§ 19. Past Glacial Action in Australia.*

1. Introductory.

One of the most remarkable facts brought to light by geology is the great contrasts of climate that have occurred in the same geographical areas at different periods of the world's history. An arboreal flora, such as is characteristic of temperate regions in the present day, has flourished at certain times in the past both within the Arctic and Antarctic circles. The seas of the Antarctic regions have also, at one time, been tenanted by coral-like organisms, which, together with allied forms of marine life, built reefs in the ocean, indicating a climate that is quite inconsistent with permanent ice-caps and floating ice.

On the other hand, there are unmistakable evidences that many parts of the world, which are now included in the warmer temperate and sub-tropical latitudes, have passed through periods in which permanent ice covered much of the land surface, or the local seas were invaded by floating ice. Geologists are not agreed as to the cause of these remarkable fluctuations of climate, but the facts are indisputable.

The evidences on which these deductions have been reached are based on the fact that the sculpturing of the land surfaces by ice is of a kind that is peculiar, and easily distinguishable from that of other denuding agents. Just as distinctive land forms are developed under arid conditions, and another class of sculpture is developed as the result of a moist climate and running water, so, again, there is a distinct and typical glacial topography which follows as a consequence of ice erosion.

To give in detail the full scope of such evidences would involve too much space, but, stated generally, in a glaciated region the hard rocks that form the floor over which the ice moves, are rounded, polished, and grooved (*roche moutonnée*); and the valleys are wide, flat-bottomed, with steep sides shewing an absence of spurs, and, generally speaking, follow a straight or gently-curved course. The tributary valleys often join the main valley at high levels, giving rise to waterfalls. The detrital matter in the valleys is of a morainic type—that is, stones and clay confusedly mixed (till), large blocks being often carried on the surface of the ice and left stranded in peculiar positions. Many of the ice-carried stones have travelled long distances, and may have been transported across minor watersheds, and are called "erratics," as being foreign to the localities in which they occur. The stones contained in the boulder-clay, or "till," are commonly ice-scratched, unevenly scraped, facetted, and irregularly worn. A glaciated country usually possesses lakes, some of which are held in rock basins that have been excavated by the ice, while others are caused by transverse moraines, left by the retreating glacier, and which act as dams to impound the drainage.

2. Periods of Glaciation in Australia.

(i.) **General.**—The present climate of Australia, as a whole, is in keeping with the latitudes in which it is situated, and is in no sense abnormal as compared with other countries that occupy a similar position in relation to the climatic zones; yet, at three distinct geological periods, there has been permanent ice, to a greater or less extent, within its geographical limits. Each of these glacial periods has left its records. In some cases the glacial features are interbedded with other sediments of a remote age, and, in others, they form the present landscape which has been fashioned in its larger contours by the heavy passage of the ice-plough over its surface.

The three glacial periods of Australia are as widely separated from each other in time as they could well be, occurring, respectively, near the top, bottom, and middle of the sedimentary rocks. Beginning with the latest, they are as follows:—(i.) Pleistocene and (?) Recent Glaciations; (ii.) Permo-Carboniferous Glaciations; and (iii.) Cambrian Glaciations.

* Contributed by Walter Howchin, F.G.S., Professor of Geology and Palæontology, University of Adelaide.

(ii.) **Pleistocene and (?) Recent Glaciations.**—(*a*) *General.*—No part of the Australian continent is, at the present time, included within the permanent snow-line, although in the highest portions of the south-eastern part of the mainland and on the central plateau of Tasmania, snow may fall at any time of the year, and, in sheltered nooks, may outlast the summer. There are abundant evidences, however, that within comparatively recent times snow was not only a permanent feature of these highlands, but valley glaciers of considerable extent existed and continued through a sufficient length of time to leave their tool-marks on the topography of the districts concerned.

(*b*) *The Glaciers of Kosciusko.*—Mount Kosciusko, which attains a maximum height of 7,328 feet, is the culminating peak of an extensive plateau that forms part of the border lands between New South Wales and Victoria, and forms the "knot" that unites the main eastern and southern ranges at the south-eastern angle of the continent. In the first instance, when the question came under discussion, several conflicting reports were received from observers as to the occurrence of glacial features on Kosciusko, but the observations of Lendenfeld, published in 1885; Helms, in 1893; David, Helms, and Pittman, in 1901; and, again, David, in 1908, placed the existence of such features beyond all doubt.*

The zone of glaciation is embraced between the heights of 7,150 feet and a mean of about 5,600 feet. The eastern side gives greater evidence of glacial action than the western. This is what might be expected on the general law that the snow-fields of the world have their greatest development on the side of greatest precipitation. At Kosciusko the moisture-laden winds come from the east, while the relatively warm and dry north-westerly winds that blow from the interior of Australia would tend to limit the accumulation of snow on the side of the range which was exposed to their influence. According to Professor David, "the ice-sheet extended to at least 12 miles N.E. from Mount Kosciusko, and moved in a general S.E. to E.S.E. direction from the main dividing range, between the Snowy and Murray rivers, towards the valley of the Thredbo . . . . while the total area covered by the ice-calotte of Kosciusko, during the maximum glaciation, was probably about 80 to 100 square miles." It is estimated that, at this period, the ice-sheet, in places, reached a thickness of not less than 1,000 feet. The largest and longest glacier was that which filled up the Snowy River Valley and its tributaries, and made an ice-fall over into the Thredbo Valley, coming down to within 4,500 feet of the present sea-level, having a length of 4½ miles.

On the western side of the divide, draining into the River Murray valley, several smaller glaciers existed, of which the Wilkinson Valley glacier was the principal. Some of the finest glaciated rock surfaces occur on this side, together with much morainic material, including erratics up to 20 feet in length, as well as impounded lakes. On this side of the watershed the glacial features come down to within 6,300 feet of sea-level.

