(4.) The second cycle of erosion, though less complete than the first, produced the fluvio-glacial Moutere drifts and the Old Man Bottom gravels, and was initiated by the forcing-up of the peneplains and the consequent reopening of the fractures. The Whakamarama peneplain was tilted to the north-west and the Victoria peneplain to the west, and to this is due their present drainage. The higher elevation of the alpine peneplain caused its western drainage to cross the Wainihinihi, Victoria, and Murchison peneplains where these abut against the alpine peneplain. The drainage of the lower country, which dates back to this time, has been most profoundly influenced by the great fracture-lines, especially in the alpine peneplain.

(5.) The third, or present, cycle of erosion is very incomplete. Further movement took place along the fracture-lines, and certain changes in the drainage.

ART. XXXVII.—*The Mount Arrowsmith District: a Study in Physiography and Plant Ecology.*

By R. SPEIGHT, M.A., M.Sc., F.G.S.; L. COCKAYNE, Ph.D., F.L.S.; and R. M. LAING, M.A., B.Sc.

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PART I.—PHYSIOGRAPHY.

By R. SPEIGHT, M.A., M.Sc., F.G.S.

[*Read before the Philosophical Institute of Canterbury, 1st June, 1910.*]

1. INTRODUCTORY.

THIS paper deals with the physiography of a part of Canterbury which is little known even now. Although reference is made to its general physical features, those which depend on glaciation, both present and past, receive most attention. In presenting this account I have to acknowledge my indebtedness to Sir Julius von Haast on points so numerous that it is impossible to mention them in detail. I therefore take this opportunity to make a general acknowledgement of my debt, and also to express, as one who has followed in his footsteps, even if a long way after, my appreciation of the work which he did in this locality nearly fifty years ago. Considering that physiographical geology was almost unknown as such at the time when he visited the head-waters of the rivers referred to later, it is most surprising to find what a wonderful grasp he had of the principles which underlie that phase of geological study, and, even if he did not know processes and results by the names which are applied nowadays, he certainly had a proper appreciation of their importance, and clearly recognized their operation in nature.

I must also acknowledge my indebtedness in a minor degree to Captain Hutton and to S. H. Cox for their descriptions of portions of this area.

My own conclusions are based on observations made during four separate journeys to various parts of the district.

2. MOUNTAIN SYSTEMS.

(*a.*) *Topography.*

(See map, p. 318.)

The district dealt with in this paper lies at the head of the Ashburton and Rakaia Rivers, and forms part of the eastern slopes of the main range of the Southern Alps, in lat. 43° 20′ south approximately. In this part of the range its average direction is north-east to south-west, but owing to extensive erosion by rivers and glaciers the valleys on either side dovetail into one another in a most remarkable manner, so that the actual crest is a very irregular line. The principal peaks, taking them in order from Whitcombe Pass to the head of the Rangitata River, are the following: Louper Peak (8,165 ft.), Mount Whitcombe (8,656 ft.), Blair Peak (8,185 ft.), Malcolm Peak (8,236 ft.), and Mount Tyndall (8,282 ft.). Running east from the main range, and forming the main divide between the upper valleys of the Rangitata and the Rakaia, is an elevated ridge connecting the Arrowsmith Range with the central mountain system. This ridge is everywhere over 5,000 ft. in height, and has several prominent peaks on it, notably Mount Goethe (over 6,000 ft.) and Mount Murray (7,065 ft.). The Arrowsmith Range stretches in a north-east to south-west direction, generally parallel to the Southern Alps, and rises to a height of 9,171 ft. in Mount Arrowsmith itself, with numerous minor points about 8,000 ft. Mount Arrowsmith is thus higher than any peak in the vicinity, and, indeed, is higher than any peak on the main divide behind it with the exception of those in the Mount Cook group. The same peculiarity in the position of the highest peaks with regard to the mountain axis of the South Island is to be observed further south, where Mount d'Archiac (9,279 ft.) in the Two Thumb Range, Malte Brun in the Maltebrun Range, and Mount Cook itself lie to the east of the main watershed, and excel in elevation the neighbouring peaks on it. The crest of the range also lies far to the east of the structural or tectonic axis of the Island, which no doubt follows up through the schistose belt between the sea and the present main range about twenty miles from the west coast. This suggests that the present configuration has been the result of excessive erosion acting for a long

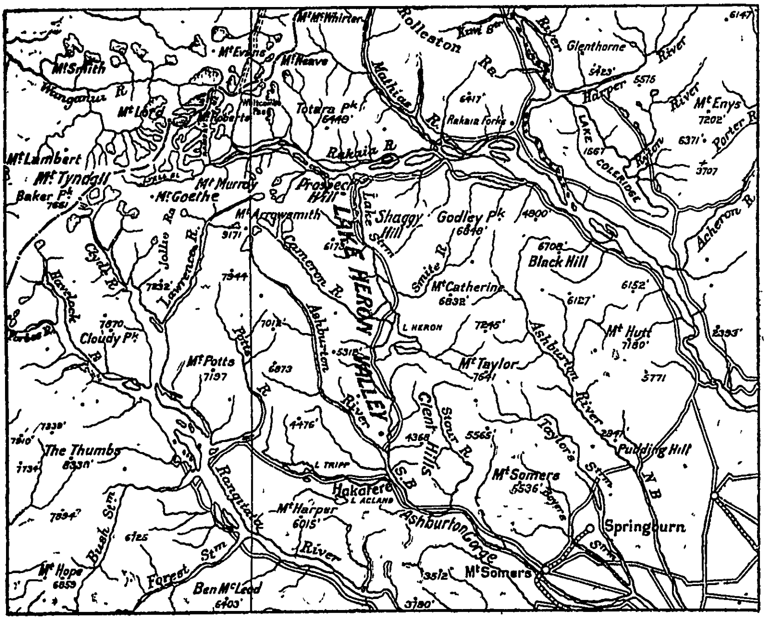

FIG. 1.—MAP OF MOUNT ARROWSMITH DISTRICT.

period of time on the western wing of the geanticline of which the range has been built, far more profoundly than it has acted on the eastern wing.

(*b.*) *Relation to Rainfall and Conditions of Erosion.*

The mountains in this locality lie right across the direction of the prevailing westerly winds of this latitude, and the bulk of the moisture is intercepted on their western slopes. The conditions are exactly the same as these further north at Otira, which, according to the records of the meteorological station recently established, has a yearly rainfall of a little over 200 in., while at Bealey, about twelve miles away in a straight line, it is only 100 in. Although no statistics are available for the Rakaia region, the effect is clearly visible in the character of the plant covering, which changes from the rain forest of Westland to the markedly xerophytic tussock steppe of the region to the east of Mount Arrowsmith. Intermediately there is the totara forest of the Upper Rakaia, which has followed the rain just across the main divide from the montane rain forest containing totara on the higher hill country of Westland.

These different conditions of rainfall have probably lasted for a very long time, and their effect is evidenced by the lower elevations to the west, where the subaerial denudation has been excessive, owing to the heavy rains causing frequent floods and the great amount of snow forming large and powerful glaciers. There is evidence from other parts of the Alps that the dominant western erosion has resulted in the capture by the western streams of the upper tributaries of some of the rivers of the eastern watershed. It is only in some such way that the formation of Arthur's Pass can be explained. This action is likely to continue when the marked difference in the height of the floors of the eastern and western valleys is considered—for example, the floor of the Bealey Valley near the tunnel-entrance is at an altitude of 2,435 ft., while the western end, at Otira, five miles and a quarter distant, is only 1,583 ft.—that is, it is 852 ft. lower. The same is generally true for the other valleys of that part of the Southern Alps, a feature well brought out by Mr. Edward Dobson's original surveys for a road across the range. This remarkable physical peculiarity can be most easily explained by the greater efficiency of eroding agents on the western side of the range. The heads of the valleys have been sapped back by glaciers, and the valleys have been deepened by ice and water action so that they have been able to encroach on their eastern neighbours; and the marked overlapping of adjacent streams on either side of the crest of the range intensifies this effect when capture of even one small tributary has taken place. The more rapid erosion on the west will lower the range progressively from that direction, so that the eastern region will become of relatively higher relief, and in future geological time Mount Hutt and Mount Torlesse, on the eastern border of the mountainous country, will, if similar meteorological conditions continue, become its highest elevations.

(c.) *Present Form of Mountain Region—a Dissected Peneplain.*

The rocks of which the area is composed consist of greywackes, slates, and mudstones of Lower Mesozoic age, which have been folded subsequently by mountain-building movements into folds whose general axes run in a N.N.E.–S.S.W. direction. Local variations appear to be frequent, so that at times the direction is almost E.–W., and again become N.W.–S.E. This variation is apparently due to change in the direction of the thrusts by which the area was folded. The date of the folding is probably Upper Jurassic, but it may have been Upper Cretaceous. A feature of the mountainous region which has thus been produced is the approximately uniform height of the great majority of peaks. A very large number of these are between 6,800 ft. and 8,200 ft. in height, with very few above or below these limits except in the Mount Cook region. This suggests that the whole area has been reduced to a level platform either by marine denudation or, more probably, has been base-levelled by a former stream system, and a few peaks, like Mount Arrowsmith, which dominate the rest are the residual elevations on the peneplain. The higher mountains which no doubt once existed further west, and have been removed by erosive agents, would represent the higher mountains on this peneplain. It is possible, however, that the present prominent elevations are the remains of an old divide which existed on it, and from which streams once flowed east and west.

In advancing this theory for the present form of the mountain region of Canterbury, I am quite aware that this is contrary to the generally accepted opinion that *in their present form* the Southern Alps are a mountain-range of the alpine type. They were undoubtedly at one time such a range, though one in which the folding was not acute, being somewhat of the nature of a series of isoclinals; but they have been base-levelled subsequently, and then raised and partially dissected. Dissection has not reached a moderately advanced stage, and a residual divide is still in existence. This is crossed by numerous passes, the lowest of which is Haast's Pass (1,716 ft. high). Such low passes are extremely unlikely to occur in a range of the alpine type unless it has suffered denudation for a long period of time In this connection compare the Southern Alps with the European Alps, the Himalayas, or the Andes The Canterbury peneplain formed from the original range of the alpine type was no doubt continuous with that of Otago, which, according to Professor Park* and Dr. Marshall,† has been traced with certainty as far north as the Waitaki River, with a general ascending slope from south to north. It is extremely unlikely that it broke off suddenly at the northerly boundary of the province, and it must have continued further north towards Mount Cook and the head of the Godley River. From an area of high land in that neighbourhood, or from a ridge continuing north and south from it, the present principal lines of drainage proceeded outward, and this may explain the remarkable orientation of the valleys of the Canterbury rivers noted by E. Dobson, who pointed out that the main valleys all appear to radiate from a point in the Tasman Sea about twenty miles west of Hokitika. McKay has suggested that the arrangement is due to a series of radiating faults, the lines of which are usually followed by the valleys. Of this there is not the slightest direct evidence available at present, the suggested explanation not being founded on observation, but is probably in sympathy with a somewhat mistaken tendency at the present to attribute a large proportion of landscape forms to crustal movements without positive evidence of these movements being brought forward. In this case it seems more reasonable to attribute the undoubted arrangement of the valleys to the shape of the original land-surface on which the drainage was established.

The peneplain explanation of the uniformity of the mountain-tops apparently fits the case best, although there is one consideration which must not be lost sight of—viz., the tendency of all mountain-summits in an area subject to similar conditions to approximate to a general even height. The dominant erosive agent on the mountain-slopes of this region is frost. Under the influence of its powerful action they are covered with immense quantities of moving *débris* which has been riven from the solid rocks. The pointed masses which form the highest peaks are just those which respond most readily to it. Owing to the more rapid weathering of the highest elevations they are gradually reduced to the level of the lower ones, and when the rocky eminences which crown them are destroyed the summits take on a more or less dome-shaped form owing to the accumulation of vast amounts of *débris*, which is formed faster than it can be removed by transporting agents. Although these are very active on the flanks of the mountains, they are somewhat sluggish on the tops, and become more and more so as weathering proceeds. This coating of *débris* acts as a protection, retards degradation of the mountains which have had

* N.Z. Geol. Surv. Bull. No. 5 (n s)—Cromwell Subdivision.
† "Geography of New Zealand."

Fig. 1.—Rakaia River Bed, with Whitcombe Pass in the Distance.

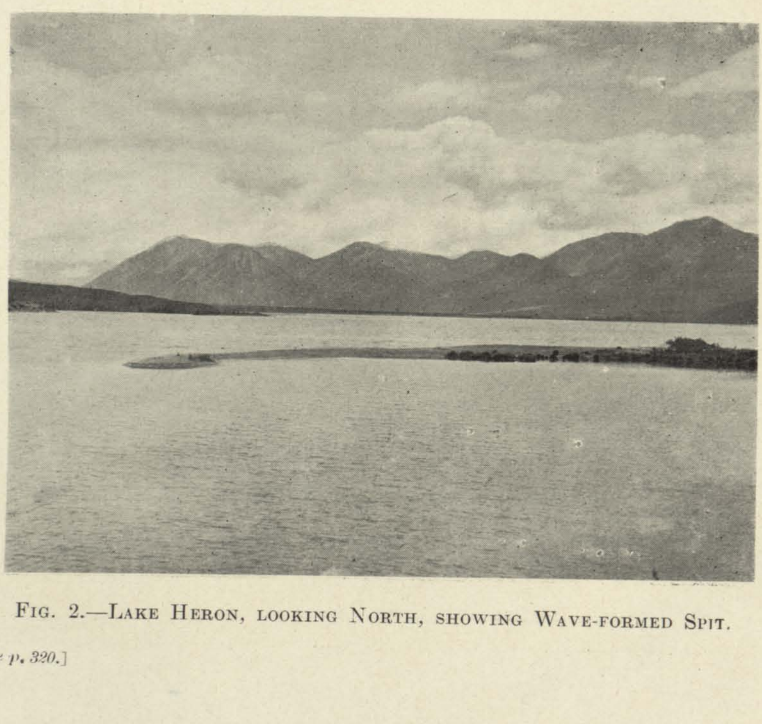

Fig. 2.—Lake Heron, looking North, showing Wave-formed Spit.

Face p. 320.]

FIG. 1.—LYELL GLACIER, FROM MEIN'S KNOB.

Mount Goethe on the left, Mount Tyndall (Haast) in the middle distance, and Malcolm Peak just showing on the right.

FIG. 2.—RAMSAY GLACIER, FROM MEIN'S KNOB.

Mount Ramsay on the left, Mount Whitcombe in the distance.

their prominent peaks removed, and thus promotes the gradual approximation in height. This action becomes increasingly effective as the hills become lower.

This phenomenon is noticed in all denuded mountain regions, but it is also in evidence in Canterbury, where the results of denudation have not reached such an advanced stage. If the old surface of the Canterbury plateau had been a peneplain, a generally uniform height of the principal elevations would follow, because those which stood out on it above the average level would be rapidly reduced to the mean height by the processes described above.

This rough plateau or peneplain has passed through a second cycle of erosion, and the drainage established on it appears to have reached a mature stage at the present time.

3. Drainage Systems.

(*a.*) *Relation to the Structure of the Country.*

Mount Arrowsmith is at present the most strongly marked physical feature of the Upper Rakaia and Ashburton district. Its great mass dominates the whole area. From its south-eastern face flow the main Ashburton River, and the Cameron River, an important tributary of the Rakaia; at the back of it rises the Lawrence; while it is flanked on the north by the valley of the Rakaia, to which it contributes numerous small streams. The mountain is therefore the meeting-place of the drainage-basins of the three important rivers of central Canterbury—the Rakaia, Ashburton, and Rangitata. It must not be assumed that this has always been the case, as the directions of the river-valleys were determined at a somewhat remote date by considerations quite independent of the present surface configuration.

Its first lines seem to have been across the strike of the beds, and this accounts for the general parallelism of the course of the main rivers both inside and immediately outside the area under consideration. The principal valleys—viz., those of the Rangitata, the Ashburton, and the Rakaia—are controlled by this factor. The secondary drainage established itself in the direction of the strike, but modifications ensued as the primary streams cut deep down into the beds of the area, a characteristic modification being that the lateral valleys trend slightly down-stream, and thus cut across the strike at a small angle.

The ternary lines of drainage appear to have reverted to the primary direction, and are seen in the Upper Ashburton and the Cameron River, but the disturbing effects of glaciation have been so marked that it is unsafe to come to any definite conclusion in the matter. Even now, however, the presence of weak beds dipping at high angles undoubtedly promotes the formation of small tributary streams and of low saddles along the strike.

This arrangement of the stream system I have attributed solely to the normal development of drainage in a region composed of folded rocks where the direction of strike is fairly constant. I am quite aware that it is also possible to attribute the arrangement to lines of faulting; but until these faults can be proved on stronger evidence than the occurrence of crushed and shattered bands of rock associated with steep slopes in an area where all the rocks are more or less crushed owing to folding while the mountains were being formed, I cannot accept the theory as sound, although subsequent more detailed work may show it to be so.

(b.) *The Rakaia Valley.*

The largest river of the district is the Rakaia, which takes its origin in the Lyell and Ramsay Glaciers, on the eastern side of the main divide, and runs first easterly for twenty miles and then turns south-east. It receives on its north bank numerous streams which rise in small glaciers on the main range and run in a southerly direction in parallel valleys till they meet the Rakaia. Further down, beyond the limits of the area under consideration, it receives two important branches—the Mathias and the Wilberforce. On the south bank several fair-sized streams rise in glaciers on the slopes of Mount Murray, but the main tributary is the Lake Stream. This is formed from the overflow waters of Lake Heron—hence its name—but its chief supply comes from the Cameron River This rises in the Cameron Glacier, on the south-east face of Mount Arrowsmith, runs in a south-easterly direction for about twelve miles, and forms an extensive fan on the north-west side of the lake. At this part of its course it changes its regular channel frequently, running into the lake at times, but at present it joins the Lake Stream about two miles below its outlet from the lake. This body of water receives several streams on its eastern side, the largest being the Swin. The Lake Stream runs between north and north-east and has a very slight fall for several miles, but then it becomes swifter and makes a descent of 200 ft. before joining the Rakaia.

