the present the following conclusions:—

(1.) That the glacier epoch of Australasia was probably comparatively mild in its effects, manifesting itself mainly by increased rainfall in lowlands, and by establishing local glaciers in the alpine regions of Southern Australia and Tasmania, and in greatly extending the spread of the existing snowfields and glaciers of the New Zealand Alps.

(2.) That probably, in Australia, the local glaciers of the Alps melted before reaching the 2,000 feet levels within the valleys which descended continuously from the elevated snowfields; and in Tasmania it is most probable that only on the western slopes of our western highlands was there suffi-

cient precipitation to yield glaciers, any of which did not reach the sea, and probably were melted within their own valleys before reaching the 1,000 feet level.

(3.) That the date at least of our most refrigerated period was probably isochronous, and mainly caused by the maximum cycle of eccentricity of the earth's orbit with winter in aphelion, probably near to the beginning of our neogene period, say, 850,000 years ago.

(4.) That if the latter be true, it proves that the astronomical theory by itself (*i.e.*, without concurrence of geographical conditions) would not adequately account for the ice age of Europe and North America, nor for the absence of marked glacial phenomena among the earlier tertiary deposits of Europe at points of time concurring with the earlier cycles of eccentricity of the earth's orbit with winter in aphelion.

I do not expect that my conclusions will be accepted at present by many geologists who have already attained to crystallised views on the matter, but even these may be prepared to allow that, granting the premises assumed by me, my conclusions follow as a logical necessity.

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