The highest points of the range, in a zone of about 200 feet, exhibit the effects of atmospheric weathering only—which has probably arisen from the thinness of the *névé* at the summit and consequent absence of driving force, as well as the mechanical effects of frost acting on exposed faces of rock—but within the intermediate zone, as defined above, the usual features of glacial topography are strikingly manifest. The period of maximum glaciation is responsible for the excavation of the U-shaped valleys and the rock basin of Lake Merewether, as also for most of the ice-scratched and ice-polished rock-faces (*roches moutonnées*), one of which, according to Lendenfeld, is 3 acres in extent.

When this period of maximum glaciation had passed, the gradual retreat of the ice-sheet was marked by the stranding of the morainic debris left by the glaciers at halting stages in their recession, first as high-level lateral moraines, and later in successive transverse moraines which were piled up as terminals at the glacier snouts. The lowest down of these transverse moraines are the largest (up to 200 feet in height), and they decreased in size as the glaciers shrank upwards, forming barriers to the drainage and giving rise to lakes and tarns. Of these the principal are Lake May (Cootapatamba), situated in Ramshaw Pass, on the southern slopes of Mount Kosciusko, which is a quarter of a mile in length, 17 feet in depth, and is held up by a moraine 75 feet in height; Lake Albina, about the same size as Lake May, situated on the eastern slopes of Mount Townsend, above where the valley plunges steeply down on the western flanks into the head waters of the River Murray; and the Blue Lake and Hedley Tarn, which occupy

* *See Proc. Linn. Soc. N.S.W.*, vol. X. (1885), pp. 44–53; vol. XVIII. (1893), pp. 349–64; vol. XXVI. (1901), pp. 26–74; vol. XXXIII. (1908), pp. 657–68.

the valley passing from Mount Twynam down to the Snowy River. Some of the more interesting features of the later glaciations are found in connexion with the Blue Lake (or Lake Merewethèr, the largest of the glacial lakes on the plateau), which was carefully surveyed by Professor David. It is, partly, a rock basin, caused by overdeepening at the time of maximum glaciation, but has been subsequently enlarged by a large transverse moraine left at its lower extremity, 20 chains wide, with a present height above the level of the lake (which David proved to be 75 feet in depth) of 160 feet. Another interesting glacial feature of these U-shaped valleys is the occurrence of "hanging-valleys," in which some of the lateral valleys show a discordance of level up to 150 feet with the trunk valleys. Glaciated erratics are common in the ground moraines.

An attempt has been made to estimate the interval of time that has elapsed since the south-eastern highlands had their capping of ice. The time factor must be estimated on three counts :—(*a*) the initial stages of glaciation leading up to a maximum, indicated by the amount of glacial erosion ; (*b*) the later stages of glaciation marked by ice-shrinkage and moraine building; and (*c*) the fluviatile stage which has intervened between the close of the ice-period and to-day. Since the ice-sheet withdrew from the Snowy River valley at a certain level, the stream has cut a V-shaped gorge; first, through the impounding moraine, and then through a bar of solid granite to a depth of 60 feet. Professor David calculated that, to do this, would require from 50,000 to 100,000 years; and that the height of the ice-flood, or maximum glaciation, speaking roughly, occurred some 100,000 to 200,000 years ago, but that only 10,000 to 20,000 years separates the present time from the close of the period of glaciation on the Kosciusko plateau.

(*c*) *The Glaciers of Tasmania.* —Until comparatively recent times Tasmania formed a part of the mainland, and owes its present isolation to a faulted segment in the earth's crust that sank below sea-level and formed Bass Strait. The island consists mainly of highlands (a continuation southwards of the eastern ranges of the Australian continent) which form a great central plateau reaching a maximum elevation of a little over 5,000 feet, the edges of which are broken by deep gorges and isolated peaks, varying in height from 2,000 feet to 5,000 feet. The elevation is inferior to that of the Kosciusko plateau, but as the country is situated some 6 degrees of latitude further south, it might be expected that at the time of the Kosciusko glaciation a permanent ice-field would also exist in the higher regions of Tasmania.

No expedition for the specific object of investigating the Pleistocene glacial remains of Tasmania has been undertaken, but incidental observations bearing on the subject have been made by several travellers who were visiting the country in pursuit of other objects. We are particularly indebted, in this respect, to Mr. E. J. Dunn,* Mr. T. B. Moore†, and Prof. J. W. Gregory,‡ whose observations were limited to the region of the West Coast Range and the Eldon Range. It is probable that further investigations will prove that this glacial field is of greater extent.

On the evidence of the travelled erratics, as well as of the direction of the striæ, the central plateau formed the great gathering ground of the *névé* which found its outlet by the western valleys, the glaciers moving in a westerly and south-westerly direction. The greater heights of the Eldon Range, Mounts Tyndall, Sedgwick, Lyell, and Owen, attaining an elevation of approximately 4,000 feet, supplied their tributary glaciers, which at such levels probably coalesced and formed a general ice-cap. One of the main glaciers occupied the valley between Mounts Tyndall and Sedgwick, flowing westward, and in its retreat left Lake Margaret in its course. Another important glacier taking its rise on the Eldon Range flowed southward by the valley of the King River, one branch passing westward between Mounts Sedgwick and Lyell, and another continuing southward to the eastern base of Mount Owen, a portion overflowing the ridge separating the Linda and Queen valleys.

The usual glacial phenomena are much in evidence in this area. The pre-glacial valleys have been widened and deepened, rocks along the paths of the glacier are smoothed and scored (*roches moutonnées*), glacial lakes and tarns are plentiful, extensive moraines cross the valleys and intercept the drainage, ice-worn and striated boulders occur in typical boulder clays, and erratics, some of immense size, have been far-carried. These and other characteristic features place the fact of the glaciation of the region beyond all question.

* Dunn, *Proc. Roy. Soc. Vict.*, vol. VI. (1894), N.S., pp. 133–38.
† Moore, *Papers and Proc. Roy. Soc. Tasmania*, 1894, pp. 147–149.
‡ Gregory, *Quar. Jour. Geol. Soc. London*, vol. LX. (1904), pp. 37–53.