The Rakaia River and most of its tributaries are overcharged with detritus, and have filled up to a fairly uniform surface the floor of the glacial trough through which they run (Plate III, fig. 1). The width of the flood-plane is about two miles, and on this the river forms many diverging and anastomozing branches, in the way so characteristic of streams laden with waste. In winter it is frequently dry, owing to the freezing of the water at its sources; but in spring and summer it becomes a large river, and often impossible to cross on horseback, although the splitting-up into different streams renders it somewhat more easy to negotiate. Near the head the valley narrows somewhat, and there the river runs in a solid body of water capable of rolling down stones a ton in weight. In this part of its course no terraces are formed except those of temporary nature, but these last long enough at times to allow of their being covered with grass and scrub; still, they are liable to rapid destruction if the river in the course of its wanderings impinges for long against their unconsolidated edges (Plate III, fig. 1).

(c.) *The Lake Heron Valley: its Features and Origin.*

(See map, p. 318.)

The valley through which the Lake Stream runs is a very striking physical feature of the district. It is continued in a south-easterly direction for nearly thirty miles, and extends across the Ashburton River as far as the Rangitata. It intersects these streams nearly at right angles, and bears little relation to the present principal lines of drainage. It severs the eastern mountainous district of middle Canterbury from the main range of the Southern Alps, and well merits some distinctive name. Haast called a part of it the Upper Ashburton Plains; but this name will hardly apply to the whole extended valley. I shall refer to it in this paper as the Lake Heron Valley, as that name has been used repeatedly by the recent Commission which examined the Canterbury runs for the purpose of closer settlement. At the upper end of the valley, about five miles from the Rakaia, it is partially blocked by Shaggy Hill, the remains of a ridge which in all probability formed part of the original divide, but which has been cut through by glacier and stream action. The floor of the valley is here about a third of a mile in width, but it immediately widens out with a broad flat section which reaches a maximum of about six miles in the neighbourhood of Lake Heron. About five miles further on it contracts somewhat, but is still four miles in width, and continues so till it reaches Hakatere Station, at the upper end of the Ashburton Gorge. Immense morainic accumulations are found here covering the whole floor and extending up a tributary valley coming in from the north-west and the direction of the Upper Rangitata, which now contains no stream at all commensurate with its size, but which was an outlet for the excess of ice in the Upper Rangitata basin. It is probable that this valley marks the original course of the Potts River before it was deflected through a low saddle which was cut down on its western side by an overflow from the Rangitata Glacier, an effect which was intensified by the overdeepening of the bed of the Rangitata itself by its own powerful ice-stream. From the junction of this tributary with the Lake Heron Valley an extension of the latter goes towards the Lower Rangitata through the Pudding Stone Valley, which is now deserted by any stream commensurate with its great width and length. From this brief description of the Lake Heron Valley it will be readily inferred that the original drainage-lines are quite distinct from those existing now.

The principal stream belonging now to this valley is the South Ashburton, which runs across it and not down it. This river rises in the Ashburton Glacier, on the south-east side of Mount Arrowsmith, and flows in a characteristically ice-eroded valley for some distance, and then passes, by means of an extremely narrow and almost impassable gorge, through elevated down country till it reaches the Lake Heron Valley. It crosses this in a wide river-bed without any distinct banks and with all the features of an aggrading stream, and afterwards penetrates the outer range of mountains by a somewhat open gorge, and emerges on to the plains near the Mount Somers Railway-station. It is joined on the northern side, about half-way through the gorge, by the Stour, the upper part of whose basin was once invaded by the ice-sheet from the great inland valley across a well-defined saddle near the Clent Hills Station. The North Ashburton does not belong to the area, as it has not cut through the outer range into the Lake Heron basin; its upper valley probably escaped the modifying influence of ice experienced by the southern branch of the river.

It seems fairly certain that in pre-glacier times the arrangement of the drainage-lines was as follows: First, a small stream joined the Rakaia where the present Lake Stream comes in. This had no great size, being only about five or six miles in length. Then the present Cameron and all the drainage of the Lake Heron basin flowed down towards Hakatere, and also received the Ashburton and the stream that came from the direction of the present Potts River, the combined streams reaching the Rangitata through the Pudding Stone Valley. The lower Ashburton Gorge was not then cut completely through, and the river rose in the hills near Mount Possession. It is certain that the formation of this gorge is of later date than the formation of the Pudding Stone Valley, and it was no doubt opened out during the glacier maximum by the overflow of ice across a low saddle, which was then lowered by its erosive action and now forms the course of the river. These remarkable alterations are certainly due to interference arising from the glaciers when at their maximum or when declining, and how this arose will be mentioned later.

4. Lakes.

Numerous small lakes and ponds lie in the hollows formed by the morainic accumulations between the Potts River and Hakatere. The two largest of these are Lake Ackland (locally known as Lake Emma), at the head of the Pudding Stone Valley, and Lake Tripp (known as Clearwater), which lies near the Potts River. The latter is about two miles in length by about one in breadth. There is a smaller one, called Lake Howard, situated between the two. All of these lakes drain to the Ashburton. To the north of the Ashburton River, near Hakatere Station, are two shallow ponds known as the Maori Lakes, whose water is held back by a barrier of detritus deposited by the aggrading Ashburton River as it crosses the great transverse Lake Heron Valley.

(a.) *Lake Heron: its General Features; with Special Reference to the Spits now forming on its Shores and to the Action of Shore Ice.*

(Plate III, fig 2.)

The largest body of water in the district, and the highest lake in Canterbury, is Lake Heron, which is at an elevation of 2,267 ft. above sea-level, and is situated on the very highest portion of the floor of the transverse valley. It has a most remarkable shape, as it almost encircles an isolated conical hill called the Sugarloaf, which rises to a height of 4,054 ft. The western part of the lake has a length from north to south of about five miles, and the southern portion a length from east to west of about four miles. Its actual breadth varies from about two miles down to very small dimensions where its two encircling arms stretch as narrow creeks behind the Sugarloaf on its north and east. The largest expanse of open water is near the south end. It is rather a shallow lake, but deep alongside the central hill, which carries down its precipitous slopes far below water-level. The shores are fringed in many places with marsh, and are usually without marked features; but my attention has been drawn to two shingle spits which are found near the south-western corner of the lake (Plate III, fig. 2). These spits are evidently the result of wave-action, without the interference of currents, usually considered to be the principal cause of the formation of such features. In this case they are so placed that it seems impossible that currents can have any part in their formation. They occur in a small lake at the end opposite to its outlet, and right at its very extremity. The most powerful wind on the lake is the north-wester, which sweeps down it from the direction of the Rakaia, and sometimes raises waves of such a size as to threaten danger to an ordinary boat. These seem to be the prime factor in the formation of the spits. Starting from a small projection of the shore, the larger spit stretches across a small bay for about 100 yards, and includes a patch of water as in a natural breakwater. The smaller spit is formed under somewhat similar conditions. When the waves are seen coming down the lake they move faster in the deeper water off shore, and gradually swing round where they meet the friction of the shelving bottom. The swing is prolonged till on breaking they are parallel to the margin of the spit; in other words, the edge of the spit is the tangent to the front of each wave as it breaks. There must, therefore, be some intimate mathematical relation between the form of the spit and the circumstances determining the wave-motion in the lake, and an examination of the spit as they occur strongly suggests that their shape is a well-defined geometrical curve. In the initial stages of the formation of the spits it is probable that they are largely built up by a feeble shore-current due to wave-action, but directly a small spit is formed the waves would be almost entirely responsible for its prolongation. Both of these spits end in a rounded nose, whose position is determined by the amount of retardation of the wave in the shallow water. The wave will tend to swing round completely, so that it actually reverses its direction, and this will maintain a blunt-nosed spit in a fixed position as long as the conditions of the bottom of the lake in the vicinity are the same. If the floor of the lake keeps on shallowing off the spit so that it makes the depth of the lake more uniform, then the wave will not swing so quickly, and the spit will thus be lengthened (see fig. 2). The peculiarity of these spits can thus be put down absolutely to wave-action, in contradistinction to those formed on the sea-coast, which are attributed largely to littoral currents. It is evident, however, that wave-action alone can form spits, and this must be a contributory cause in a large proportion of marine spits.

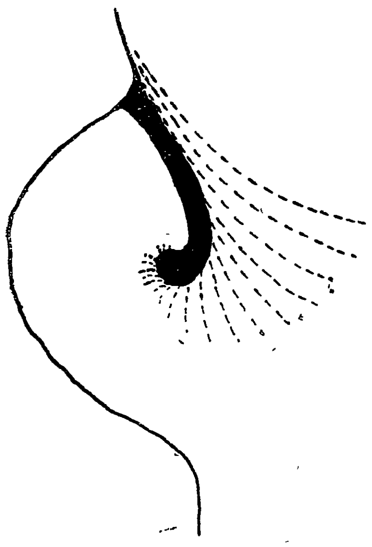

FIG. 2.—SHOWING RELATION OF WAVES TO FORM OF SPIT.

Hooked spits in lakes are specially referred to by G. K. Gilbert in his paper on the "Topographic Features of Lake-shores" (5th Annual Report, United States Geological Survey), but he ascribes them principally to the action of the littoral currents; in Lake Heron, however, these appear to play an insignificant part in their formation.

Lake Heron is at such an elevation above the sea that every winter it is heavily coated with ice. In ordinary seasons there is a covering of as much as 9 in. in thickness, a remarkable feature for such a large lake in an insular climate like ours in a latitude of only 43° S. The shores exhibit traces of the action of ice in the ridges of gravel which are pushed up by it as it expands after contraction in cold weather. Ice contracts as the temperature is lowered, and in doing so draws away from the shore, leaving a narrow lane of open water; this freezes immediately, and when the temperature rises the ice expands again and is forced up the beach. Ridges formed in this way occur on Lake Heron, as well as on the smaller lakes Tripp and Acland. The stones composing the beaches are rounded on their edges and corners by the movement of the ice, and especially so when the ice breaks up in spring before an early north-wester. The floes are then piled in heaps on the exposed shore of the lake, and the wind keeps on driving others forward, which occasionally shoot up on the inclined planes formed by the masses underneath, so that they are carried as much as a chain from the edge of the lake, scoring the ground and ploughing it into furrows. This is especially well seen on the south shore of Lake Heron, where the full force of the northerly wind is felt and the beach is shelving and low.

5. Present Glaciers.

The existing glaciers of the area are divided into two groups—(1) those coming from Mount Arrowsmith and its immediate neighbouring heights; (2) those which belong to the main Rakaia Valley. The principal glaciers of the first group are those at the head of the Cameron and Ashburton Rivers. Several other small ones occur, notably those at the head of the Lawrence, on the western flanks of Mount Arrowsmith.

(a.) *Cameron and Ashburton Glaciers.*

The former glacier occupies about two miles of the upper part of the Cameron Valley. It is a small glacier of the first order, and is fed from tributaries coming from the south-eastern slopes of Mount Arrowsmith and its extension to the north. The lower part is covered with *débris*, and shows undoubted signs of recent retreat. At the present time it is almost impossible to tell the actual position of the terminal face, owing to its extreme thinness and the mantle of *débris* which passes insensibly from actual moraine to the apron of detritus before the glacier. This retreat is also evidenced by the presence of old lateral moraines lying parallel to the valley-sides far above the present level of the ice, and extending down the valley for some distance beyond the present termination. There is also there a well-marked terminal moraine about half a mile from the present face. At various positions, besides, down the valley are old terminals passing into laterals, and partially blocking the stream in several places, which marked in former times undoubted halting-stages in the retreat of the ice.

A special feature of the valley is the wide basin which forms its head, a basin evidently expanded by the sapping-back of the containing-walls in all directions by the ice which partially filled it. This case certainly suggests that corrie glaciers and glaciers which are closely related to them in size have under some conditions the power of widening their upper reaches at a faster rate than the streams which issue from them can widen that part of the valley where they flow. There is no suggestion furnished by this locality that such glaciers act as protecting agents.

The Ashburton Glacier lies to the west of the Cameron in a parallel valley, and exhibits features very similar to those of its neighbour. It is not as large as the Cameron, and hardly reaches the floor of the valley before it melts; but it is very beautiful, and shows striking crevasses and ice-pinnacles, and a fine ice-fall at its head, depending from the slopes of Arrowsmith. All down the valley in its front are the remnants of old lateral and terminal moraines in positions where they have escaped destruction by the river, and marking halting-stages in the general retreat of the ice. Immediately in front of the present face lies an immense accumulation of angular *débris* belonging to a former period, and there is evidence that the glacier has been dwindling within very recent times, though, judging from the present form of the ice-face and also from the fact that in one or two places it is crowding on to the old moraine, a temporary advance is now taking place.

The valley through which the Ashburton River flows is at first broad and flat-bottomed, but about twelve miles from its commencement it suddenly contracts, and the river passes through a deep, narrow gorge, of recent origin, cut for about three miles through a solid rock barrier, the height of the lip above the floor of the basin on its up-stream side being over 200 ft. It is extremely likely that a lake once occupied this basin, which has been drained by the river cutting down its bed through the solid obstruction. It seems impossible to explain the peculiar relation of basin and barrier on any other assumption than that large valley glaciers have under certain circumstances great powers of basal excavation. No locality that I am acquainted with shows this better.

Immediately outside this ice-eroded basin the moderately elevated country has been dissected and the drainage-directions changed, largely as the result of glacier erosion; but I have not examined the country in sufficient detail to speak definitely on the matter, though I feel certain that it will furnish very interesting material bearing on the much-discussed question of the efficiency of glaciers as erosive agents.

(*b*.) *Rakaia Glaciers.*

The glaciers of the main Rakaia basin are (1) those on the flank of Mount Murray, (2) those at the head of the river, and (3) those on the north side in the system of valleys which rise in the main divide and run towards the south-west.

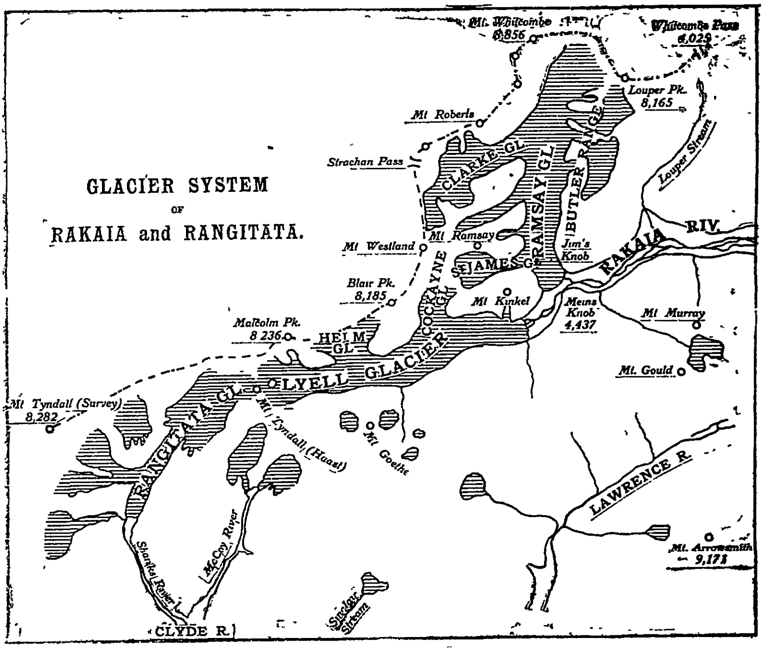

FIG. 3.—MAP OF RAKAIA GLACIERS.

On the north side of Mount Murray there are small cliff glaciers heading a stream known as the Little Washbourne, which joins the Rakaia about five miles above the outlet of the Lake Stream. Another glacier, of slightly larger size, heads a ravine on the north-west of Mount Gould, and almost exactly opposite Whitcombe Pass. But by far the most important are the glaciers at the actual head of the Rakaia, from which the river derives a great part of its water. The furthest west of these is the Lyell Glacier.

(i.) Lyell Glacier.

(See fig. 3, and Plate IV, fig. 1.)

The Lyell Glacier was discovered by Dr. von Haast in the year 1862. He saw it from Mein's Knob, but did not actually visit it, although he must have sent on some one to take an aneroid reading of the height of the terminal face. Mr. G. J. Roberts, the late Chief Surveyor for Westland, crossed the end of it when he made his survey of the Ramsay Glacier and its neighbourhood, but he does not seem to have done more. It is thus an unknown glacier, although within a reasonable distance of settled parts of Canterbury. The present writer, with two students, made an exploration of it in December last, and the following facts about it are the result of observations made on that occasion.

The Lyell Glacier extends from Mount Tyndall* in an easterly direction for nearly five miles till it reaches to within a mile and a half of Mein's Knob, the bluff which fronts the Ramsay Glacier on the south side of the Rakaia River. It is bounded on the south by Mount Goethe, and on the north by the main range of the Southern Alps, and then by a spur from that range stretching in an easterly direction towards Mount Kinkel. The floor of the valley is a little over a half a mile wide on the average; it is wider than lower down, immediately between Mount Kinkel and Mein's Knob, where the valley takes a turn to the north towards the Ramsay Glacier. In former times the Lyell Glacier overrode the end of the spur where Mein's Knob now is, and truncated it partially, leaving the knob with the characteristic shape produced by this mode of glacier erosion. Jim's Knob, on the opposite side of the river, has been formed in the same way by the Ramsay Glacier. The river which issues from the present Lyell Glacier may well be called the Lyell River, the name "Rakaia" being given to the stream formed by the junction of the Lyell with the twin stream from the Ramsay, the present confluence being between Mein's Knob and Jim's Knob. The two streams from the Ramsay and the Lyell appear to be of about equal size.