The Gormanston moraine, which originally crossed the Linda valley, on the eastern side of Mount Lyell mine, has been much eroded by the Linda Creek, but the fragment left on the southern bank of the stream is a mile long and half-a-mile wide, and rises to a height of 320 feet above the level of the creek. The west coast railway shows numerous cuttings intersecting moraines and boulder clays. In the Pieman valley the glacial marks come down to within 400 feet of present sea-level, but as there has been a considerable uplift of the land within recent times in that part of Tasmania, it is not improbable that some of the glaciers came down to sea-level.

There is an apparent correlation between the Australian Pleistocene glaciations and similar features in other parts of the world. The Pleistocene period in the Northern Hemisphere was specially characterized by the "Ice Age" of Europe and North America. About the same time New Zealand, so far as the South Island is concerned, was largely buried under ice, and it is interesting to note that concurrently with the disappearance of permanent ice-fields from Australia and Tasmania there has been a gradual decrease in the size of the ice-covered areas of New Zealand. The ice-flood period of that country has long since passed its maximum, and the wasting glaciers are slowly shrinking upwards towards their source and, in many cases, are now confined to the central portions of their flat-bottomed valleys.

(iii.) **Permo-Carboniferous Glaciations.**—(*a*) *General.*—The Permo-Carboniferous System is the last of the great geological systems that make up the Palæozoic Division in the classification of the stratified rocks. It is a very remote period in the history of this world, and belongs to a time that antedates the beginnings of all the higher vertebrates in the Animal Kingdom. It marks a most important era in the development of this continent, being the period when the plants that formed the coal of the great Sydney Coal Basin flourished in luxuriant growths, and it is their accumulated remains, preserved by a slow subsidence of the land, that yield the greatest source of mechanical energy in the industries of Australia to-day.

The Permo-Carboniferous period is also remarkable for its widespread glacial conditions that have left their evidences in many countries and on both sides of the equator to an extent that may well suggest that it was the most important "Ice Age" that this world has experienced. Australia possesses one of the greatest of these extinct ice-fields and, while the evidences are most marked in the southern portions of the continent, it is remarkable that each of the respective States of Australia give some evidences of ice action belonging to this period, extending northwards into low latitudes that border on the tropics. The time that has elapsed since the Permo-Carboniferous beds were laid down is so vast, and the geological changes that have occurred in the interval have so altered the face of things, that the glacial remains of the period occur only as isolated patches. How far these were originally united to form a more or less continuous ice-sheet cannot be determined, but the evidences shew that, in some localities, the ice was terrestrial and formed ice-caps of great extent; while, in other parts, the deposits were laid down by floating ice under marine conditions. The presence of marine sediments of this age in many parts of Australia and Tasmania makes it probable that, at that time, the land masses formed islands rather than continental areas.

(*b*) *Victoria.*—The absence of marine beds of Permo-Carboniferous age from the southern portions of Australia makes it probable that at that time most of South Australia and Victoria, together with Bass Strait and the north-western portions of Tasmania, formed a continuous land area. This is also suggested by the fact that the only remains of that age known to exist within the areas mentioned are such as indicate terrestrial conditions, and, particularly, the existence of land ice on a large scale. The inter-stratification of true tillites with mudstones, sandstones, and conglomerates suggests the presence of both glacial and fluvio-glacial agencies.

In Victoria, disconnected fragments of these glacial remains occur both on the northern and southern slopes of the Dividing Range. On the northern side of the range, Mr. E. J. Dunn* has observed them at Wahgunyah, Rutherglen, The Springs, El Dorado, Wooragee, Tarrawingee, Baddaginnie, to the north-east of Costerfield, and at Wild Duck Creek, west of Heathcote. The glacial beds are also met with in exploiting the auriferous beds in the deep leads of the district. The beds occupy a trough or valley in the Ordovician rocks, by which they have been protected from erosion. The best exposures

* Dunn, *Report Aus. Assoc. Adv. Science*, vol. II. (1890), pp. 452–458.

on the northern side of the Divide are in the neighbourhood of Wild Duck Creek, where the area covered amounts to 35½ square miles. The floor over which the ice moved is glaciated in places, the *striæ* having a nearly north and south direction. The erratics are numerous and very varied, apparently gathered from the older rocks that form the geological axis of the country. The boulders scattered over the surface are very often facetted and ice-scratched, and, in some instances, reach a diameter of from 20 to 30 feet. The best locality to study the features is at a point where the railway from Heathcote to Bendigo crosses the Wild Duck Creek. As in the case of the Bacchus Marsh section (referred to below), the upper beds consist of a soft sandstone carrying impressions of the fern *Gangamopteris*.

The most important exposures of the glacial beds on the southern side of the Dividing Range occur in the gorges of the Lerderderg Ranges, a few miles to the westward of Bacchus Marsh. Excellent sections can be seen in the Werribee River and its tributaries, Pike's Creek, the Myrniong and Korkuperrimul Creeks, also in the Lerderderg River and its tributaries.

The beds consist of variously-coloured mudstones (the thickest of these measures 193 feet), with numerous erratics, up to 5½ feet in diameter, many of which are strongly glaciated; sandstones and conglomerates, which occasionally contain glaciated erratics, and, in the upper members, sandstones that have an average thickness of 30 feet,* carrying plant-remains. Sandstone is a bad medium for the preservation of plant-remains, but three species of *Gangamopteris*, as well as the remains of *Schizoneura*, and *Zeugophyllites* have been determined, which are all characteristic forms in the Permo-Carboniferous flora. The presence of these plants near the top of the series is a very important item of evidence, as it fixes the date of the glaciation as not later than the Permo-Carboniferous, and probably not much, if any, earlier than that period.

The inference that it was land ice that gave rise to the deposits in question is based on two factors; one that the Ordovician rocks on which they rest have been deeply fluted, scored, and polished by glacier movement; and the other that the ploughed up material of which the mudstones consist has been worn away from the local rocks over which the glacier moved. Another conclusion, based on the direction of the glacial striæ, is that the ice came from the south and travelled in a north-easterly direction.

(*c*) *Tasmania.*—The Permo-Carboniferous System in Tasmania is extensively developed, making surface features over about half of the island, and is very generally distributed. Tasmania, at that period, appears to have formed a coastal fringe bordering a mainland, as the sediments show alternating conditions of dry land, fresh water, carbonaceous swamps, and shallow seas.

The Permo-Carboniferous glacial features of Tasmania are of two kinds, the one indicating land ice and glaciers, situated in the north; and the other, floating ice, which dropped its burden of stones and mud in a shallow sea in the south. The most important section in the country belongs to the first of these kinds, and outcrops on the north coast (at a low angle of dip) for a distance of 5 miles, in the neighbourhood of Wynyard. The beds aggregate a thickness of over 1,200 feet,† and consist of tillites, conglomerates, and thinner beds of sandstones and shales. Glaciated erratics, measuring up to 5 feet in diameter, are plentiful in the section. The existence of three striated pavements, at various levels in the beds, noted by Professor David, is an interesting feature, and probably represents an advancing ice-sheet over its own bed after a temporary recession. The western end of the glacial outcrop is capped by the fossiliferous Tertiary beds of Table Cape, and the eastern end or basal portion is covered by a narrow basaltic flow in an old Tertiary valley, which unfortunately obscures the junction of the glacial beds with the older rocks, but as the Ordovician slates form the outcrop on the other side of the basaltic cap there can be no doubt that they form the glacial floor. Many of the erratics included in the tillite shew a very close resemblance to the rocks occurring around Heazlewood and Zeehan and about 30 miles to the southward, which shew a northerly trend for the ice, and also agree with the direction indicated by the striated pavements, the latter trending from S.S.W. towards the N.N.E.

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* For a complete section of these beds *see* David, *Quar. Jour. Geol. Soc. London*, vol. LII. (1896), pp. 289–301.

† For a detailed section of the beds *see* David, *Report Aus. Assoc. Adv. Science*, vol. XI. (1907), p. 278.

There are no marine beds in the Wynyard section, and a microscopical examination of the finer material of the boulder bed, near its base, shews it to be composed of Ordovician shales and quartzites in a triturated condition. As the latter formed the floor over which the ice moved it is confirmatory evidence of its terrestrial character. There is also a very close analogy in the lithological features between the Victorian and Wynyard sections, and it is probable that the latter represents the southern extension of the terrestrial ice-sheet which had its greater developments in the regions now represented by South Australia and Victoria.

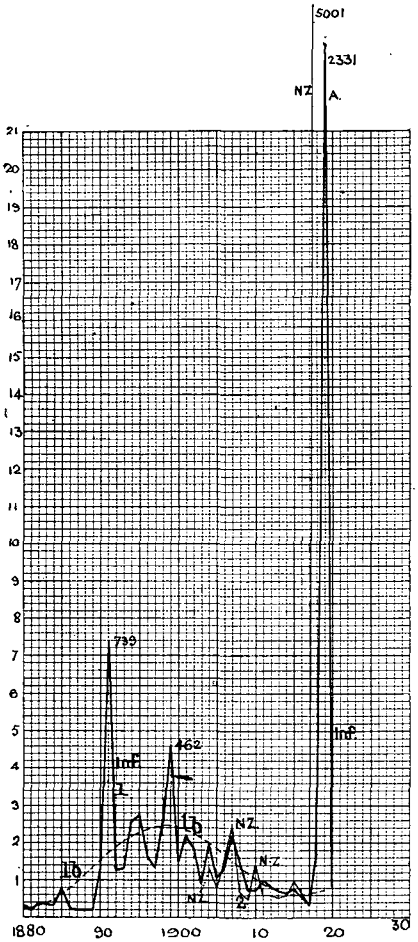
In the southern portions of Tasmania, dark-coloured muds carrying glaciated stones foreign to the neighbourhoods in which they occur, are found in many places. Examples may be seen in the Derwent Valley, Bruni Island, Maria Island, Little Peppermint Bay, in the neighbourhood of Port Cygnet, and other places. These boulder beds either carry marine fossils, intermixed with the glacial erratics, or are closely associated with marine beds, giving evidence that the glaciers in those localities came down to sea-level and, together with shore-ice, became the means of distributing the morainic material from the adjacent land over the sea floor.

(*d*) *South Australia.*—In connexion with this subject South Australia is distinguished in two ways. It was in South Australia that the first evidence of ice action was discovered on the Australian continent, and it is the State in which the most extensive evidences of Permo-Carboniferous glaciation occur. In 1859, Mr. A. R. C. Selwyn, Government Geologist of Victoria, when passing through the Inman Valley, recognised an ice-smoothed surface in the bed of the River Inman, and stated, " this is the first and only instance of the kind I have met with in Australia." Later observations proved that the glaciation was of Permo-Carboniferous age. This discovery of Selwyn's attracted little notice and remained unverified for many years. In 1877, the late Professor Tate discovered a glaciated pavement on the sea cliffs at Hallett's Cove, 30 miles north of Selwyn's discovery and within 15 miles of Adelaide. Subsequent investigations proved that the Hallett's Cove example was only a small outlier (two miles long and half-a-mile broad) of a much greater glacial field further to the south, covering many hundreds of square miles.