The Lyell River issued at the time of our visit from near the north side of the terminal face. A large body of water came from an ice-cave near the middle, ran by a tunnel under the ice in a northerly direction, and added considerably to the volume of the main stream. Behind the ice-cave the cliffs rose to a height of 60 ft. A small creek coming from the east side of Mount Goethe enters the valley on its south side immediately below the end of the glacier. This marks roughly the present position of the face. The floor of the valley is kept fairly clear of morainic accumulations by the transporting action of the powerful stream issuing from the glacier. About a half a mile down a high mound still remains which belonged to a former lateral moraine; but even this shows signs of being rapidly removed by the river. It is hard to tell from the present form of the terminal face whether the glacier is retreating at the present time, but the southern side shows signs of a collapse, which suggests that this is the case.

* This is not Mount Tyndall of the Westland survey, but the peak called so by Haast when exploring the Upper Rakaia Valley. The name has been retained in this paper, although it must certainly be replaced by another at an early date.

The terminal face is easily climbed by means of the moraines, and for some distance up—nearly half a mile—the whole surface of the ice is completely buried; after that the lines of moraines from glaciers are separate and better defined.

Mount Goethe, which flanks the glacier on the southern side, is a mountain of considerable bulk, but without a distinct peak forming its summit. Small perched glaciers occur on it, particularly on the side of a small valley joining the main one about three-quarters of a mile from the end of the glacier; but no glacier joins the main stream at the valley-level, except a small one near the head. Although Mount Goethe is high enough to nourish fair-sized glaciers, the high range to the west precipitates the vapour and the wind reaches the other side of the Lyell Valley in a comparatively dry condition. The heavy precipitation causes the north side of the valley, which is also the shady side, to be thickly covered with snow and ice. About half a mile above the terminal face a small hanging glacier comes down from the slope of Mount Kinkel, and a little further on a very fine tributary comes in from behind Mount Kinkel and extends back to a snow saddle evidently leading on to the St. James Glacier, a tributary of the Ramsay. On its western side are some very fine ice-cliffs, and the lower part is crossed by numerous crevasses and is very dirty, while from the upper side a well-defined medial moraine takes its origin. This glacier I have called the Cockayne Glacier, after Dr. L. Cockayne, who has done so much work on our alpine vegetation.

About a mile further on another fine tributary comes in from the north side, and I have called it the Heim Glacier, after the well-known Swiss glaciologist, in order to be in keeping with the scheme of nomenclature which Haast followed with regard to names in the locality. It rises in a large snowfield, apparently fairly level, lying between Malcolm Peak in the west, Blair Peak on the north, and an unnamed peak on the east. The ice issues from the amphitheatre, and joins the main glacier by a very fine fall. From the western side a well-marked moraine stretches down the middle of the Lyell Glacier. Malcolm Peak is a fine pointed mountain heavily covered with ice, and with a beautiful hanging glacier dropping down from behind a small dome immediately to the south of the main peak. At this point the floor of the valley is very flat, with the ice slightly crevassed, but it then extends on a generally rising slope right to the base of Mount Tyndall, about three-quarters of a mile further on. This is a fine mountain, strongly reminiscent of the shape of the Matterhorn. It culminates in a rocky peak, with a snow-covered saddle on either side. According to Mr. Earle, who recently visited the locality from the Rangitata and made important topographical discoveries, the western saddle leads to the Wanganui River, flowing to the west coast, while the eastern one leads to the Clyde, one of the main head-waters of the Rangitata. The height of these saddles probably exceeds 6,000 ft., as the floor of the valley at the base of Mount Tyndall reaches 5,000 ft. as measured by aneroid. The amphitheatre which forms the head of the Lyell Glacier is very fine, with Mount Tyndall forming its actual head and Mount Goethe and Malcolm Peak its southern and northern flanks. The length of the glacier cannot exceed five miles at the outside, judging the distance roughly, and considering that our return journey from the base of Mount Tyndall to the terminal face was made in an hour and a half.

This estimate certainly necessitates an alteration in the position of Mount Goethe on the most recent official map, since it is put too far to the south-west. The mountain called Tyndall by Haast, and pictured in his report on the Rakaia, is not the same Mount Tyndall to which he gave the name from the valley of the Rangitata, nor yet again from the Godley. It is also probable that the Mount Tyndall of the excellent Westland survey is none of the mountains to which Haast gave the name. This is somewhat unfortunate, and appears to result from the mistake made originally by Haast, who thought that he saw the same peak from each of these three great valleys. Mr. Earle has recently pointed out that the mountain called "Tyndall" by Haast when he explored the Rakaia is probably a peak not really marked on the maps, but one to which a new name should be assigned. Dr. Teichelmann has still more recently confirmed this observation in a letter to the author, and says that this peak is called variously McCoy Peak and Mount Nicholson, and that it is not on the main divide, but lies to the east of it.

The Lyell Glacier presents no features of special importance. Its surface is fairly smooth and little crevassed, the roughest portion being that near the confluence of the Cockayne Glacier and its disturbing influence. The lower portion is covered with moraine, which comes principally from those mountains not covered with ice and perpetual snow, but from those specially subject to the action of frost. This weathering-agent attacks the exposed surfaces of the rocks by means of their frequent joints and bedding-planes, and produces in this region a particularly large amount of angular material, which is poured on to the surface of the glaciers by numerous "shingle-slips." Although the Lyell has a thick covering in many places, its moraine is small as compared with that of its near neighbour, the Ramsay.

(ii.) Ramsay Glacier.

(Plate IV, fig. 2.)

This glacier takes its origin in the snowfield on the west side of Louper Peak, between it and Mount Whitcombe. It stretches for six miles in a S.S.W. direction between Mounts Ramsay and Kinkel on the west and the Butler Range on the east, and maintains a direction parallel to that of the valleys on the north of the Rakaia. It receives from the west two important tributaries—(i) the Clarke Glacier, which rises between Mount Westland and Mount Whitcombe, and runs in a north-westerly direction to a low saddle leading to the Upper Wanganui River on the western side of the range; and (ii) the St. James Glacier, which rises between Mounts Kinkel and Ramsay. Although the upper portions are comparatively free from *débris*, the lower three miles is more covered with moraine than any glacier with which I am acquainted. Even the Mueller and Tasman fail to come up to the Ramsay in respect to the size of the blocks and the completeness of the covering. Not only is there an abnormal amount of small material, but angular masses of the size of cottages occur piled together in disorderly heaps. Most of this comes from the precipitous faces of Mounts Ramsay and Whitcombe, which are so steep that little snow can cling to their bare crags, and are therefore rapidly broken up by the action of frost. The amount of material which comes from the Butler Range on the east is of comparatively little importance.

On the east side or the terminal face the Ramsay branch of the Rakaia rises from an ice-cave, but water certainly soaks through from all the face between Mein's Knob and Jim's Knob. The glacier is here just over half a mile wide.

There are clear signs of the decrease in size of the glacier, as abandoned lateral moraines marking old ice-levels occur in places along the valley-walls, and it is extremely probable that at a comparatively recent date it stretched right across the Lyell River till it impinged on the lower slopes of Mein's Knob. This river would then take a course through a tunnel partly under the ice and partly under the edge of the knob. A large part of this has at a fairly recent time slipped away from the face of the bluff and left a narrow chasm which affords a path round the shoulder of the knob, overlooking the river.

(*c.*) *Absence of Terminal Moraines from Present Glaciers.*

The glaciers of this region, like the great majority of those in New Zealand, are not forming any well-marked terminal moraines. Neither the Fox or the Franz Josef on the west coast nor the Tasman or Mueller on the east have any sign of a terminal moraine; those formed by the Mueller are really lateral moraines formed by a glacier crossing a valley. In all the cases that I have observed the *débris* which reaches the terminal face is removed by the transporting agency of powerful streams. The Lyell Glacier has no true terminal moraine, and, although the Ramsay Glacier is heavily laden with waste from the neighbouring hills, there is no accumulation in the form of irregular heaps or a barrier at its end; in fact, there is no sign of such a moraine in the Rakaia Valley till the plains are reached. The Cameron Glacier is not forming a terminal moraine at present, although a very well-marked one lies some 800 yards away from the present face. In the Rangitata Valley an exceptionally distinct one occurs about five miles from the terminal of the glaciers. These moraines were formed when the glacier reached further down the valleys than now, but there must have been some difference in the then conditions which promoted the accumulation of *débris* across a valley, when no such accumulations are forming now. The actual circumstances under which terminal moraines are formed seem somewhat obscure. They are taken for granted as a feature of every glacier, but such is not the case. Why is it that the Fox and Franz Josef have formed huge terminal moraines some distance away from the ice, a little further down the valley, and are not forming any now? If the Ramsay Glacier, heavily encumbered as it is, were to disappear, and the loads of waste that lies on it were to coat the surface of the ground, there would be no sign of the heaps which characterize true terminal moraines. The question must resolve itself into one of supply and demand. If the glacier furnishes material in such quantity that the river can remove it, then no moraine will form. If for any cause the supply becomes greater or the volume of the river less, then accumulations will take place. At the present time the material supplied to the Ramsay Glacier is excessive and a moraine should result, but no moraine is forming. On the Lyell the amount is not really great, and its front is swept quite clear. It may be that our rivers have such a steep bed that they are equal to removing even the fullest supply that the glaciers can furnish. But when the case of the two great West Coast glaciers is considered this explanation does not appear quite so satisfactory. In former times, when forming great moraines, they had the same steep slope as now. The same remark also applies to the Cameron. We must suppose, therefore, that a little time ago the conditions were such as promoted the formation of enormous supplies of waste. This may be explained by an increase in the height of the mountains, due to an elevation of the land, rendering larger areas subject to the action of heavy frost, which is the chief agent of denudation on mountain areas. The same effect may be produced by supposing the climate to have been slightly more rigorous than that existing at present. In a former paper on the "Terrace-development in the Valleys of the Canterbury Rivers" I have already noted as a deduction from the condition of shingle fans, and from peculiarities in the form of the river-beds, that there has been a falling-off in the supply of waste, and this observation on the moraines tends in the same direction. In the paper referred to, I attributed this falling-off to a lowering of the land, just as I attributed the severer glaciation to elevation of the land. My present opinion is by no means decided that this was the predominating cause. Elevation certainly occurred, and this would assist other causes tending in the same direction, such as a modification of the climate. Whether the retreat of the glaciers has been due to a lowering of the land or to an amelioration of the climate, the supply of waste has fallen off, as well as the supply of snow, which determines the existence of the glaciers. If the former falls off in a higher ratio, then there will be no moraines; if, however, the waste increases in a higher ratio than that of the transporting-power of the streams resulting from the melting of the snow, moraines will certainly form. This will occur in general when there is a temporary advance of the ice due to climatic or other causes, just as failure to form moraines will occur during retreat. The frequent absence of moraines from the front of Pleistocene ice-sheets may perhaps be explained by the amount of water formed at their terminals being in excess —probably much in excess—of that necessary to transport the relatively small amount of material which usually accumulates on the surface of the ice-sheet and beneath it.

6. Former Glaciation.

(*a.*) *General.*

It may be inferred from the statements made previously in this article that in former times the country was subjected to a more severe glaciation. The proofs of the former extension of the ice are found on every hand. These may be summarized as follows: Old moraines, *roches moutonnées*, striated surfaces, ice-shorn and ice-terraced slopes, valleys with characteristic U section with truncated and semi-truncated spurs, and spurs with triangular facets. A deposit of boulder-clay with large angular fragments is found at the Potts River, where, according to Haast, there are the most characteristic subglacial deposits to be found in New Zealand. I do not know of any discovery recorded later which necessitates a revision of this statement.

The limits of this glaciation to the eastward were in all probability not beyond the line of the foothills flanking the eastern mountains. Glaciers certainly came through the Ashburton Gorge down to the neighbourhood of the Mount Somers Township, since immediately behind it there is a terrace formed of washed material containing large angular blocks which look like those deposited in streams at the immediate front of a glacier. The smoothed and rounded hills in the locality are also suggestive of ice-action. But the occurrence of lateral moraines high up on the hills flanking the gorge on the south is conclusive proof of its presence, and shows that even in that part of the country there was very great thickness of ice at the maximum glaciation. On the northern side of Mount Hutt, glaciers came through the Rakaia Gorge on to the plains near the Point Station. Haast says that they extended several miles on to the plains, but I am inclined to think that the evidence for this extreme extension is of a somewhat doubtful character, and what he took for morainic accumulations are fluvio-glacial deposits such as are formed by the powerful streams issuing from the edge on an ice-sheet or glacier. In the neighbourhood of the Point Station there are very extensive areas covered with reassorted detritus arranged in irregular heaps of the Drumlin type, showing that the glacier reached almost to that point, and so must have been over sixty miles in length.

In the Rangitata Valley there are undoubted signs of glaciation where the river debouches on to the plains.

Thus the valleys of the Rakaia and Rangitata were filled with exceedingly large glaciers of the ordinary type, but there is no indication that they approached even distantly to the character of an ice-sheet. In the Lake Heron Valley, with its flat floor and wide cross-section, and its relatively higher altitude, they possessed in certain respects a remote resemblance to an ice-sheet of very small dimensions. The area of land in this valley formerly covered with glaciers extended twenty miles in length by at least eight in breadth; but it must be regarded as a great basin filled principally with snow and *névé* fields at the height of the glaciation rather than a true ice-sheet.

(*b.*) *Old Moraines.*

The chief morainic accumulations are those of the Hakatere and its tributary valleys. Here for over several square miles the floor is covered with irregular heaps of angular material forming the terminal moraines of ancient glaciers; fairly extensive accumulations occur at various points in the Cameron Valley and at its outlet, in the Upper Ashburton Valley, as well as on the north side of Lake Heron, on the slopes of the Sugarloaf, but these are insignificant when compared to the square miles of *débris* lying to the south of the lake, and forming the great dam which acts as the containing-wall on that side. This great deposit stretches across the floor of the valley, and also extends down it for several miles towards the Clent Hills Station and the Ashburton River, especially on the north-west side of the valley. At one place this has been cut through by a former river-channel which drained the lake, and has left as proofs of its former existence high terraces on either side of its bed. In the floor of the great deserted channel a tiny stream meanders, an insignificant remnant of the great river which at one time flowed from the front of the glacier and for a time served as the means of discharge for the surplus water of the greater Lake Heron.

The next extensive deposit is that which stretches from Hakatere Station right through to the Potts River. For miles the floor of this stream-deserted valley is covered with heaps of angular material. It forms a great barrier across the upper end of the Pudding Stone Valley and on the low saddles which lead to the small valleys behind Mount Possession Station. These were terminal moraines of the ice as it halted in its retreat from the eastern hills of the area.

Apart from these, the only morainic accumulations of any extent are those lateral moraines which mark the high ice-level on the valley-sides. They are common up the Rangitata and in the valley leading from Hakatere to the Potts, and occasionally in other places. A frequent position is rounding the shoulder of a spur, or in the wider part of a valley, where in some corner or indentation in the side they have not been exposed to the full action of denuding and transporting agents. They sometimes occur near the mouth of tributary streams coming into a larger valley. These moraines are at times the terminals of the tributary glaciers, but in some cases they are undoubted lateral moraines of the main glacier. The incoming stream of ice has pushed the main glacier over, and accumulations have taken place on both sides of the tributary, especially on its upper side, and the stream of water which has succeeded the glacier has pushed over the main river in its turn, thus preserving the moraines at that spot, even if they have been removed from other parts of the valley by the transporting action of the river.

A peculiarity may sometimes be observed in the arrangement of the blocks of the lateral moraines which is occasionally useful for differentiating them from terminal moraines. In the latter case there is no order or arrangement—the blocks lie quite at haphazard; but in the case of lateral moraines the blocks usually lie with their long axes parallel to the direction of motion, and also the upper ones overlap the lower ones like pebbles in a stream. This arrangement is certainly rude at times, but it is quite distinct, and is brought about by the movement of the glacier causing a drag on the heavy accumulations between it and the valley-sides where the latter are not in close contact with the ice, such as at those parts where the valley is slightly wider, or where the glacier is showing signs of decreasing activity near its terminal face.

Thin coatings of moraine also lie on the tops of truncated and semi-truncated spurs left by the receding tide of ice. An excellent example of this occurs on the downs behind Prospect Hill, in the angle between the Rakaia and the Lake Stream (Plate V, fig. 2).

(*c.*) *Ice-planed Slopes.*

These are a special feature of the Lake Heron Valley, all the north-west side of which is smoothed and terraced to a remarkable extent (Plate V, fig. 1), recalling the photographs which appear in Professor Park's bulletin on the Wakatipu district. The similarity of the landscape in the two districts is really surprising. Judging from the shape and slope of the glacier-shelves, the ice must have come from the north, even in that part of the valley adjacent to the Rakaia. This undoubtedly proves that a section of the Great Rakaia Glacier overflowed from the present Rakaia basin, came up the valley of the Lake Stream, and left its marks on the ice-planed hills towards Hakatere. As it overflowed the Clent Hills towards the Stour River it modified the landscape similarly.