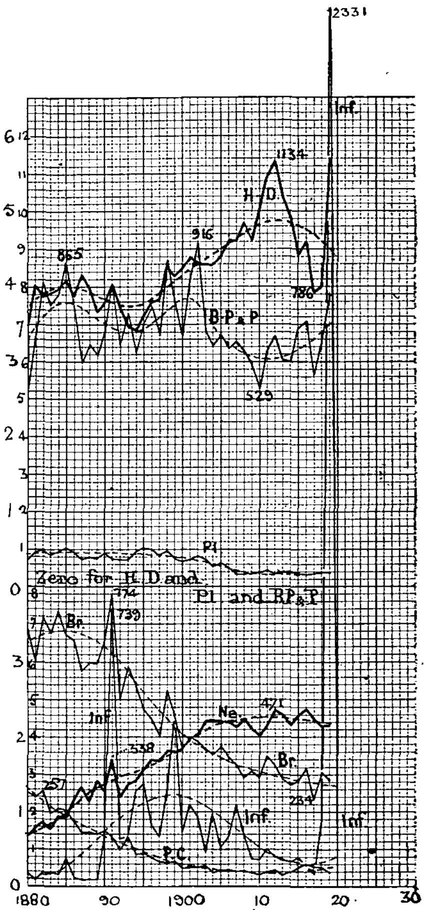
Since the Permo-Carboniferous ice-period the plateau of the Mount Lofty Ranges has been elevated and broken up into very large faulted blocks that have undergone much waste in the interval. The Hallett's Cove fragment is the only survival of the glacial mantle that once overspread the earth-block that, in its present configuration, has Mount Lofty as its highest point, and which dips away southwards to the base of the Willunga Ranges. The last-named ranges form the northern scarp of another faulted block that slopes again southwards to the southern coast. This region is largely covered with glacial debris and ice-marks. The area in which such features are especially manifested takes in most of the Cape Jervis peninsula from Myponga following the coastline by Second Valley to Cape Jervis, and from Myponga in a north-easterly direction by Mount Compass to near Bull's Creek and Strathalbyn. On the east it is bounded by the Strathalbyn and Victor Harbor railway as far as the last-named township. Then, in a westerly direction, it follows the coast again, to Cape Jervis. This block of country includes the glacial valleys of the Myponga and Yankalilla Creeks, the Inman, the Hindmarsh, and the Finniss Rivers, in addition to several ice-smoothed granite islands lying off the coast.

The Inman Valley forms one of the most striking features in this region. The Inman and Hindmarsh valleys together represent an old Palæozoic valley of erosion having an average width of 5 miles, which in its later stages became deluged with an ice flood that has moulded its physical features into a characteristic glacial topography. The ice filled the valley and overflowed the present watersheds, to do which would require an ice-sheet of, approximately, 2,000 feet in thickness. Wherever the glacier floor has been laid bare (which has been noted in over a dozen places, in one of which the exposure is 100 yards in length), it is seen to be powerfully glaciated. All rock prominences on the floor of the valley are ice-smoothed, shewing the characteristic gentle slope on the advancing side of the ice-sheet and the crag face on the lee side. Erratics, up to 25 feet in diameter, in countless numbers, are scattered over the face of the country, many shewing the usual glacial outline and scratches, while typical examples of till can be seen in the banks of the river Inman and elsewhere. Most of the larger erratics have been ploughed up from the granite zone, bordering the southern coast, and have been carried in a N.N.W. direction. The present superimposed drainage is slowly acting on the glacial clays and

SECULAR FLUCTUATION IN THE FREQUENCY OF INFLUENZA AND OTHER DISEASES.



GRAPH NO. 1.



GRAPH NO. 1A.

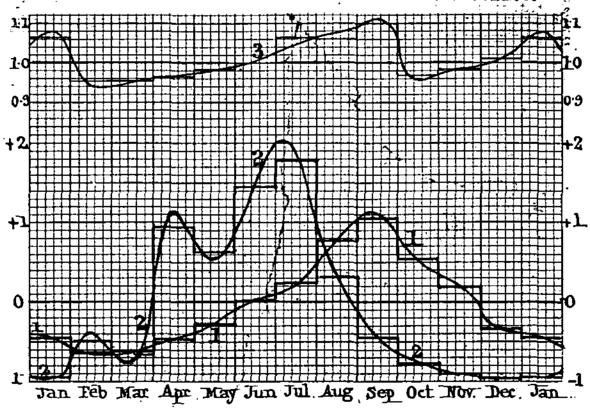
No. 1. Curve 1 represents the death rate per million persons from influenza 1880 to 1919. The light line is the corresponding death rate for New Zealand from 1904 to 1918. The oscillation is shewn by the broken line 1b.

No. 1A. The death rates per million persons are given for various diseases as follows :—

H.D. ..	Heart disease.	Br. ..	Bronchitis.
B.P. and P. ..	Broncho pneumonia and pneumonia.	Ne. ..	Nephritis.
		P.C. ..	Pulmonary congestion.
Pl. ..	Pleurisy.	Inf. ..	Influenza.

In the vertical scale each small square represents a death rate of 20 per million persons.

FLUCTUATION OF THE ANNUAL PERIOD OF INFLUENZA.



GRAPH NO. 2.

NO. 2. Curve 1 shews the ratios of death rates per annum for million persons during each calendar month to their mean annual value.

Curve 2 shews the difference in annual distribution of influenza during 1919, and curve 3 the normal distribution in calendar months.

AGE–INCIDENCE GRAPHS (see next page).

Curves 1 and 1′ shew the deaths from influenza per million of males and per million of females of each age group during the 9 years 1907–15, curves 2 and 2′ for the 3 years 1916–18, and 3a and 3′a for 1919. Curves 4 and 4′ are the corresponding figures for pneumonia for the 9 years 1907–15.

Curves 3 and 3′ represent the ratio of deaths per million males and females of same age to deaths per million males and females of all ages.