(*d.*) *Roches Moutonnées.*

Ice-shorn rocks are a feature of certain parts of the land-surface. They occur in the Lake Heron Valley between the Clent Hills Station and Lake Heron, where their long scour slopes presented towards the north clearly indicate the direction from which the ice has come. In the Rakaia they appear at the sides of the river-beds, but lower down we find Double Hill and Little Double Hill, typical *roches moutonnées,* in the actual floor of the valley. In the Rangitata, the Jumped-up Downs, and the isolated hills in the floor of the valley between them and the Potts are also excellent examples of this result of glaciation. Clearly marked striae are rarely seen but if the surface coating of soil and *débris* were removed they would appear plentifully, since the rocks are hard and resistant enough to retain the finest markings. *Roches moutonnées* of small size are very infrequent, and the larger ones grade into the general ice-shorn slopes and truncated spurs.

(*e*.) *Truncated and Semi-truncated Spurs.*

These are exhibited in all stages of development in the Rakaia Valley. Its sides have been straightened so that their alignment is almost perfect, and the spurs exhibit the triangular facets which result from the shearing-off of their ends. I have shown elsewhere that such a land-form is stable, and persists after other features resulting from glaciation have been destroyed by denuding agents. Even in the Ashburton Gorge these faceted spurs occur in an almost perfect condition. In the earlier stages, if the valley is not very deep, the mode of truncation of the spur appears to be that a series of strips is planed off the ends from above downwards. Shelves left in an unfinished condition suggest that this is a common procedure, although erosion at the base of the spur and along its whole face must occur as well. These processes heighten the steep slope that the end of the spur presents to the main valley, and it must become so high in time that the glacier cannot overtop it, so that the valley can be widened only by scouring away the end and by eroding the base.

The angle of slope of the end of the spur is related to the width of the valley and the amount of ice passing through a particular cross-section. Where the valley is wider in its pre-glacial stage and the supply of ice is small the walls flare more and the angle of slope is not so steep. Where the valley is narrow and the supply of ice is great the angle approaches the perpendicular. An exceptional instance of this action is seen on the north side of Milford Sound, where the Lion Rock is vertical for hundreds, even thousands, of feet. The height of the face of the spur is increased by the deepening of the valley as the ice erodes its bed, and the slope tends to become more and more steep as the valley is more deeply cut and the stream of ice more confined, a result quite analogous to that produced by a river when actively eroding its bed. In some cases the spurs are only partially truncated, and specially so where a strongly marked ridge is overridden by ice coming in from a tributary or round a pronounced bend in the valley. Both Mein's Knob and Jim's Knob, at the head of the Rakaia River, owe their form to this action, and in their case the result has been intensified by the mutual interference of the Lyell and Ramsay Glaciers as they forced their way together through the somewhat narrow valley just below their junction. The ice has thus been crowded up on the slopes of the spurs at the sides, and they both show the well-defined notch cut close to the valley-wall by the more active erosion of the ice as it swings round a corner. If this process is carried further it produces a rounded knob separated from the main portion of the spur. Prospect Hill (Plate V, fig. 2), at the junction of the Lake Stream and the Rakaia, owes its form to a part of the Rakaia Glacier turning out of the main valley in the direction of Lake Heron and cutting off the projecting spur on the western side. It is a splendid example of a semi-detached knob, and the downs behind it are the remnant of the spur which has been reduced, but still remains at a height of 600 ft. above the present floor of the main valley. In a former plateau country in which the valleys are well developed the ice frequently crosses saddles and cuts them down to a greater or less extent. In this way ridges are often partially or completely separated from the mountain mass which they were originally connected with. Such ridges will generally lie parallel to the direction of the ice-flow, and will be abraded and reduced in height if the ice can pass over them, and reduced in length where it cannot pass over them. Thus all stages appear between the long spur and the conical hill. In the valley of the Waimakariri and in the Lake Coleridge basin on the north side of the Rakaia River the intermediate forms occur in perfect sequence ; but in the Lake Heron district the destruction has been more complete, and the spurs grade into low flat *roches moutonnées* or into ice-planed slopes. An instance of such a cut-out spur can be seen in Shaggy Hill, five miles north of Lake Heron, where lay the original divide between the Ashburton and Rakaia basins, which has been lowered, and one of the spurs reduced to an immense *roche moutonnée.* An advanced stage in the destruction of such a ridge occurs in the Sugarloaf, at Lake Heron. This mass is evidently the remains of a spur which divided two valleys, and which projected above the stream of ice as a nunatak even at its maximum, for its top shows no sign of glaciation, while its sides and northern end have been rasped and smoothed away.

(*f.*) *Valley-features.*

The profiles and cross-sections of the valleys are those produced by the action of glaciers on a matured stream system. Their special features, such as the alignment of the valley-walls, the truncation of the spurs, and the presence of glacier-shelves, *roches moutonnées*, and moraines, have been just dealt with. The surface features of the Lake Heron Valley have been little altered since the glaciation, and this suggests that it cannot have occurred at a distant period of time, geologically speaking. The Rakaia Valley has been subject to the action of a great river overcharged with detrital matter, so that the U-shaped floor has been filled to considerable depth with material derived from the glaciers at its head and from tributary streams and shingle-slips. The U-shaped form has thus been modified and the floor has been flattened by the deposits of an aggrading stream. The actual depth of the deposit is unknown at present, but it must amount in places in hundreds of feet.

The cross-sections of the valleys present some interesting features. Above the level of the truncated spurs, or above the level to which the glaciers filled the valleys—and this applies to the tributaries with equal force—the slopes become concave in shape (Plate VI, fig. 1). These are to be found in the whole mountain area of Canterbury. At higher levels they are occupied for a part of the year with snow, and they seem to owe their origin to its weathering action. By its presence the surface of the rocks is maintained in a moist condition, and slow but sure chemical and other erosion takes place, a shell-like hollow being eventually formed. The snow forms these hollows, in which afterwards, as weathering action proceeds, thick drifts accumulate. If the climate grows more rigorous or other circumstances promote the progressive accumulation of snow, then a small glacier forms. Such conchoidal slopes, developed under former more severe climatic conditions, are the favourite location of our moisture-loving alpine plants and our mountain meadows, with their rich displays of *Ranunculus* and *Ourisia.*

(*g.*) *Corrie Glaciers in Relation to the Formation of Passes and the Dissection of Spurs.*

In former times, when the conditions favoured the accumulation of thick drifts of snow, these concave hollows were gradually filled with ice

FIG. 1.—ICE SCOURED AND TERRACED LANDSCAPE, LAKE HERON VALLEY.

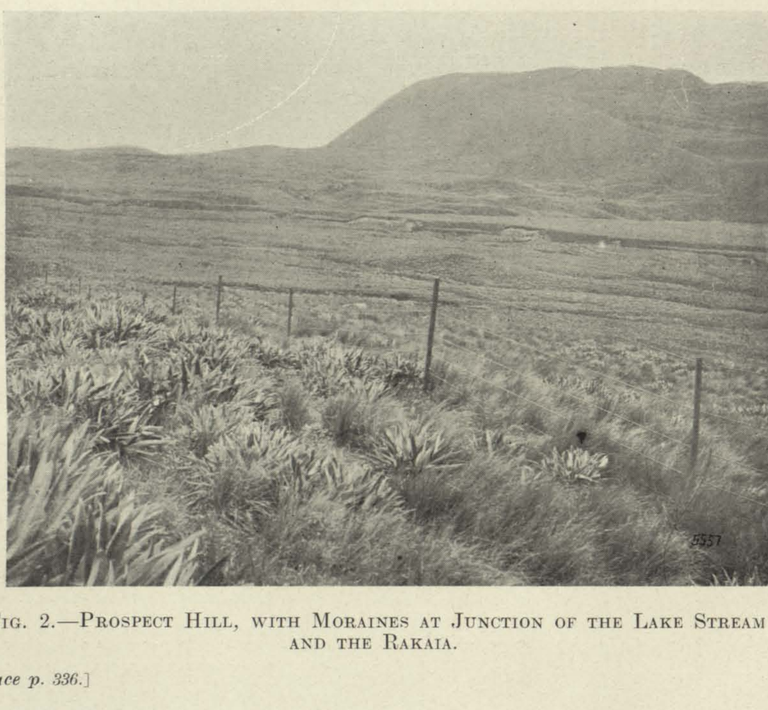

FIG. 2.—PROSPECT HILL, WITH MORAINES AT JUNCTION OF THE LAKE STREAM AND THE RAKAIA.

Face p. 336.]

Fig. 1.—Valley of Louper Stream, leading to Whitcombe Pass.

Showing ice-eroded lower slopes and conchoidal snow slopes above them. The Rakaia River bed and characteristic fan of the Louper Stream in the foreground, Louper Peak in the background.

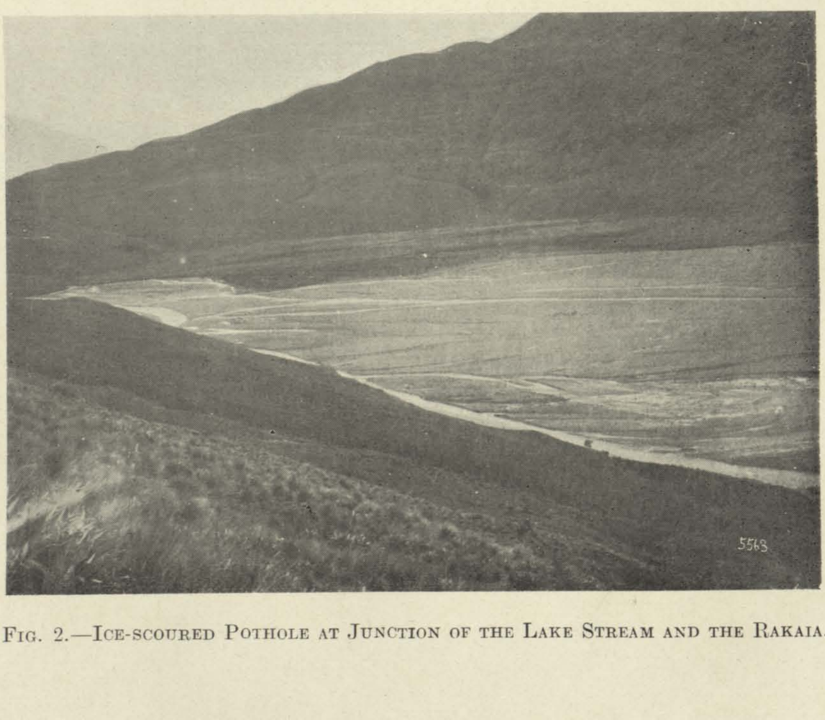

Fig. 2.—Ice-scoured Pothole at Junction of the Lake Stream and the Rakaia.

and became corrie glaciers. The process of erosion begun by the snow was continued by the ice, but on different lines. The walls and sides were sapped back and the basins were enlarged till the glaciers they held became small ones of the valley type. As this went on, the floor was eroded deeper and deeper at the head, while little erosion went on near the lip, so that when the ice disappeared the hollow left behind was usually occupied by a lake. This seems to be the ordinary course of the development of a corrie glacier and the hollow usually associated with it, according to the most advanced school of physiographers; but there is a weighty body of opinion totally opposed to the idea that corrie glaciers are potent agents in modifying landscapes. Although the present writer is somewhat chary of expressing a dogmatic opinion on a subject which has lead to so much controversy, his experience in the glaciated districts of this country, notably in the Sounds region, leads him to think that the course of development outlined above accounts best for the phenomena that occur.

By granting the capacity of glaciers of this type to sap back their heads one can explain the formation of the jagged and razor-backed ridges which so frequently separate the head of one tributary glacier from that of its neighbour across a divide. The usual sequence of events in such a case appears to be as follows: First there is a ridge, more or less rounded, with two shell-like hollows containing snow on either side. In process of time a corrie glacier forms. Then sapping goes on, and the divide becomes narrower and narrower; then it is a mere wall, and finally this collapses and a saddle results. At the head of the Rakaia there are existent glaciers which show all stages of this development and furnish some idea of the modification which results from their action on mountain-ridges; but in those parts from which the glaciers have retreated the landscape-forms resulting from this action can be readily noted and studied in detail. We see here all the stages from the shell-like hollows, through the razor-backed ridges, to the final "pass" form. The latter are usually U-shaped in cross-section, but they tend to become parabolic by the accumulation on their floors of detritus shed from the walls. It seems possible that the isolated ridges which so frequently occur in all the great valleys of Canterbury owe their dissection to this process, especially as the main valleys run across the strike and the cross valleys are developed in the soft beds parallel with it, these beds furnishing an opportunity for snow to weather rapidly the shell-like hollow where thicker and more persistent drifts can gather. When the lowering of the divide has been accomplished by this action the main glaciers occasionally pass through them, especially if they are on the increase; they are cut down further still by the usual methods of glacier erosion. The occurrence of parallel or subparallel ridges in the mountainous district of Canterbury are of such a frequent occurrence, and such an important feature of the landscape, that their formation appears to be connected with the former glaciation, and the explanation I have given seems to me to be the most satisfactory way of accounting for their existence.

NOTE.—Since writing the above I have seen an interesting paper by Professor W. H. Hobbs, of Michigan University, published in the *Geographical Journal* for February, 1910, which emphasizes the important effect produced on the mountain topography by the sapping-back of the walls of corrie glaciers. Most of the landscape-features mentioned by Professor Hobbs are exemplified in that part of the mountain district of

Canterbury which has been subject to glaciation in the past, or where glaciers occur now. The conclusions I have come to were made quite independently, and this may perhaps lend additional weight to them, as they are the result of observations in a country far distant from that where Professor Hobbs made his. Professor W. M. Davis, of Harvard University, has lately informed me in a letter that Matthes was the first to point out the relation of corrie glaciers to saddles and passes, in a report on the glaciation of the Big Horn Mountains (United States Geol. Survey, 21st Annual Report, 1899–1900).

(*h.*) *Glacier Potholes.*

(Plate VI, fig. 2.)

A very interesting and suggestive landscape-form occurs at the junction of the Lake Stream with the Rakaia. This is a round hollow over 300 ft. deep and about half a mile across, with the whole interior cut into horizontal or nearly horizontal shelves. These have evidently been produced by the erosion of ice moving in an approximately circular direction in horizontal planes. There is a remarkable resemblance to a pothole in an ordinary river, and the occurrence serves to emphasize the close resemblance that exists under certain circumstances between the erosion of a river and that of a glacier.

If the similarity in the action of the two streams be granted, the explanation of the formation of the hollow is quite easy. A portion of the great Rakaia Glacier running from west to east turned south just above the Lake Stream, rounded the spur at Prospect Hill, and turned up the valley towards Lake Heron. The ice impinged against the massive hill to the east of that valley, and just at the junction an eddy was formed which scoured out the hole, the horizontal terraces being a result of that gyratory motion. When the ice disappeared a rock-bound lake occupied the hole, which has since been emptied through the degradation of the barrier by the outflowing stream. An exactly analogous case occurs at the junction of the Cass River with the Waimakariri. The Waimakariri Glacier at the time of its greatest power flowed from west to east, and on reaching Goldeney's Saddle, about six miles below the Bealey, overrode the end of the spur and turned south-east into the valley towards Lake Pearson and the head of Sloven's Creek, following the line of the Midland Railway. On the east side of Goldeney's Saddle it formed a rock-bound basin exactly similar to the one in the Rakaia, but not quite so perfect. The Cass River now runs through it, and passes through a notch in the rim towards the Waimakariri. The whole locality presents a remarkable resemblance to that of the Rakaia. Goldeney's Saddle and its semi-detached knob corresponds exactly to Prospect Hill. There is a mountain mass on the east side of the inflowing stream, against which a part of a great glacier impinged. The rock-bound and ice-scoured pool with horizontal terraces lies between the two, no doubt in both cases forming a lake on the retreat of the ice, and then this has been emptied in both cases by the erosive action of a stream coming in from the south. Both occurrences emphasize the erosive action of the ice under similar conditions, and its capacity to scour out rock-bound basins in circumstances such as would favour the formation of eddies if water and not ice were the moving element. This action explains the formation of many of the rock-bound ponds and small lakes which occur freely in countries which have been glaciated. Numerous instances of this action can be seen in the Sounds district on the south-west of the South Island of New Zealand, and those at the head of George Sound may be specially cited as furnishing excellent examples of the phenomenon.

(*i.*) *Efficiency of Glaciers as Eroding Agents: Evidence furnished by the Locality.*

A consideration of the glaciation of the area would be incomplete without some reference, however slight, to the evidence bearing on the much-discussed problem of the efficiency of glaciers as erosive agents. It is admitted, even by those who admit least, that glaciers act as flexible rasps, and remove the minor inequalities of the land-surface. The landscapes of the area under consideration give abundant evidence of this, but they are not so decided on the major question of the power of glaciers to excavate the beds on which they lie. It appears to the present writer that corrie glaciers, instead of acting as protective agents, as suggested by some observers of wide experience, do actively erode their beds, and also their side walls and their heads, especially the last, much more rapidly than the streams which issue from them erode their beds. Also, small valley glaciers have this power as well, and enlarge the amphitheatres at their heads at a more rapid rate than the rivers which they give birth to erode their valleys, so that these are narrow in their lower reaches, whereas their upper portions, which have till recently been filled with ice, are wide and of basinlike form. In this case, however, full consideration must be given to the possible neutralization of the erosive power of a stream overloaded with waste, as many of these streams are. Still, after making full allowance for this, there appears to be ample proof that ice in corrie glaciers and in the smaller valley ones related to them does not act as a protecting but as a powerful erosive agent.

There are other matters suggested by the landscape-forms of the Rakaia Valley which require very careful consideration in this connection, and apparently point in the opposite direction. First of all, there is a marked absence of waterfalls and hanging valleys. On the northern side of the main river the numerous parallel streams which rise in the main divide and flow south enter at grade (Plate VI, fig. 2), and the same is true of those on the southern bank, although they are few in number, and, with the exception of the Lake Stream, are much smaller. At first sight it would appear that the glaciers have only acted as a rasp, and modified but slightly the features of the previous valley system, were their efficiency as erosive agents not clearly indicated by the basin which occurs in the main valley of the Rakaia below the intake of the Lake Stream. Here there is a great hollow over twenty miles in length and 500 ft. deep in places, shut in at its lower extremity by a rock wall, which was once occupied by a great glacier and was subsequently either partially or wholly filled with silt. It was finally drained by the outflowing river cutting down a narrow gorge through the lip of the basin, a result hastened by the pouring-in of enormous supplies of waste as the glaciers retreated up the valley. This landscape-form is reproduced perfectly, but on a smaller scale, in the Upper Ashburton Valley. In this case it seems impossible to attribute the rock-barred hollow to any other cause than basal excavation by a glacier. Exactly similar features can be seen in the valleys of the Rangitata and the Waimakariri, and they no doubt occur in the less-advanced condition in the valleys of the Tasman and Godley, in the basin of the Waitaki, further south. Here lakes still occupy basins once filled with ice; but they also, like the basins further north, are destined to obliteration by the rapid lowering of their outlets and by filling up by detritus poured in by waste-laden streams. There appears to be no reasonable doubt that in these cases, too, water has collected in the hollows excavated by former glaciers.

The only other hypothesis which may be put forward to explain these rock-bound basins is the somewhat unsatisfactory one of faulting or warping. Although a system of radiating faults has been suggested as the reason for the peculiar orientation of the valleys of Canterbury (McKay, Geological Report, 1892), the basins, as they occur, could only be explained by a series of peripheral faults or lines of warping disposed in a rude circular arrangement around a centre. Of this there is no evidence at present, and, unless the occurrence of earth-movements such as these can be thoroughly demonstrated, it seems best to adhere for the present to glacier excavation as the most satisfactory explanation for the formation of these lake-basins. Further, if earth-movements are a prime cause of their formation, why are lakes found only in those parts of the South Island which have till recently been subjected to the action of ice, and not found in parts which have undoubtedly experienced very recent faulting and other dislocation?

In the face of this contention the absence of waterfalls and hanging valleys and the accordance of the grade of the tributaries with that of the main stream may be accounted for in two ways:—

(1.) That the solid floors are really discordant, but the valley of the main stream and the lower part of the tributary have been so filled with detritus that the discordance is completely masked. We have really no idea of the depth to which these valleys have been filled with waste, but it may amount to hundreds of feet. Borings in the bed of the Waimakariri in a similarly situated position disclosed nothing but shingle for 30 ft. This is a very shallow depth, but it represents all that has been done in the way of exploration by boring in these river-beds. If the thickness be very great, as it probably is, then the tributary valleys of the Rakaia may resemble, perhaps remotely, the tributary valleys of the Milford Sound, such as Sinbad Valley and Harrison's Cove, which are accordant with the level of the sea, or nearly so, but markedly discordant with the floor of the sound.

(2.) It is possible from the arrangement of the tributary valleys that they were filled with ice long after it retreated from the main valley. The latter for some distance makes a very small angle with the direction of the main range, where the snow collects and forms glaciers. At the present time the Ramsay Glacier runs at right angles to the main valley, and ends on reaching it. The same would be true for every tributary on the northern side of the river at some previous time. At one stage in the retreat of the ice a great river would run across the terminal faces of several large glaciers coming in from the north and occupying a series of parallel valleys. Ice erosion would therefore proceed in them after it had ceased in the main valley. The same accordance in the tributaries can be observed in the Waimakariri, and the same explanation fits this case as well. However, there are facts which undoubtedly lean to the other side. The valley system had no doubt reached a mature stage, and the valleys were accordant before they were modified by glacier-action, and the fact that they are still accordant may be taken as proof that glaciers have little power of differential erosion. If it were not for the evidence that they have eroded their beds lower down the valley, I should be inclined to say that the advantage lay with the opponents of ice erosion. My opinion is, however, greatly influenced by experience in the fiord region of the south-west of New Zealand, where the landscape-features are apparently inexplicable on any hypothesis which denies to glaciers the possession of marked powers of excavation, though it is possible that we are not aware of all the factors which control this power.

7. Changes in Drainage in the Rakaia Valley.

The case of the change of drainage in connection with the Lake Heron Valley has been referred to several times previously. In the pre-glacial river system the Cameron undoubtedly drained south toward the Ashburton, and in all probability a small tributary ran north to the Rakaia from a divide between that river and Lake Heron. This divide was lowered by glacier-action, and the drainage was reversed. The change resulted largely from two causes—viz., (1) the piling-up of a barrier across the Lake Heron Valley at the south end of the lake, and (2) the lowering of the bed of the Rakaia by the erosion of its great valley glacier. The Lake Stream has thus been given a high gradient, and it has therefore rapidly removed any barriers that may have existed to the north of the lake, and has degraded the rocky ridge which formed the lake's containing-wall on that side, so that its size has been materially reduced from that which it had immediately succeeding the retreat of the glaciers. The great swamp north of Lake Heron is the old bed of that lake in its extended form.

The overdeepening of the bed of the Rakaia also allowed the small rock-bound lake at the junction of the Lake Stream and the main river to be emptied as well.

In other parts of the Rakaia Valley drainage anomalies occur, the most remarkable being that of Lake Coleridge. This lake occupies a valley parallel to that of the Rakaia, down which the Wilberforce River and glacier once flowed. A great terminal moraine was left by this glacier, which was also added to by a lateral one from the main Rakaia, across the south end of the lake, blocking the drainage in that direction. The effect was accentuated by the lowering of a saddle in the ridge between the upper end of the lake and the Rakaia Valley, so that at one stage the glacier flowed over this and reduced it so far that the Wilberforce River deserted its old bed and joined the Rakaia ten miles further up stream. The lake followed this direction too, and now discharges at its upper end by a small stream which joins the Harper River and flows into the Wilberforce. The Harper River also once flowed down a valley to the east of the Lake Coleridge Valley and parallel with it; but it, too, turned over a low saddle in the direction of the Rakaia, and flowed through the Wilberforce gap. Other small streams have behaved in a similar way, and have turned from their own valleys through gaps in the ridges that once separated their own valleys from the Coleridge Valley. These gaps were in all probability formed primarily by the action of corrie glaciers in the manner described previously. These remarkable changes in drainage seem to have been made possible by the overdeepening of the Rakaia Valley by its more powerful glacier below the level of the parallel valleys, thus providing a lower temporary base-level for the tributary streams. The same fact is also true to a modified extent of the valley to the east of Lake Coleridge, which has been eroded deeper than they have by the large glacier which occupied its floor.

While the Rakaia has been gaining in the upper part of its course as a result of glacier interference, it has lost lower down. Between the Rockwood Hills and the Big Ben Range there is a wide valley which was occupied once by a large glacier which flowed south-west, as evidenced by the smoothed slopes of Fighting Hill near its junction with the Rakaia. The outlet of the valley is very wide and open towards the Rakaia, but it is partially blocked by a large moraine, partly a terminal of the glacier which issued from this valley, and partly a lateral of the main glacier. This ponded back a large lake in the basin once occupied by the glacier, which secured an outlet not by the Rakaia, but by the Selwyn Valley—a result no doubt aided by the active erosion of the latter stream, which enabled it to cut back its head through the range of foothills and to draw on the basin in the rear. The existence of this lake is demonstrated by the deposit of glacial silt which occupies a part of the floor of the emptied basin near the High Peak Station. The Selwyn now flows from the valley through a narrow gorge of more recent date than its upper basin, and it has gathered to itself all the drainage belonging to this basin which once added to the Rakaia. The Rakaia Glacier has thus been directly or indirectly responsible for several remarkable changes in the drainage directions in its basin and those of its immediate neighbours.

8. Totara Forest.

A very striking feature of the Upper Rakaia Valley is the forest, composed chiefly of totara (*Podocarpus Hallii*), which clothes the hillsides for miles on the north bank of the river, and which occurs in large patches on the southern bank (see Plate VII, fig. 1). In this locality the wet westerly winds reach well across the main divide before they become parching and dry with the usual characters of the Canterbury north-wester, and the mountain ranges on the south of the Rakaia shelter the upper part of the valley from cold southerlies; so that the conditions are thus favourable to the growth of this rain-forest tree. The patch in the Rakaia is but the remnant of an ancient forest containing totara which extended over a wide area on the eastern side of the range, and reached southward through the Mackenzie country into Central Otago, the important bearing of which on the question of post-glacial climates is considered by the author in another paper in this volume. Further details regarding this plant formation will be found on page 363.

PART II.—PLANT ECOLOGY.

By L. Cockayne, Ph.D., F.L.S., and R. M. Laing, M.A., B.Sc.

[*Read before the Philosophical Institute of Canterbury, 5th October, 1910.*]

1. INTRODUCTION.

Very little has been published regarding the botany of the Rakaia, Ashburton, and Rangitata Valleys and the mountains adjacent. Sir Julius von Haast* made considerable collections of the plants during his early explorations in 1861, 1864, 1865, and 1866 (Haast, 1879), and these were determined by Sir Joseph Hooker, the new species being described in the "Handbook of the New Zealand Flora," while the rarer species are

* In his first expedition Haast was accompanied by Dr. A. Sinclair, who was, unfortunately, drowned in the Rangitata River, falling, as Haast writes, "a victim to his zeal for his cherished science."

mentioned in the same work. Haast (1866) noted a few of the plants of Browning's Pass, and calls attention to the subalpine scrub on Mein's Knob, describing his passage through it as "a herculean task." Mr. J. B. Armstrong (1879) described several new species from material collected by Mr. J. F. Armstrong, who, with the late Mr. W. Gray, of Governor's Bay, had made an excursion to the Rangitata Valley in 1869. These species were, for the most part, again described by J. B. Armstrong in the "Transactions of the New Zealand Institute" (1881). Mr. R. Brown, of Christchurch, accompanied by Mr. F. N. Adams, botanized in the Wilberforce Valley in 1885, following the Moa Creek to its source. A popular account of the excursion was written by the latter, enumerating some of the plants met with—*e.g.*, *Hymenophyllum Mallingii*, *Alsophila Colensoi*, *Polystichum cystotegia*, *Ranunculus Godleyanus* (abundant), *Veronica macrantha* (Adams, 1885). *Libocedrus Bidwillii* is stated to be the leading forest-tree. Brown published his results later (1894, 1895, 1899), describing several new species of mosses. During the progress of the present geological survey of New Zealand a few plants were collected in the vicinity of Browning's Pass, and these, identified by Mr. A. H. Cockayne, are published in the report dealing with the "Hokitika Sheet" (Bell and Fraser 1906, p. 101).

The authors visited the Arrowsmith district in the summer of 1909–10, but independently of one another, and at different times. Laing examined the vegetation of Mount Potts and the adjacent parts of the Rangitata and Clyde Valleys, and also the Cameron Valley to its glacier; Cockayne, who had the special advantage of Mr. R. Speight's company and geological knowledge, paid attention to the country in the vicinity of Lake Heron, and thence to the neighbourhood of Mein's Knob, on the south side of the River Rakaia, opposite the terminal face of the Ramsay Glacier, and for the account of the associations, &c., of that part of the district he is alone responsible. Both authors studied the plant covering of the lower Ashburton Gorge, and the upper Ashburton Plain as far as the stony bed of the River Cameron. Only a few weeks were spent on the work, even when both excursions are considered. It is plain, therefore, that but a very superficial knowledge of the district was gained, and were it not that matters of general interest are discussed, and formations considered, which concern also other river-valleys of eastern Canterbury, &c., with which we are better acquainted, and which also belong to the glaciated area, this paper would not have appeared.

The term "Arrowsmith district" is used in a broad sense. It includes not merely the actual range itself, but portions of the adjacent country, including the mountains lying to the east and north of the upper Ashburton Plain; but its topography and geology is sufficiently described in Part I. It must, however, be pointed out that the word "district" is not used in its phytogeographical sense, the area dealt with including, in point of fact, portions of two botanical districts.

2. PRIMARY CAUSES AFFECTING THE CHARACTER AND DISTRIBUTION OF THE VEGETATION.

(A.) THE GLACIAL PERIOD.

All authorities agree that the present glaciers, extensive though they are, represent a fraction merely of their former area; the only point in dispute is as to how far they extended into the lower country. But with regard to phytogeography the extent of the glaciation matters little, so long as sufficient room is allowed eastwards, southwards, and perhaps westwards, for the plants driven out of the mountains to find a haven of refuge. On the contrary, if it is assumed that an ice-sheet has covered the southern end of Greater New Zealand, *leaving no land eastwards or westwards of the present subantarctic islands,* then, for reasons already given by Cockayne (1909, p. 7), the present distribution of species is inexplicable.

There then remains only to be considered the repeopling of the glaciated area from the east during the retreat of the glaciers and the synchronous advance of the plants. Let us consider, therefore, the state of affairs at the time the terminal faces of the Canterbury glaciers, and of the Rangitata-Rakaia in particular, extended just on to the Canterbury Plain, taking into consideration at the same time the effect of elevation, the generally accepted cause of our glacial period (Hutton, 1900; Haast, 1879; Park, 1910) upon the climate.

Although the glaciers may have extended not merely on to the plain, but even far beyond the foothills, it by no means follows that the eastern ranges (Mount Somers, Mount Hutt, &c.) were altogether ice-clad, or even snow-covered. On the contrary, increase in altitude of the actual Divide would lead to a drier climate on the eastern ranges than the present one, and to a much diminished snowfall, so that it is quite possible, even at the greatest assumed extent of the glaciers (see Park 1909, 1910), these eastern mountains still preserved more or less of their primitive plant covering. But the increase of drought would bring about a semi-desert climate on the east, and, as Diels and Cockayne have shown, the forest-plants would either perish or be modified (Diels, 1896; Cockayne, 1901). So it is assumed that various xeromorphic growth-forms have arisen—*e.g., the divaricating, the flat-stemmed leafless,* &c. On the mountains the drought-conditions would be still more severe, and then may have originated the *Raoulia* cushions of the rocks and the highly differentiated shingle-slip plants.

Whether the above speculations are approximately true or the contrary, the first ground available in quantity for plant-colonization would be the rocky slopes above the ice-line of the valley glaciers, such as are to be seen near any of the large eastern glaciers at the present time. The populating by plants of such ground would be very similar to the evolution of fell-field, treated of below, while the final soil would be formed by slow degrees from the easily disintegrated rock (greywacke, &c.) together with humus from the plants, the plant covering favouring the formation of a true soil.

As the ice retreated, the smoothed lower slopes of the hills, the *roches moutonées,* the moraines, and the valley-floors, much of which would be river-bed, would be by degrees exposed. Soil of a different character to that mentioned above would finally accumulate, and would consist of the wind-blown rock-flour from the river-beds, of the subglacial material (boulder-clay, &c.) which would be left on the rock, &c., as the ice melted, and, in special positions, of extensive deposits of lateral moraine. That the surface soil of the valleys and lower slopes is principally wind-transported (*i.e.,* loess), though beneath there may be clay, is evidenced by what is going on to-day during any dry wind, when clouds of dust rise from the river-beds, but such loess may not infrequently be mixed with other soil.

Clay, formed *in situ* from the underlying rock, does not appear to be a specially important constituent of the soil. For instance, on certain *roches* *moutonnées*, as Speight has recently shown (1911), the ice-scratches are still to be seen on the non-disintegrated rock-surface when the boulder-clay and loess are removed, such rock having been preserved from weathering by its special hardness, the softer rock having been removed by ice-action.*

The plant-colonization of a river-bed at the present time must be very similar in character to that of the Pleistocene river-valleys, while the rock-faces left by the ice, where not covered by lateral moraine or boulder-clay, would rapidly become disintegrated and extensive shingle-slips be formed. Here loess would at first play no part in soil-forming; this would not come in till the valley glacier melted, and the earliest associations would probably consist of the higher alpine plants, which would later on be replaced on the drier mountains by steppe-plants. A further cause which would assist the spread of these latter would be the gradual decrease of cold water from the melting cliff glaciers, and the consequently warmer soil.

As the *névé* and ice of the highest summits grew less and less the supply of *débris*, owing to disintegration due to the action of frost, would increase, while at the same time the rivers below would be cutting their deep beds and forming their terraces, plant-occupation going on simultaneously, the invading plants being those from close at hand. Between the new plant covering and the *débris*, whether of disintegrated rock or of river-shingle, there would be a constant battle, the plant covering nevertheless slowly increasing in area. This struggle still goes on, river-fans in particular showing all stages of occupation, destruction, and rejuvenescence. Algae, mosses, and lichens would be the first colonizers to settle down, followed by herbaceous plants and xerophytic shrubs, which together would make the first associations. Trees would come later as soil became more plentiful, but they would occupy only gullies, sheltered terrace-slopes, or ground where shrubs had already settled and some shelter was provided.

(B.) CLIMATE.

Besides the physiographic factor with which is bound up the various edaphic distinctions, climate has played an important part not only in the distribution of species, but in the selection and evolution of growth-forms.

As in other Canterbury river-valleys, there are here two distinct climates, a wet and a dry; or, to give them ecological designations, *a forest and a steppe climate.*

The forest climate occurs only near the source of the Rakaia, extending eastwards for perhaps 5 km. from the dividing range, and marking by an irregular line the average distance reached by the north-west rainfall (see also Cockayne, 1900, pp. 117, 118, and 130–33), the rain especially following a main river-valley. When the wind is blowing a gale from the latter quarter there is frequently not a drop of rain in the vicinity of Lake Heron,† and transpiration conditions are at a maximum, but from the neighbouring heights a heavy rain-storm can be seen in progress in the Rakaia Valley.

To be sure, the steppe climate is far from being really dry, but clear skies with strong insolation are frequent, and *the ever-present wind would demand a much higher rainfall before forest could establish itself naturally.*

* This is just the same as occurs in Europe, &c.