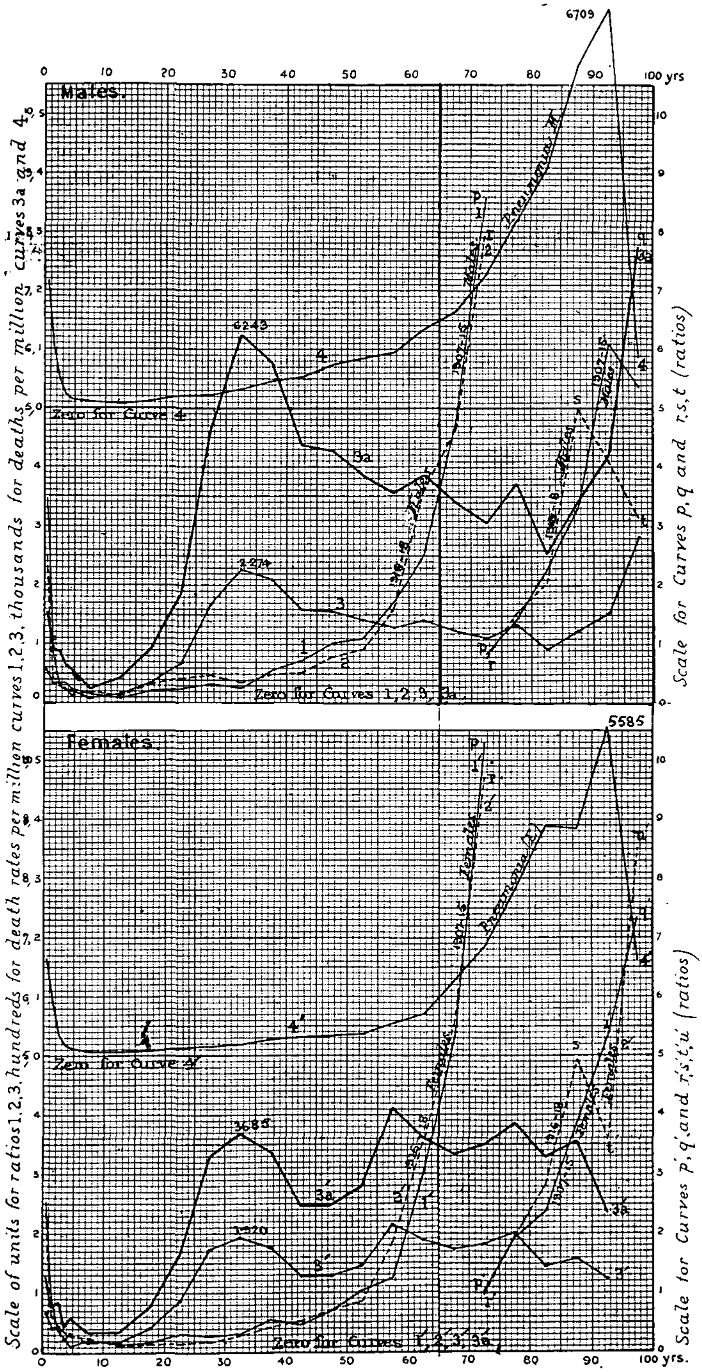
To compare the death rates per million per annum take curves 1, 2, 3a and 1′, 2′, 3′a.

To compare the death rates if the total deaths were equal take curves 1, 2, 3 and 1′, 2′, 3′.

CHARACTER OF THE AGE-INCIDENCE IN THE MORTALITY FROM INFLUENZA.

GRAPH NO. 3.

GRAPH NO. 4.



(For explanation of Graphs see preceding page).

sandstones, thereby exposing a buried landscape that was shaped by the conditions of waste that were operative, by water and ice, as far back as Palæozoic times, and therefore ranks as one of the oldest examples of surface features that the world can shew.

The eastward extension of this old ice-field has been obliterated by the important earth movements connected with the Murray plains, (where there has been a great subsidence below sea-level since the Permo-Carboniferous ice period), but to the westward it is strongly in evidence over the southern half of Yorke Peninsula and the north-eastern portions of Kangaroo Island, and undoubtedly covered the intervening areas now drowned by the sea. A bore put down at Kingscote (Kangaroo Island), at sea-level, penetrated 1,094 feet of boulder clays before reaching bed-rock.

What remains of the great Permo-Carboniferous ice-field in South Australia indicates an area of glaciation at least 130 miles by 100 miles, but the actual extent must have been much greater than this. It is significant that in Northern Tasmania, as well as in Victoria and South Australia, the ice-sheet was travelling from south to north, which proved that one centre of radiation was to the south of the continent and is now probably submerged. In South Australia, from the mouth of the River Hindmarsh, near Victor Harbor, to Cape Jervis, the coast is severely glaciated and burdened with morainic material, while the coastal islands show similar glaciated features, with the glacial striæ pointing south and north. There is plenty of scope for the imagination in restoring the physical features of those remote days with its limitless landscapes of ice and dazzling surface of snow.

(e) *New South Wales.*—When, in 1885, Mr. R. D. Oldham, the Director of the Geological Survey of India, was visiting New South Wales, he was greatly struck with the resemblance which certain beds at Branxton bore to the Talchir glacial beds of India, of a similar geological age, and after a little searching he was rewarded by finding a definitely glaciated pebble in these beds. This was the first discovery of its kind in New South Wales, and was the forerunner of many similar ones in later years.

The glacial features as developed in New South Wales are of a quite different kind from those found in the southern States. While the highlands of Victoria, South Australia, and North-western Tasmania were above sea-level and ice-capped, in Permo-Carboniferous times, the great Sydney coal basin was slowly sinking below sea-level. The system reaches a maximum thickness of 17,000 feet, and includes three well-defined glacial horizons.

The lowest series of glacial beds is included in the Lochinvar stage, of which they form the base, and is over 200 feet in thickness. They consist of mudstones, shales, and sandstones, and while not of the nature of a till, they carry water-worn pebbles, with occasional ice-marked boulders. The beds, in their earlier members, indicate fresh-water conditions, but pass up into marine sediments which, classed under the general name of the Lower Marine Series, have a thickness of 4,800 feet.

A period of emergence followed, when the land was covered with vegetation which took the form of fern brakes and peaty swamps yielding layers of carbonaceous material that formed the Greta and Clyde coal measures, the maximum thickness of which is 250 feet.

Following on the interval of dry land conditions which produced the Greta Coal, a second submergence of the land took place, which resulted in 5,500 feet of marine sediments being deposited, forming the Upper Marine Series, which contain a great assemblage of organic remains. The lower half of the Upper Marine Series is known as the Branxton beds, and towards their upper portions is a well-marked glacial horizon. Mud and stones brought by icebergs, or other forms of floating ice, were scattered over the sea floor, and ice-scratched stones are found mingled with marine forms of life. Where this bed comes to the surface it makes good hunting ground for erratics, some of which reach a weight of over 2 tons, and indented the mud into which they were dropped.