† The great mass of Mount Arrowsmith also keeps back no small amount of rain.

The wind is, indeed, a factor of paramount importance. For several days at a time the north-west gale will rage, accompanied by heavy rain in the west, *but in the east quite dry.* Apart from its powerful effect on transpiration, the wind is strongly antagonistic to tall growths, especially where its presence is most felt, as in narrow river-valleys, and the low growth of the majority of the steppe-plants, as also the divaricating-shrub form, are "adaptations" against both the mechanical and transpiration-promoting action of the wind, whatever their origin in the first instance. The south-west wind is of quite minor importance in the Rakaia Valley, but on the heights it may at first bring more or less snow at any season. In the east its effect is more marked. It is a cold wind, and is frequently accompanied at first by rain on the lower and snow on the higher ground.

The winter snowfall is most felt at above 1,200 m. altitude, and plant-distribution according to altitude, as Cockayne pointed out some years ago (1900, p. 128), depends, in part at any rate, upon the average length of time the snow lies upon the ground. In gullies and hollows where the snow accumulates the higher alpine plants may occur at below their usual altitude. Besides acting as a warm covering to the plants and checking transpiration, snow acts mechanically, especially on the evergreen subalpine shrubs, pressing their branches to the ground. The fell-field herbs and subshrubs are also in places submitted to a great pressure, and look, after the snow has melted, as if a heavy roller had passed over them; but this flattening has no effect on their aftergrowth, the shoots rapidly assuming their usual position when the weight is removed. Very effective is the work of snow in keeping the ground cold during the vegetative season, and thus more than in any other way does it regulate the belts of vegetation and local distribution. Further, its gradual melting leads at the higher levels to a constant supply of soil-water for a considerable period, and this is especially noticeable in hollows which may have a distinctive vegetation dependent partly thereon and partly upon the longer time the snow lies.

Frost occurs at all seasons of the year, and in positions where there is no snow-covering young shoots are exposed to its effect. One and the same species may grow, however, in spots protected or unprotected by snow, and in each be equally undamaged. Certain species of *Celmisia* in winter may be coated with ice, and this will function in checking transpiration. Probably even at the highest altitude the thermometer never sinks below 18° C.,* and we should not be surprised if the average minimum is higher.

With regard to xeromorphy, too much stress cannot be laid on the effect of quite short rainless periods in the wettest mountain climate. Plants accustomed to a wet soil, a moist atmosphere, and a frequent downpour are exposed all on a sudden to quite opposite conditions, the porous soil also rapidly losing its available moisture. In such a case xerophytic structure or form sufficient to ward off the danger of excessive loss of water even for a few days is imperative.

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* In 1908–9, when on one occasion the thermometer at Kew sank to 10° Fahr., the previous weather having been mild, *Gaya Lyallii* was destroyed to the ground-level, *Sophora tetraptera* was killed, *Griselinia littoralis*, though escaping the winter frost, was much damaged by the winds of March, and ten species of *Veronica* were killed or severely injured (Kew Bull., 237, 1909). Many other examples could be cited, but this sufficently testifies to the comparatively mild climate of the New Zealand lower subalpine belt at any rate.

3. THE PLANT FORMATIONS.

(A.) GENERAL.

Here the term "formation" is used in the generic sense indicated by Warming (1909, p. 140), the fell-field, for instance, being a portion of the general fell-field of New Zealand and of mountains in other parts of the world, while the associations are local, and, though made up of similar growth-forms to those of the formation elsewhere, differ in their floristic components. Subassociations are smaller communities within the association, and within these latter again may be groups of species. Finer distinctions still could be made, but for such a most careful analysis of the vegetation would be required, and this is not demanded or desirable in New Zealand so long as the broad features of so much of the vegetation remain unknown. To estimate rightly the limits of certain associations, and especially subassociations, is not so easy as might be thought.

It must also be pointed out that the study of vegetation should be dynamic, and not static. Associations are not independent creations, but each has its life-history—its birth, its youth, its manhood—and in certain instances its evolution may be seen in progress, especially where there is a rapidly changing topography, as on a river-bed,* or where rock changes to fell-field by way of shingle-slip.

The same climax formation may come into being from different beginnings, or may be the result not of progression, but of reversion. Notwithstanding that an association is part of a series, it is a distinct association for all that, and may be just as much a feature of the landscape as a climax association, from which it differs only in its much shorter life.

(B.) STEPPE-CLIMATE FORMATIONS.

(*a*.) THE STEPPE SERIES.

(1.) *General.*

Steppe, in one or other of its phases, occupies the greater part of the Arrowsmith district up to an average altitude of perhaps 900 m., though this is somewhat exceeded in the east. Above it gives place to fell-field or scrub, according to the rainfall. There is both edaphic and climatic steppe, as also combinations of the two.

The term "steppe" was first used for the New Zealand plant formation in 1908 by Cockayne, when dealing with the volcanic plateau in the North Island; previously the same author had used the term "meadow" for this and other xerophytic formations of grasses and herbs. Laing and Blackwell, however, in 1906 had already shown that "tussock country," as they called it (1906, pp. 3, 4), was a vegetation-form of a different type from meadow proper.† How nearly related the New Zealand steppe may be to that of Warming (1909, pp. 281–88) is another matter. Certainly the rainfall and number of rainy days is much greater than Warming gives for a steppe climate; but it must be borne in mind how greatly a heavy rainfall can be discounted by frequent high winds plus a non-retentive soil. The formation also seems related to Warming's "chersophyte vegetation,"

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* See Part I *re* topography of a river-bed.

† "Grass steppe is found where the rain is moderate in amount, but falls only a few days in the year; grass steppe as a rule can be utilized for cultivation without artificial irrigation" (Warming, 1909, p. 274).

but this latter we consider with Tansley (1909) an unsatisfactory class, since, on the one hand, it is evidently very close to steppe, and, on the other, its forms are often altogether artificial.

The land-surface of the mountain steppe consists of hill-slopes; river-beds, sometimes lying deep below the general surface of the land; high river-terraces whose remarkably flat tops are old flood-plains, but whose stony faces slope steeply to the river-bed beneath; heaps of old morainic matter with the surface crumpled and irregular; *roches moutonnées* and river and torrent fans.

The surface soil is a soft silty clay, the loess or semi-loess already spoken of, which is readily denuded, easily moved by the wind, and rapidly becomes dried up. Beneath, the clay may be stiffer, and there is nearly always a porous gravelly and shingly subsoil which frequently comes close to the surface.

(2.) *Succession.*

So far as our observations go, steppe has originated in the following ways:—

(α.) Through occupation of actual river-bed, a form of succession easily studied at the present time.

(β.) Through disintegration of rock followed either by shingle-slip or by a fan at the mouth of a river or torrent.

(γ.) Through occupation of moraine, boulder-clay, or other stranded glacial *débris*.

(δ.) Through soil blowing on to a rock-surface which by degrees becomes occupied by plants, these further trapping and holding fresh blown soil.

(ε.) Through a shallow lake being turned by various stages into dry land.

(3.) *The Associations.*

(*a.*) Rock.

Unfortunately our notes contain but little regarding the rock-vegetation; in fact, rock-faces are much less in evidence in the steppe belt than in that of shingle-slip and fell-field. The rock-plants, leaving a number of mosses and lichens on one side, are generally species also belonging to the steppe proper, and their numbers depend altogether upon the form of the rock-surface and its capacity for catching blown soil and accumulating humus.

Asplenium Richardi, a fern 5–12 cm. tall, with dark-green rather thick much-cut tufted leaves given off from a short stout rounded caudex, is abundant in shaded hollows of the rock. Tussocks of the grass *Poa caespitosa* and *Festuca rubra* var. are common, even where there is little soil. The small succulent herb *Crassula Sieberiana* is abundant, and the following are also common: *Danthonia semiannularis* (tufted grass with slender involute leaves), *Muehlenbeckia axillaris* (creeping, prostrate, wiry stemmed, small-leaved shrub), *Cardamine heterophylla* (annual herb 10 cm. or less tall with slender decumbent stems and short moderately thick smooth pinnate leaves), *Oxalis corniculata* (prostrate creeping herb with slender matted stems and very small rather thick leaves), *Epilobium pubens* (semi-erect herb with stems suffruticose at base and pubescent leaves about 2·5 cm. long and red beneath), *Anisotome aromatica* (rosette herb with very long fleshy root and moderately thick pinnate linear leaves flattened to rock), *Raoulia australis* (low cushion plant with much-rooting stems and small close tomentose silvery leaves), *Crepis novae-zelandiae* (rosette herb with moderate-sized thick pinnatifid leaves and stout fleshy root). Various xerophytic shrubs occur on rock—*e.g.*, *Hymenanthera dentata* var. *alpina* (cushion of most rigid stout semi-spinous stems bearing, sparsely, small thick smooth dark-green leaves and with very long deeply descending root), *Carmichaelia robusta* (flat, assimilating leafless stems about 30 cm. tall and very long deeply descending root), *Discaria toumatou* (described further on), *Olearia avicenniaefolia* (shrub-composite form, much-stunted, leaves thick, tomentose).

Besides the above a good many of the steppe-plants may occur on rock, the number varying according to the amount of soil and position of rock-surface with regard to sun and wind.

(*b.*) Fan.

Where gullies or gorges open out on to the plain or river-bed there are fans of *débris*, sometimes of great extent. The vegetation of these depends altogether upon the supply of *débris* brought down by the torrent, and this again is correlated with the plant covering of the gully-walls. Fans are either active or passive, and every transition between the two may be traced. The surface of the fan is much steeper than river-bed in general. There are water-channels, but these are usually dry except during heavy rain, the stream being generally underground. The stones are frequently in part very coarse, and are often piled into comparatively high but quite unstable terraces, liable during any flood to damage or absolute destruction.

The vegetation commences with the appearance of certain herbs whose "seeds" are wind-borne, and the formation is markedly open. Competition is altogether absent. These first-comers are: Erect *Epilobia* (*E. melanocaulon*, *E. microphyllum*), creeping mat-forming *Epilobia* with slender interlacing rooting stems (*E. pedunculare* in various forms, *E. nerterioides*), herbaceous species of low cushion or rounded mat-forming *Raoulias* (*R. tenuicaulis*, *R. australis*, *R. lutescens*), and the curious half-dead-looking grey-coloured cupressoid shrub *Helichrysum depressum*, some 40 cm. tall, with spreading branches bearing a few closely appressed woolly scale leaves. As the substratum becomes stable the tussock-grasses *Poa caespitosa* and *Festuca rubra* var., one or both, appear, probably occupying first of all a soil-making *Raoulia* cushion or patch; *Muehlenbeckia axillaris* forms extensive circular patches; the creeping fern *Blechnum penna marina*, its leaves thick and stunted, forms considerable colonies; the vegetation gets closer and typical steppe is installed.

On the other hand, the vegetation may develop otherwise, and the stable but quite stony ground be occupied by a shrub steppe of almost pure *Discaria toumatou*, a more or less leafless divaricating shrub 90 cm. to 1·5 m., or more, tall, furnished with abundant assimilating spines. At a distance such shrub steppe is black in colour and is an invariable sign of fan or of old river-bed. Between the shrubs there are frequently more or less tussocks.

(*c.*) River-bed.

The procession of events on river-bed is much the same as on fan, and the climax association will be tussock steppe or shrub steppe (*Discaria*), or, in the west, modified subalpine scrub. The most important pioneer plant of western river-bed is *Raoulia Haastii*, which builds true cushions of considerable diameter, green in colour, full of raw humus within, and which can cover not merely the smaller stones, but even enwrap such as are 60 cm. tall A detailed account of the ecological history of a western subalpine river-bed by Cockayne will shortly appear in the "Transactions of the Botanical Society of Edinburgh," so little more need be said here.

Eastern river-bed vegetation commences with the same *Raoulia* species as eastern fan, and the procession of events is very similar, while it is obvious that the tussock steppe of a river-terrace summit has gone through the same changes as are happening on river-bed at the present time.

The old bed of the Ashburton near Hakatere is occupied by an extremely xerophytic subassociation, which would repay detailed investigation. Tussocks are few in number and far apart. The vegetation is quite open. The substratum is flat, very stony, and with but little fine soil. The xerophytic whitish moss *Racromitrium lanuginosum* is abundant, growing between the stones. There are many broad patches of the narrow erect flat green leafless stems of *Carmichaelia uniflora* and *C. Enysii*. Low silvery circular cushions of *Raoulia lutescens* are abundant. *Discaria toumatou* and *Helichrysum depressum*, no longer erect, are flattened to the ground. *Coprosma Petriei* (close turf-making subshrub with stout creeping stems and very small linear-oblong coriaceous leaves), *Wahlenbergia saxicola* (mat-forming, creeping, and rooting herb with small thick coriaceous leaves in open rosettes), *Acaena inermis* (mat-forming, creeping, and rooting subshrub with wiry stems and rather thin glaucous or reddish pinnate leaves in open rosettes), some green cushions of *Raoulia Haastii*, and a few flat or raised silvery round patches of *R. australis*. There are doubtless other species present. The subassociation occupies a wide area. It probably owes its structure and character not only to the edaphic conditions, but to the wind-swept habitat. An epharmonically similar subassociation occurs on the most stony ground of the Canterbury Plain, but the *Carmichaelia* is *C. nana* and the principal *Raoulia* is *R. Monroi*.

(*d.*) Tussock Steppe.

* *General.*

Montane and subalpine tussock steppe is merely a continuation of the same formation of the lowlands, and extends over much of the mountain area on the east of the Southern Alps, and has a fairly uniform floristic composition throughout. Tussock steppe is economically far and away the most important indigenous plant formation of the Dominion, and a thorough knowledge of its ecology is distinctly a matter of national importance. This statement is emphasized by the fact that overstocking and burning have so modified the original tussock steppe in various parts of the South Island that the value as pasture land is gone, a true desert having replaced the original grass land (see Cockayne, A. H., 1910).

** *Growth-forms.*

There are doubtless considerably more species in the association than given in our list, but a consideration of those contained therein should be quite sufficient to give a clear idea as to the growth-forms and their relative abundance.

The number of species noted is 103, of which 15 are *shrubs*, 12 *subshrubs*, and 76 *herbs*.

The shrubs are: *Evergreen*, 10; *deciduous*, 2; and *leafless*, 3. The following growth-forms are represented: The *creeping and rooting*, 9, of which 2 are *the flat-stemmed leafless; the prostrate non-rooting*, 2; *the divaricating*, 2, of which 1 is spiny; *the bushy*, 1; the *tall flat-stemmed leafless*, 1.

The subshrubs are: *Evergreen*, 9; *summer-green*, 3. The following growth-forms are represented: *Creeping* (*rooting*), 11, comprising *turf-making* 2 and *leafless* 1; *erect*, 1.

The herbs are: *Evergreen*, 72; *summer-green*, 4. The growth-forms are represented by—*annuals and biennials*, 4, made up of *erect and branching*, 3; *rosette*, 1: and *perennials*, 68, of which 4 are *summer-green*, made up of the following growth-forms—*tussock*, 6; *tufted grass*, 12; *creeping and rooting*, 24, of which 7 are *turf-formers; rosette*, 18, 2 of which are of the *Yucca form; prostrate not rooting*, 3; *cushion*, 3, but some of the creeping may assume this form; *erect and branching*, 2.

If the leaves of all the plants are considered it will be found that those of 47 species are very small, 14 have margins incurved or recurved, and 4 are leafless. Larger leaves are frequently stiff, thick or coriaceous, or flattened to the ground as rosettes. The number of glabrous leaves (70) is larger than might be expected, but these are frequently more or less coriaceous; tomentose leaves number 13.

Just as the steppe develops in connection with increasingly mesophytic edaphic conditions, so does the combination of growth-forms become gradually more mesophytic. But the freely developed steppe itself provides an altogether different environment to the unoccupied wind-swept ground, and it is the taller members of the formation alone (*tussock-grass, Yucca form, xeromorphic shrubs*) or the plants of special stony wind-swept ground (*dwarf leafless flat-stemmed shrubs, leafless summer-green subshrub, cushion and patch plants, turf-making creeping herbs*) that are exposed to severe conditions. Tall plants without very special adaptations cannot establish themselves, and about 80 per cent. of the florula consists of dwarf plants, mostly prostrate or creeping, which grow under conditions of considerable shelter.

*** *Physiognomy.*

The tussock steppe of the Arrowsmith district is no longer a virgin formation. Burning and overstocking have brought about a more xerophytic environment, and, although probably all the original species are present, their relative proportion is much changed, the originally dominant tussock having decreased together with the mesophytic grasses and herbs which grew in its shelter, while various xeromorphs (species of *Raoulia*, tomentose rosette plants, &c.) have increased and certain introduced plants have gained a footing.