A few hundreds of feet higher in the series than the Branxton horizon, just referred to, are the Muree beds, consisting of fossiliferous sandstones and conglomerates, in which glacial erratics again make their appearance. There are thus, in the Permo-Carboniferous System of New South Wales, three distinct periods of ice aggression and two interglacial periods. The absence of ice-borne material between the Lochinvar stage and the Branxton stage, and the same between the latter and the Muree stage, appears capable of explanation by the well-known fact that glacial intensity is subject to various modifying causes. We may assume that the three occasions when floating ice reached the latitude of the Sydney basin were periods of maxima in the ice floods of the highlands, while the intervals in which the seas in question were left free from glacial detritus, corresponded with periods in which warmer conditions prevailed when the land ice failed to come down to sea-level. The Muree stage, in the development of the Permo-Carboniferous of New South Wales, appears to be the latest at which there is evidence of glacial conditions of that age. The amelioration of climate, dependent on certain physical changes of which we have no knowledge, led to the disappearance of the permanent ice-cap; first, the glaciers failed to come down to sea-level, and then the tongues of ice, slowly shrinking, receded to higher altitudes until the permanent snow-field ceased to exist.

(*f*) *Queensland.*—The Permo-Carboniferous System passes northwards from the New South Wales border into Queensland, and occurs in several disconnected areas as far north as Townsville. Upper and Lower Marine beds alternate with Upper and Lower Coal Measures, the latter including very thick and valuable coal seams. No typical tillites or well-defined boulder beds occur in the series, but, in places, boulders of granite and other stones foreign to the series occur, either singly or in groups, included within the finer marine sediments, which is suggestive of similar glacial conditions to those which existed in New South Wales and Western Australia at that time. These sporadic pockets of boulders probably represent the northern limits of the floating ice of the period on the north-eastern portions of the continent.

(*g*) *Western Australia.*—The Permo-Carboniferous System of Western Australia includes the Collie Coal-field (an isolated fragment, 500 square miles in extent, situated to the east of Bunbury), an outlier in the Irwin River district, and a somewhat narrow zone extending in a north and south direction from the Murchison River, in the south, to Kimberley, in the north. With the exception of the Collie Coal-field the beds are supposed to be of marine origin, and carry a rich Permo-Carboniferous fauna with an admixture of forms that shew a close relationship with the true carboniferous marine fauna of the Northern Hemisphere and Indian types, which feature distinguishes the Western Australian beds from those of a similar age in the eastern States of Australia.

As in other parts of Australia, the Permo-Carboniferous System of Western Australia includes a glacial horizon, known as the Lyons Conglomerate, which, although limited to a few feet in thickness, is very persistent. The most southerly exposure of the glacial conglomerate is in the River Irwin district, where it can be traced for a distance of 24 miles. It is next seen in the Wooramel Valley, about 180 miles north of the Irwin, and continues from there, northwards, in an uninterrupted outcrop for over 200 miles. In this district it crosses the valleys of the Gascoyne, the Minilya, the Lyndon, and other rivers, in which excellent sections are visible. The bed is interstratified with calcareous shales and limestones which are generally highly fossiliferous, and the glacial conglomerate itself is sometimes fossiliferous. The beds usually dip at a low angle, so that notwithstanding the limited thickness of the glacial bed it often makes a considerable spread over the flats adjacent to the rivers, which become covered with erratics weathered out from the matrix. Many of these are glaciated and some are very large—one on the Irwin is 18 feet long and 13 feet wide, and is exposed 7 feet out of the ground. The erratics are said to have been derived from the older rocks which occur in outcrops further to the eastward. The glacial bed has been followed in its northward extension beyond the Lyndon Valley, into the tropics, in about 23° south latitude.

(*h*) *General Remarks on the Permo-Carboniferous Glaciation.*—So distinctive a feature as an Ice Period suggests more or less contemporaniety in its phenomena, as well as in the associated beds, within the regions concerned. Thus, the Permo-Carboniferous Ice Period is represented in a wide circle of countries, including the Falkland Islands, Brazil, South Africa, India, and Australia, which together comprise what has come to be known as Gondwanaland. Notwithstanding the great extent of the earth's surface involved there was a remarkable similarity in the flora of these countries during the Ice Period which they experienced in common. There is reason to think that on account of the refrigeration of the climate and the prevalence of land ice, which often reached to sea-level, the flora of these countries became greatly changed. With some measure of exception in the case of South Africa, the typical plants of the Coal Measures of the Northern Hemisphere (*Lepidodendra*, etc.), which were of the nature of a rank-growing and warm-climate flora, died out very suddenly, and their place was taken by a dwarfed herbage, characterized chiefly by the ferns *Glossopteris* and *Gangamopteris*. These plants and some other associated types flourished abundantly in the countries named at the time of the great ice-flood (possibly during interglacial warmer periods), and in many places were the origin of important coal seams. The effect of the cold seems equally evident in the marine life of the period. Floating ice would chill the water and produce uncongenial conditions for some forms of life. Corals, some of which were reef-building, were abundantly developed in Carboniferous seas, as well as certain characteristic brachiopods. These warm-water forms (with the exception of a few survivals in the Western Australian region) became extinct within the Australian area before the Lochinvar glacial deposits were laid down, while some new forms took their place which find their analogues in corresponding beds in India and South Africa.

[NOTE.—By the courtesy of Professor David I have received (under date of 23rd January, 1920) an advance statement of an important discovery made by him and Mr. Süssmilch of glacial beds below what has hitherto been regarded as the base of the Permo-Carboniferous System of New South Wales. He states, "We have now proved glacial conglomerates and their tillites, with occasional striated pebbles interstratified with our *Rhacopteris* (Middle Carboniferous, or even Culm) beds at several places east of Maitland. These glacial conglomerates and their tillites underlie conformably the base of our Lower Marine Permo-Carboniferous System. There may, perhaps, be disconformity, but it does not look like it." This important discovery may mean, either that the Permo-Carboniferous Ice Period began earlier than has been estimated hitherto, or we have, in this latest find, a distinct glacial period that took place in Australia in an older geological system.]

(iv.) **Cambrian Glaciations (the Sturtian Tillite).**—(*a*) *General.*—While the Permo-Carboniferous glaciation is included in the highest system of the Palæozoic Division of the stratified rocks, the Cambrian glaciation belongs to the lowest member of that Division. The length of time that separates us from that remote period is inconceivably great, for the Permo-Carboniferous Ice-Age, remote as it is, takes us only about half-way to the glaciation that occurred in the Cambrian Period.

(*b*) *South Australia.*—South Australia holds the distinction of being the first to give definite evidences of glaciation at so early a stage in the geological history of the world*. The discovery was made in 1899, and the first public announcement in 1901†. With the exception of an extension of the glacial beds to the Barrier Ranges, on the New South Wales side of the borders, the Cambrian tillite on the Australian continent, so far as is known, is limited to South Australia.

Notwithstanding the great age of the glacial beds, their resemblance to a recent boulder clay, or till, is very striking. The matrix is a bluish or brownish, flaky mudstone, irregularly indurated, gritty in texture, and contains angular and subangular erratics of all sizes up to 10 feet in diameter. Many of the boulders are facetted and glacially striated. At the Appila Gorge, 155 miles to the north of Adelaide, the beds are nearly vertical and shew a thickness of about 1,526 feet. The basal portion of the section consists of an unstratified boulder clay, or tillite, 750 feet in thickness; then follows a middle series of shales, quartzites, and thin limestones, containing few erratics, totalling 656 feet; and an upper tillite, 120 feet in thickness.

The Cambrian tillite has been traced, in a north and south direction, from the southern banks of the River Onkaparinga (18 miles south of Adelaide) to the Willouran Ranges near Marree (Hergott Springs), a distance of 450 miles; and in an east and west direction, from the ranges near Port Augusta to the Barrier Ranges in New South Wales, a distance of about 200 miles. The beds probably, at one time, formed a continuous sheet over this vast area, but, through folding, the anticlinal curves have been worn away, and by downthrow faulting the continuity of the deposits has been broken.

The Sturt Valley may be regarded as the type locality for these beds. It was there that their glacial origin was first recognised, and in the gorge of the Sturt River some of the grandest exposures of the tillite can be seen. It is on such considerations that the name of the "Sturtian Tillite" has been applied to the formation as a whole. The type

* For particulars of other ancient tillites, *see* Howchin's *Geology of South Australia*, pp. 505–509, Education Department, Adelaide.

† Howchin, "Preliminary Note on the Existence of Glacial Beds of Cambrian Age in South Australia," *Trans. and Proc. Roy. Soc. S. Aus.*, vol. XXV. (1901), pp. 10–13. "Glacial Beds of Cambrian Age in South Australia," *Quar. Jour. Geol. Soc. of London*, vol. LXIV. (1908), pp. 234–259.

locality begins about 9 miles south of Adelaide, and is included in the area bordered by the Adelaide to Melbourne railway on the eastern side and the Sturt Gorge on the western. It forms an isolated patch, rather more than a mile square, the base being on the south-eastern side and the upper limits on the north-western, while the beds are determined on the northern side by an east and west fault.

Within the area that has come under observation in South Australia it is probable that the glacial material was dropped from floating ice. The grounds on which this deduction is made are as follows:—(*a*) The great extent of country covered and the (original) continuity of the deposits within the area. (*b*) The absence of any glacial floor or evidence of unconformity at the base. (*c*) The erratics have not been gathered from the beds which, for several thousands of feet, underlie the glacial horizon, but are gathered from the Pre-Cambrian complex that formed the boundaries of the Cambrian geosyncline on the south and west. (*d*) While the beds consist, for the most part, of a characteristic till, the latter, in places, is interbedded with laminated shales, sandstones, grits, and impure limestones, which are either destitute of erratics or possess these to a sparing degree, suggestive of intervals when the absence of floating ice permitted ordinary sedimentation of suspended matter in the water to take place. On the other hand, there are evidences that indicate that the permanent snow-field and centres of dispersion were at no great distance. Many of the erratics can, with some degree of confidence, be identified as belonging to Pre-Cambrian forms that occur in the outcrops of rocks of that age in southern Yorke Peninsula, Port Lincoln region, and the Gawler Ranges—regions which, at that remote period, probably formed a highland plateau. As the Pre-Cambrian basement occurs as far south as the Neptunes and Kangaroo Island, it is probable that the ice-clad plateau extended far into what is now the Southern Ocean.

3. Persistence of Natural Records.

These climatal facts, as bearing on the earth's condition in the past, are of very great importance in influencing geological deductions. It had previously been thought, chiefly on account of the very wide distribution of certain genera and species in these early times, that there was a marked uniformity of temperature on the earth's surface at this period, and that it was of a mild type. It is now evident that there were temperature zones on the earth's surface in Cambrian times as strongly marked as they are in the present day—extensive regions in which permanent snow and ice must have existed and which, in some localities, must have come down to sea-level. It supplies a further proof of the uniformity and persistence of natural processes, and in the preservation of such frail indications as scratches left by moving ice, fossil rain-pits left by a passing shower, and the track of a marine worm that had crawled over the sand on the shore, we have remarkable instances of conservation in Nature. Nature has blazed her track through the ages, with her tool marks, her fitful changes, her ideals of animal structure, her derelicts, leaving at every step her footprints and an imperishable record of the stages by which she has risen from a primitive simplicity to the complexity of the present age.

§ 20. International Currency.

1. **Coinage.**—Half a century ago economists were much concerned with the possibility of establishing an international coinage. For this purpose it is not necessary that the coinage of every country in the world should be unified. But, if the currency systems of the most important trading countries of the world are examined, it will be found that very close relationships can be established between simple multiples of their units. Thus, the British sovereign contains 7.32238 grams of fine (pure) gold: the American 5-dollar piece 7.52299 grams: the French 25-franc piece—if such a coin were in circulation—would contain 7.25805 grams: the German 20-mark piece 7.16846 grams: and the Japanese 10-yen piece 7.50000 grams. The nearness of these results suggests that if these nations could be induced to make such alterations in their respective currencies as to bring these five values into exact agreement, then one single piece of gold-money could be struck, circulating in the British Empire as a sovereign, in America as a 5-dollar piece.