Seen from a distance, tussock steppe appears as a smooth brown carpet on the dimpled hillside. A closer view dispels the illusion and reveals the bunched-up grass culms and leaves, close together at the round base of the tussock but spreading above and mostly dead at the apices, growing side by side, each some 40 cm. tall, in some places their leaves intermingling, and in others distant and with partially covered and more or less eroded ground between the clumps. Here and there stand above the tussock low dark-coloured bushes of *Discaria toumatou*. On the ground between the tussocks there are the creeping plants forming mats—glaucous of *Acaena Sanguisorbae* var. *pilosa*, reddish of *A. inermis*, brown of *Styphelia Fraseri*, pale whitish-green of *Raoulia subsericea*, green of *Brachycome Sinclairii*—orange-coloured small cushions of *Scleranthus biflorus* and great green semi-cushions or high circular mats of *Celmisia spectabilis*, rosettes flattened to the ground of *Senecio bellidioides* (dark green and hairy), *Craspedia uniflora* var. (whitish or greyish-green), the small round leaves of *Hydrocotyle novae-zealandiae* flattened to the ground, and round patches of *Muehlenbeckia axillaris* its stems creeping beneath the surface. Other plants are quite common—*e.g.*, small tussocks of *Poa Colensoi*, tufted *Danthonia semiannularis*, *Carex breviculmis*, *Uncinia rubra*, *Colobanthus Billardieri* in tiny rosettes which may make small cushions, *Ranunculus multiscapus*, *Geranium sessiliflorum*, *Pimelea laevigata* var. *repens*, *Epilobium elegans*, the great bayonets of *Aciphylla Colensoi* (much less common than formerly), *A. squarrosa*, *Anisotome aromatica*, *Gaultheria antipoda* var. *depressa*, close turf of *Coprosma Petriei* on stony ground making in places a special "group," and in the most exposed and dry stations yellowish-green cushion 5 cm. in diameter of *Colobanthus brevisepalus*, *Wahlenbergia saxicola*, *Lagenophora petiolata*, *Celmisia longifolia*, *Vittadinia australis*, *Helichrysum bellidioides*, *H. filicaule*, *Cotula squalida*, *Microseris Forsteri*, and *Taraxacum glabratum*.

**** *Subassociations.*

† *Danthonia Raoulii* Steppe.

This subassociation frequently occupies wide areas. Its presence appears to depend upon increase of altitude, poverty of soil, acid or cold soil, and perhaps exposure to wind; but the conditions governing its distribution throughout New Zealand have been altogether insufficiently studied. The tussock itself is much taller than that of *Poa caespitosa* or *Festuca rubra* var. It is also much less relished by stock, and so its present distribution may not be a natural one.

†† *Danthonia flavescens* Steppe.

This subassociation generally occupies a higher altitude than *D. Raoulii* or *Poa caespitosa* steppe. Certain of the higher mountain plants enter into the combination, and the subassociation itself may grade off into fell-field. The dominant species is much relished by sheep, so the true ecology of the subassociation is not easy to determine.

††† Dwarf *Carmichaelia* Steppe.

This has been already described. Besides *C. Enysii* and *C. uniflora*, *C. nana* is in some places an important member, and the much stouter *C. Monroi* builds stiff open cushions, its stout woody root descending deeply and its short stiff stems more or less vertical. The low-growing *Veronica pimeleoides* var. *minor* grows here and there, a species with small glaucous leaves and blue flowers—a most unusual colour in New Zealand; and the leafless grey stems of *Muehlenbeckia ephedroides* may lie upon the stony ground, their very much stouter creeping stem hidden beneath the stones.

†††† *Triodia* Steppe.

This subassociation consists principally of an extremely dense turf of the small grass *Triodia exigua*, which spreads most extensively by means of its long much-branching rhizomes, which form eventually a matted tangle. The leaves are very narrow, 2·5 cm. long more or less, filiform, convolute, stiff, and almost pungent. *Styphelia Fraseri* grows through the turf, hugging the ground. *Carmichaelia Enysii*, *C. nana*, and *Stackhousia minima* are, so far as we remember, members of the combination, but unfortunately our notes are too brief for an accurate, detailed description.

(*e.*) *Gaya ribifolia* Association.

On fairly sheltered hillsides, in gullies, on river-terraces, and frequently where the ground is quite stony, especially in the lower Ashburton Gorge, the monotony of the tussock is relieved by green clumps of trees. These consist of *Gaya ribifolia*, a low tree 6 m. tall, more or less. A few ferns may grow beneath the trees—*e.g.*, *Blechnum penna marina*, *Hypolepis millefolium*, *Polystichum vestitum*, and on the outskirts a few divaricating shrubs.

The presence of *Gaya ribifolia* is a sign of steppe climate, since a forest climate at once replaces it with the closely allied *G. Lyallii*. Both are strictly deciduous, but differ ecologically in their leaves, those of *G. ribifolia*, covered with hairs, being more xerophytic than the almost glabrous adult leaves of *G. Lyallii*. Both species pass through a somewhat similar persistent juvenile stage of development.

(*f*.) *Nothofagus cliffortioides* Forest.

N. cliffortioides forest may be considered the climax association of the subalpine-steppe climate. It occurs very sparingly in the Arrowsmith district, and is confined to a few gullies, or there may be merely a few trees, scattered or in clumps on the banks of streams.

N. cliffortioides is a low canopy tree with a close head of small stiff leaves. The branching is distichous, and the foliage consequently lies in layers. The trees are probably not very long-lived, and fall before the wind as they decay, their place being taken by a close growth of saplings, which, as seedlings, formed most of the undergrowth.

The following were noted as forming the undergrowth: *Blechnum penna marina* (creeping fern), *B. capense* (tufted fern), *Hypolepis millefolium* (summer-green creeping fern), *Podocarpus nivalis* (prostrate rooting shrub), *Aristotelia fruticosa*, *Coprosma propinqua*, *C. parviflora* (divaricating-shrub form), *Griselinia littoralis* (bushy shrub), *Fuchsia excorticata* (small deciduous tree), *Urtica incisa* (erect herb). Doubtless a number of other species are present, but at the best this association has few members. *Elytranthe flavida* (hemi-parasite) grows on the *Nothofagus*.

At one period, as also in Central Otago and elsewhere, as already noted by Speight, where now a steppe climate prevails there must have been extensive totara forests, for remains of trees lying on the ground have been frequently noted, as, for example, in the Cameron Valley according to Mr. L. Wood (see also Monro, 1869; Buchanan, 1869).

If such a forest existed, and occupied a wide area in the eastern subalpine and montane belts of the South Island, it seems almost impossible that it could have been altogether destroyed by fire, as popular and even scientific opinion has declared (see Monro, 1869; Buchanan, 1869). The only feasible explanation, then, is that put forth by Speight—that the climate not very long ago, geologically speaking, was more mesophytic than at the present time. If the Rakaia Valley be alone considered, it is almost certain an advance of the average western rain-line a few miles to the east would be followed by an advance of the present totara forest, and, although extending no further, it would persist for a long time after the climate had become xerophytic. On the other hand, a rainfall similar to that of the western Rakaia has only brought *Nothofagus cliffortioides* forest in the western Waimakariri district.

(*g*.) Lake, Swamp, Bog, &c.

The above series of associations are dealt with in this place because the climax association of a lake captured by vegetation is steppe, though the process is a slow one, which, however, may be much accelerated by a stream depositing shingle, &c., on the lake-floor.

* *Lake.*

The most important lake is Lake Heron, situated at about 670 m. above sea-level. There are several smaller lakes on the Upper Ashburton Plain, also tarns on spurs which were formerly overridden by the ice, as well as small ponds in various places.

We have no details as to the lake-vegetation beyond the facts that *Typha angustifolia* var. forms the innermost girdle in some parts, and that towards the southern extremity of Lake Heron there is an extensive colony of niggerhead, probably *Carex secta*, with tall and stout trunks.

** *Swamp.*

On both sides of the so-called Lake Stream near where it issues from Lake Heron, and in certain places near the margin of the lake itself, there are extensive swamps which merge into bog and this into steppe. The water-content varies much at different seasons of the year, as likewise at times of heavy rain. Furthermore, their ecology has been much modified by burning and the trampling of stock.

Two principal subassociations were noted according to depth of the surface water—viz., *Schoenus pauciflorus* (deepest water), *Carex ternaria* (shallower water).

At a distance the swamp appears of a uniform grey colour. It is traversed by various streams, and pools of water lie permanently in many places. A close view shows that the grasslike *Carex Gaudichaudiana* is the most abundant plant. The two subassociations differ in colour, *Schoenus pauciflorus* being reddish and *Carex ternaria* green. On the surface of pools there is abundance of *Ranunculus rivularis*, which may quite hide the water. *Montia fontana*, a species of *Myriophyllum*, and *Epilobium macropus* occur more or less abundantly in the streams. *Schizeilema nitens* (creeping and rooting slender-stemmed herb with small trifoliate shining glabrous leaves) is abundant where water lies and the light is sufficient.

Epilobium insulare, Carex diandra, C. stellulata, C. Oederi var. *cataractae*, and *Elaeocharis Cunninghamii* are common on the very wet ground.

As the soil gets drier *Mazus radicans*, its thin spotted yellowish leaves flattened to the ground, is abundant, and both *Carex ternaria* and *Schoenus pauciflorus* are absent. Drier soil still favours the presence of *Pratia angulata*, and probably *Isotoma fluviatilis*, a creeping herb of similar growth-form, is present. The following are other plants of the boggy ground: *Utricularia monanthos, Plantago triandra* (rosette plant), *Asperula perpusilla*, a species of *Cotula, Viola Cunninghamii, Luzula* species (flat, red leaves).

Finally, *Bulbinella Hookeri* var. *angustifolia* (summer-green herb with tuberous roots) is common both on wet and on dry ground, forming most noticeable colonies when in bloom with its bright-yellow flowers, but it is absent in the wettest part of the swamp. Also, this plant is extremely common in wet ground throughout the montane and subalpine belts of the district, and increases enormously after the vegetation is burnt.

*** Sphagnum *Bog.*

Only the bog connected with steppe is here dealt with; that of the forest climate, and which elsewhere in New Zealand is related to fell-field and moor, was not examined.

Bog surrounded by steppe can be seen at various stages of development. In one place on Prospect Hill (about 900 m. altitude) the hollow clearly indicates a former tarn in a rock-basin, but the whole is now *Sphagnum* bog, while in another place, close by, a tarn is in course of occupation by bog. Let us first consider the tarn.

This, where it joins the bog, is about 30 cm. deep. The water, then, will get quite warm on a hot summer's day. Growing in it is *Elaeocharis Cunninghamii?* (slender rush form), *Carex ternaria* (grasslike sedge), and the *Sphagnum* moss grows out into the water, its margin unevenly undulating. With the advancing moss there is *Schizeilema nitens* and tussocks of *Schoenus pauciflorus*, the former also floating on the water just at the edge of the tarn. *Drosera arcturi* (small herb with short rootstock and reddish linear-ligulate leaves furnished above with glandular hairs) and *Carex stellulata* are amongst the first plants to settle on the *Sphagnum*. Tussocks of *Danthonia Raoulii* also come occasionally right to the front. The grassy and far-spreading *Carex Gaudichaudiana* is abundant, but it is a later arrival than any of the above. Other plants are *Oreobolus pectinatus* (dense small green cushions of distichous stiff short linear-subulate leaves with broad equitant bases), *Carex subdola, Pratia angulata. Drosera arcturi* and *Carex stellulata* are very abundant all over the bog, but there is much less tussock than on the older bog to be next described.

The bog which has buried the tarn is made up of close masses of *Sphagnum*, which for the most part is concealed by the grassy *Carex Gaudichaudiana*. In many parts steppe is virtually installed, as tussocks of *Danthonia Raoulii* are dominant. Where these do not touch there are open spaces occupied by *C. Gaudichaudiana, Bulbinella Hookeri* var. *angustifolia, Blechnum penna marina*, some tussocks of *Poa caespitosa, Anisotome aromatica*, creeping *Gaultheria depressa*, a species of *Polytrichum, Viola Cunninghamii, Schizeilema nitens* and *Ranunculus rivularis* (where water lies), *Celmisia longifolia, Epilobium chloraefolium, Helichrysum bellidioides, Wahlenbergia saxicola.* Here and there, right on the *Sphagnum* cushions, are rounded low bushes of *Dacrydium Bidwillii.* As is well known, the *Sphagnum* plants die below and are gradually converted into peat, while their apices continue to grow upwards ; and if the plants which have settled upon the moss are not able to grow upwards at the same rate as the bog, rooting at the same time, they will be eventually buried by the moss and killed. Thus on this particular bog plants of the dwarf taxad, *Dacrydium Bidwillii*, exhibit various stages of burial, notwithstanding the power this shrub has of extending by means of creeping and rooting prostrate stems furnished with spreading juvenile leaves. On the other hand, the rhizomatous sedge, *Carex Gaudichaudiana*, can grow faster than the moss, form a turf, and check its upward growth altogether ; so that the moss in its turn is the vanquished. With the consequent drying of the ground, steppe is by degrees established, but it must be understood that the first-coming tussocks on the bog-moss are liable to burial, and a growth of these does not of necessity denote the installation of steppe.

† Growth-forms of Bog.

The following growth-forms were noted on the bogs of the district :—

The number of species in the list of plants is 36 (35 evergreen, 1 summergreen). This would have been greater most undoubtedly had we reached the bogs (1,200 m. altitude) on Mein's Knob.

The growth-forms are as follows :—

Shrubs : Creeping and rooting, 2, of which 1 is *prostrate with subterranean stem* and 1 *bushy* and 60 cm. or so tall.

Herbs : Creeping and rooting, 21, of which 5 are *grasslike*, 1 *rushlike*, 2 frequently *aquatic with floating leaves ; rosette form*, 5 ; *erect*, 3, of which 1 is *grasslike ; tussock*, 3, of which 1 is *rushlike* (slender) ; *cushion form*, 1 ; *prostrate non-rooting*, 1.

At least 70 per cent. of the species are also plants of steppe or other dry habitats.

Bog at a higher altitude, or exposed to greater snowfall—*i.e.*, to colder water—on an average is more xerophytic, and contains especially a higher percentage of cushion plants.

Also, pure *Sphagnum* cushions in vigorous growth, thanks to the non-acid rain-water absorbed by the upper surface, will allow mesophytes to settle down which cannot tolerate acid peat (see Cockayne, 1910, p. 111).

(β.) ROCK FELL-FIELD SERIES.

(1.) *General.*

The altitude of the upper line of the steppe is very variable, but probably corresponds to a large extent with the line of the ancient valley glacier. It also constitutes the lower limit of the series of plant-associations under consideration, which depends in large measure upon the presence of an easily disintegrated rock, though it is governed to no small degree by altitude and climate.

Under the influence of frost the much-jointed sandstones, greywackes, and slates become rapidly disintegrated, the stone-fragments (too great in quantity to be removed by rain) accumulate to such an extent that great fields of *débris* occupy almost the entire mountain-surfaces for hundreds of metres. Here and there jagged masses of much-corroded rock jut out from the stone-fields and break the uniformity of the long grey even slopes. Gullies with more or less precipitous walls seam the mountain-sides, a stream sometimes occupying their floors, the water issuing all on a sudden from the base of a great stone-field at the head of the gully, and perhaps as suddenly disappearing lower down beneath the ever-increasing mass of loose stones. From the above it is plain that the edaphic conditions of the upper subalpine and alpine belts are those of desert, and it is plain also that increase of altitude, irrigation by snow-water, strong insolation, high winds, and occasional droughts help to increase the xerophytic character of the plant-habitats during the vegetative period.

Altitude and the average height of the winter snow-line, above which the snow lies from four to six months,‡ separates the area into alpine and subalpine belts.

The three following plant-formations occur, arranged in order of succession : *Rock, shingle-slip, fell-field.*

(2.) *The Associations.*

(*a.*) Rock.

The following are the only special rock-plants : *Hymenophyllum villosum* (filmy fern), *Polypodium pumilum* (very small fern with tufted leaves),

‡ This is undoubtedly the outside limit.

Trisetum subspicatum (small tufted pubescent grass), *Cardamine depressa* (small rosette herb), *Colobanthus acicularis* (small cushions of rigid glabrous linear-subulate acicular leaves), *Hectorella caespitosa* (dense cushions of small imbricated coriaceous leaves and thick root), *Pimelea Traversii* (small shrub with tortuous branches and short thick glabrous imbricating leaves), *Celmisia bellidioides* (subshrub forming loose cushion of leaves in rosettes), *Raoulia eximia* (very large dense tomentose-leaved cushion plant with woody main stems and stout woody deeply descending root), *Helichrysum grandiceps* (short-stemmed subshrub with small imbricating silvery tomentose leaves), *H. microphyllum* and *H. Selago* (tomentose cupressoid shrubs, more or less of cushion habit).

Also, the following are common rock-plants, though not absolutely confined to rocks: *Luzula pumila* (small cushion), *Veronica pinguifolia* (decumbent low shrub with thick glaucous leaves), *V. tetrasticha* (dwarf cupressoid shrub), *V. epacridea* (decumbent shrub with imbricating thick recurved concave leaves).

The rock-vegetation is scanty. It is most abundant on the shaded parts. The true rock-plants are chasmophytes. Where there are deep chinks and ledges peat forms, and then various plants of the fell-field occur —*e.g.*, *Ranunculus Monroi* var. *dentatus*, *Anisotome aromatica*, *Aciphylla Monroi*, *Gaultheria rupestris*, *Dracophyllum rosmarinifolium*, *Helichrysum bellidioides*, *Celmisia spectabilis*, and sheets of *Hymenophyllum multifidum* (hardly a fell-field plant on a dry mountain).

So far as the true rock-plants are concerned, they are a category by themselves, and have no relation to fell-field vegetation, but the remainder can play their part in populating stone-fields.

* *Vegetable-sheep Subassociation.*

Where the rock is almost weathered away, and stands raised here and there as a small island in the stony desert, it is frequently occupied by the great cushions of *Raoulia eximia* 1 m. or more in diameter. This most curious shrub has exactly the same growth-form as its herbaceous relatives of the river-beds. There is a central main stem and a few primary woody branches radiating therefrom which branch repeatedly, the secondary branches and those which follow having a tendency to grow upwards, and this is assisted by the frequent branching and consequently increasing density preventing their otherwise horizontal extension. The closeness of growth, through cutting off the light, causes the death of all the interior leaves and many of the stems, so that only the stouter remain, the interspaces becoming filled closely with a sticky raw humus into which the ultimate branches send abundant roots. The only living leaves are those pressed closely to the shoot-axis for a few centimetres near the apices of the ultimate branches; they are narrow-obovate, 3 cm. or so long, and densely covered near their apices with white hairs which stand almost erect. The shrub as a whole forms a great hard cushion, the ultimate shoots being pressed together as closely as possible. The interior peat even in the driest weather is soaking with water, and it is probable that the plant gets its chief food and water supply from this source, the main root, sent far into the rock, serving principally as an anchor.

Certain of the fell-field plants may grow upon the cushions, thanks to the wet raw humus contained therein.

(b.) Shingle-slip.

* *General.*

The edaphic distinction between shingle-slip and fell-field lies in the fact that the former consists altogether of loose stones lying at so steep a slope that those of the uppermost layer move downwards from time to time, whereas the stones of the fell-field are in a much more stable position, and there is generally a considerable percentage of true soil. This instability of shingle-slip has led to the occupation of this land-form not merely by certain growth-forms, but actually by distinct species *which do not occur in any other formation.* Furthermore, the plants are distant so far from one another, and the general plant covering is so scanty, that it plays no part worth mentioning in adding humus to the soil, while the formation is distinct in itself and has nothing to do with the installation of fell-field. It is, in fact, a definite vegetation entity whose life-history it is now impossible to examine, and whose origin is wrapped in obscurity.

The shingle-slip species are confined to the South Island,‡ and the majority to the drier mountains of the east. The following is a list of those found in the Arrowsmith district in its widest sense: *Stellaria Roughii* (Caryophyll.); *Ranunculus Haastii, R. crithmifolius, R. chordorhizos* (Ranunc.); *Notothlaspi rosulatum* (Crucif.); *Acaena glabra* (Rosac.); *Swainsona novae-zealandiae* (Legum.); *Epilobium pycnostachyum* (Onagrac.); *Anisotome carnosula* (Umbell.); *Myosotis Traversii* (Borag.); *Lobelia Roughii* (Campan.); *Veronica Haastii* (Scrophular.); *Haastia Sinclairii, Craspedia alpina, Cotula atrata* (Compos.).

The following are also frequent members, but are not confined to shingle-slip: *Claytonia australasica* (Portulac.), *Anisotome filifolia* (Umbell.), *Veronica tetrasticha, V. lycopodioides, V. epacridea* (Scrophular.).

** *Growth-forms.*

The shingle-slip plants afford a most admirable example of convergent epharmony. Nearly all are summer-green low-growing or prostrate herbs, with the leaves more or less in rosettes, though these are frequently masked through the stems, which have the power of lengthening as buried, being covered with *débris.* The leaves of almost all are fleshy or coriaceous, glabrous, glaucous, and almost the colour of the stones, and in some cases very deeply divided, the bending-together of the final segments much reducing the leaf-surface. *Haastia Sinclairii* and *Craspedia alpina* are densely woolly, the latter, clothed with long snow-white wool, being especially noticeable. The species of *Ranunculus* and *Anisotome carnosula* have stout fleshy rhizomes; *Lobelia Roughii* and *Swainsona* slender but far-spreading much-branching stems creeping amongst the stones. *Notothlaspi rosulatum* is annual or biennial.

The texture of leaves and stems is such as to withstand the blows of sliding stones, and the plants as a whole can grow upwards, as buried, after the manner somewhat of dune-plants, though, of course, to a much lesser degree.

*** *Ecological Conditions.*

† Edaphic.

The soil consists of loose angular fragments of stone, frequently quite small, lying upon one another, and the slope of the surface is so steep that

‡ *Veronica spathulata* of scoria slopes in the central volcanic plateau has a shingle-slip form.

the stones are very liable to move downwards, considerable breadths of the uppermost layer frequently slipping *en masse.* In some places there is little finer soil, but generally there is a good deal of sandy *débris,* and not infrequently a certain amount of sandy clay, especially at some distance below the surface, where the ground is more stable.

Although the stones are quite dry on the surface, at a depth of a few centimetres they are damp, and lower still there is ample moisture available for deep-rooting plants.

Movement of the stones, the most important distinguishing feature of the soil from that of fell-field, is much less near the sides of the shingle-slip than elsewhere, and there sufficient stability is provided for plants other than those of the true shingle-slip formation to settle down.

The looseness of the surface acts as a "dry mulch" and prevents evaporation from below.

†† Climatic.

The general climate is, of course, that of the district and the altitudinal belt. The special climate depends upon lack of shelter, and consequently great exposure to wind; strong radiation of heat from the stones; powerful heating of the stones themselves; and occasionally very bright light. Within the space of a few hours the plants are frequently subjected first to a burning heat and then to considerable frost; one hour they may be surrounded by a moist atmosphere and the next exposed to a strong dry wind. In winter they are covered by snow for four months or more, but this covering is of little moment to the summer-green herbs. Shortly after the snow has melted the leaves appear above the stones, and even by the beginning of November *Veronica epacridea* may be in bloom.

(*c.*) Fell-field.

* *General.*

Warming's description of fell-field (1909, p. 256) might have been written on a New Zealand dry mountain: "The soil is never completely covered by plants. One individual stands here, and another there; between them we see bare, stony, sandy or clayey soil, which is devoid of humus and determines the prevailing colour of the landscape." An English name was much needed for this formation, previously called by Cockayne "alpine meadow" (1900, p. 128), and a combination of "fell" = a barren or stony hill, and "field" = a wide expanse, chosen by Groom as the English equivalent of "fjeldmark," seems to us to meet the case.

Fell-field is poorly developed in many parts of the Arrowsmith district, and forms patches or lines, oasis-like, in the desert of unstable stones. It commences by a few plants settling on the stable margin of the shingle-slip or where the stone-field happens to be flat, and as soil is slowly formed so do the species increase in number, but never make here a closed formation. At its lowest limit steppe and fell-field merge into one another, and are not distinguishable; even to quite a high altitude occasional tussocks of *Danthonia flavescens* are present.

The following are amongst the earliest plants to occupy the stable *débris*: *Danthonia semiannularis* var. *setifolia, Acaena Sanguisorbae* var. *pilosa, Pimelea Lyallii, Epilobium* sp. (formerly merged with *E. confertifolium*), *Hydrocotyle novae-zelandiae, Anisotome aromatica Gaultheria rupestris, Dracophyllum rosmarinifolium, D. unifolium, Pratia macrodon, Phyllachne Colensoi, Forstera Bidwillii Brachycome Sinclairii, Celmisia discolor, C. spectabilis, Helichrysum bellidioides,* and *Cotula pyrethrifolia.*

Celmisia viscosa, Veronica pulvinaris, Luzula pumila, and *Phyllachne Colensoi* are virtually confined to the alpine belt.

** *Growth-forms.*

Our list of eastern fell-field plants is too meagre to warrant a detailed inquiry into the growth-forms, and such would be misleading. Suffice it to say that there are represented *creeping and rooting shrubs, subshrubs and herbs, herbs and subshrubs of the cushion form, rosette plants,* and *tussock-grasses,* while xerophytic structure of many kinds is exhibited.

(C.) Forest-climate Formations.

(α.) General.

The very much greater rainfall and the increase in number of rainy days lead to a more rapid growth and speedy establishment of species, together with a much closer plant covering, than does the steppe climate. Likewise there are much more extensive formations of trees and shrubs. The formation and accumulation of raw humus is strongly favoured—so much so, indeed, that even rocks may be covered with a true soil, and bear a fairly dense and rich plant covering. On the other hand, the winter snowfall is greater, and the proximity of permanent snowfields and glaciers are counteracting factors.

(β.) The Rock-forest Series.

(1.) *General.*

The sequence of events in the succession of the plant-associations in the Upper Rakaia Valley can be well seen on the northern bank of the river, taking the mouth of the River Louper as a central point.‡

Thus, "Bare rock is the first. Its disintegration leads to shingle-slip, on which special shingle-slip plants, or those of rock or fell-field possessing suitable adaptations, can settle. These prepare the way for fell-field, and this in its turn may give place to forest by way of scrub at the lowest altitude.

"At the same time reversion frequently occurs, and there are excellent examples to be seen where forest has been destroyed by a shingle-stream. Recolonizing ensues, the plants coming from those close at hand. On the south side of the river the process is also in progress. Here a descending stream of stones has cut a path through the forest. Shingle-slip plants come first, then a grassy fell-field, which is replaced by shrubs, and these, at a suitable elevation, by forest."

(2.) *The Associations.*

(a.) Rock.

Although plenty of the alpine rocks bear an abundant plant covering, this does not betoken a pioneer association, but is much younger than a good deal of the vegetation adjoining, many of the species depending on the peaty soil and having probably come by way of the fell-field.

The rocks examined were at an altitude of from 1,280 m. to 1,390 m. They were covered in places with a good deal of raw humus. The species noted

‡ What follows is almost word for word from notes written by Cockayne on the spot.

were: *Gaultheria rupestris* (small erect thick-leaved shrub), *Dracophyllum Kirkii* (small prostrate shrub with stiff coriaceous crowded leaves), *Helichrysum grandiceps* (subshrub more or less erect, leaves small, imbricating, silvery, tomentose), *Senecio Bidwillii* (stiff-branched shrub with very thick leaves tomentose beneath), *Coprosma serrulata* (shrub creeping beneath the surface and rooting, its leaves moderate-sized and stiff)—the above may be called rock-plants, though all occur elsewhere; *Danthonia flavescens, Ranunculus Lyallii, Anisotome Haastii, A. pilifera, Aciphylla Colensoi* var. *maxima, Dracophyllum Urvilleanum* var. *montanum, Coprosma cuneata, Celmisia Sinclairii, C. coriacea, C. petiolata*—all of which are plants of the fell-field.

(*b*.) Shingle-slip.

The most important shingle-slips are those which descend to the valley glaciers, and where alone succession can be accurately investigated, but owing to various causes there was no opportunity for examining such.

The only shingle-slip studied consisted of rather large stones, and was much more stable than those already described for the steppe climate.

The earliest plants to occupy the stony ground appear to be *Epilobium pycnostachyum*,‡ *E. melanocaulon* (at the lowest altitude), *E. glabellum, Muehlenbeckia axillaris, Helichrysum bellidioides, Veronica Bidwillii, Senecio lautus* var. *montanus, Raoulia tenuicaulis*—a combination very similar to that of river-bed, since the stability of the slip renders the station very similar.

Very soon the grass *Poa anceps* var. makes its appearance, and forms a deep carpet, quite hiding the stones, and by the great amount of dead matter it produces makes much soil and encourages various fell-field plants to settle down. Shrubs invade the shingle-slip, and capture not only the grass but even the stable stones, and herbaceous plants come in early, especially *Hypolepis millefolium, Viola Cunninghamii,* and *Geranium microphyllum*, so that scrub or fell-field, as the case may be, is established.

(*c*.) Fell-field.

* *Species, &c.*

The plants are fairly close, in some places growing into one another. Tussocks of *Danthonia flavescens* are dotted about, as also clumps of *Phormium Cookianum* and low rounded green bushes of *Veronica subalpina. Ranunculus Lyallii* forms large colonies, its massive rhizomes hardly below the surface, and its great glossy green peltate leaves raised on stout petioles 30 cm. or often more in height. There are tall *Yucca*-like plants of *Aciphylla Colensoi* var. *maxima.* The following herbaceous plants of considerable dimensions are common: *Celmisia coriacea, Anisotome Haastii, Astelia montana, C. Sinclairii, Polystichum vestitum.* The stout low-growing shrubby stiff-leaved *Coprosma serrulata*, spreading by its underground stems, is abundant. Other plants belonging to the association are *Hypolepis millefolium, Trisetum Youngii, Hierochloe Fraseri; Poa anceps* var., *Viola Cunninghamii, Acaena Sanguisorbae* var., *Taraxacum glabratum, Senecio scorzoneroides, Coprosma ramulosa,* the shrub *Carmichaelia grandiflora* (often abundant), *Geranium microphyllum, Coriaria angustissima.*

‡ The only true shingle-slip species; but shingle-slip plants are virtually confined to mountains with a steppe climate.

At 1,390 m. altitude, where the ground is rocky, the erect needle-leaved shrub *Dracophyllum Urvilleanum* var. *montanum*, distinguished by its brown colour, is very plentiful, associated with tussocks of *Danthonia flavescens*, and mixed with them the large-leaved herbaceous plants, the whole making a closed association.

On some of the Rakaia fell-fields there are wide stretches of *Ranunculus Lyallii* mixed with *Ourisia macrocarpa*, and I suspect there would be also plenty of *Ranunculus Godleyanus*, but there was no opportunity of examining such a combination.

** *Growth-forms.*

The growth-forms of forest-climate fell-field differ from those of the steppe climate chiefly in the presence of a much more mesophytic element, with leaves sometimes of great size—*e.g.*, *Ranunculus Lyallii*, *Ourisia macrocarpa*, *Anisotome Haastii*, *Senecio scorzoneroides*. But xerophytes are not absent—*e.g.*, *Aciphylla Colensoi* var. *maxima*, *Phormium Cookianum*, *Astelia montana*, *Celmisia coriacea*, *C. Sinclairii*—though such as these are not to be compared with *Celmisia Lyallii*, *C. viscosa*, or *C. pseudo-Lyallii* of the drier fell-field, also large plants. At above 1,500 m. doubtless, as in fell-field in general, true xerophytes increase in numbers, but so high an altitude on the mountains of the forest climate was not reached.

(*d.*) Subalpine Scrub.

* *General.*

It has been already seen that a good many shrubs are present on fell-field or rock. It is only necessary for certain conditions to prevail and the shrubs will get the ascendency and scrub be installed These conditions are probably an altitude of not more than about 1,200 m. (with which is connected a snow-covering of shorter duration than at a higher altitude), shelter from the more intense winds, a soil containing a considerable percentage of humus.

Subalpine scrub occurs on old river-terrace, moraine, slopes near the source of rivers, and as a belt on the hillsides, frequently between the upper margin of the forest and the fell-field.

The general character of subalpine scrub has been sufficiently described by various authors (see, *e.g.*, Haast, 1866; Green, 1883; Harper, 1896; Laing and Blackwell, 1907; Cockayne, 1906, 1909, 1910). That of the Rakaia, as Haast first pointed out (1866), is of a maximum density. The roof is fairly even; its dominating colour is green, but there are many patches of brown. Its height varies according to altitude and exposure, it being tallest on river-bed, in gullies, and at its lowest altitude. At 1,000 m. elevation it may average 1·8 m. The shrubs grow into one another, their stiff or rigid branches frequently stretch horizontally *down* the slope, the scrub as a whole being in places virtually impenetrable.

** *Composition.*

The following were the species noted: *Polystichum vestitum* (Fil.); *Podocarpus nivalis*, *Phyllocladus alpinus* (Taxac.); *Clematis australis* (Ranun.); *Carmichaelia grandiflora* (Legum.); *Aristotelia fruticosa* (Elaeocarpac.); *Gaya Lyallii* (Malv.); *Nothopanax simplex*, *N. parvum*, *N. Colensoi* (Araliac.); *Griselinia littoralis* (Cornac.); *Aciphylla Colensoi* var. *maxima* (Umbell.); *Archeria Traversii*, *Dracophyllum longifolium*, *D. Urvilleanum* var. *montanum* (Epacrid.); *Veronica salicifolia*, *V. subalpina* (Scroph.); *Coprosma serrulata*, *C. ciliata, C. parviflora. C. rugosa* (Rubiac.); *Olearia nitida, O. macrodonta, O. ilicifolia, O. nummularifolia, Cassinia Vauvilliersii, Senecio cassinioides, S. elaeagnifolius* (Comp.).

**** Growth-forms.*

The "normal" forms of scrub plants are much modified by the mechanical action of wind and snow, and it is to the dwarfing, the horizontal spread of branches, and, above all, the close intermingled growth that the scrub maintains its position rather than to any special growth-forms of the constituents. This is admirably shown by the forest-tree *Nothofagus cliffortioides*, which, like the ecologically equivalent *Pinus montana* of Europe, can assume a scrub form, and so make a special type of subalpine scrub, as in the Nelson mountains.

Regarding the Rakaia shrubs, all except two are *evergreen*. The *shrub-composite* form, the *divaricating form*, the *ball-like form*, the *creeping and rooting form*, the *bushy form*, the *Dracophyllum form*,‡ are all represented. Nearly all have stiff, coriaceous, or thick leaves. The leaves of six are tomentose; of two erect, needle-like, isolateral or nearly so; of nine quite small. In short, with the exception of the deciduous element, *Veronica salicifolia* and perhaps *V. subalpina*, the leaf-form and structure is xerophytic or subxerophytic. *Clematis australis* is a tendril-climber, with much-divided rather thick leaves. The other lianes occur in the scrub of the river-bed.

(*e.*) Subalpine Totara Forest.

** General.*

An association in which the totara (*Podocarpus Hallii*, and perhaps *P. totara* also) is the dominant tall tree occupies the base of the mountain-slopes on both sides of the Rakaia Valley, extending on the sunny side to a higher altitude (perhaps 970 m.) than on the shady side. Only the forest on the southern side (sunny side) of the river was examined, it being impossible to ford the river on foot.

The formation is the same as that composing the upper forest of Westland extending from the Taramakau Valley to the River Paringa, but it differs considerably floristically.

The association under consideration changes considerably both floristically and ecologically according to altitude, the lower and upper portions constituting respectively two subassociations.

The lower forest contains the following species which are wanting (or rare) in the upper forest: *Asplenium flabellifolium, Carpodetus serratus, Pittosporum tenuifolium, Sophora microphylla, Fuchsia excorticata, Pseudopanax crassifolium.*

*** Upper Forest (Totara-Kawaka Subassociation).*

† Character.

The upper forest (see Plate VII, fig. 1) is distinguished by the presence of *Libocedrus Bidwillii* (kawaka) as a tall tree, in addition to the totara; by the presence of certain members of the subalpine scrub, which, shrubs no longer, have now the form of small trees; and, above all, by the generally horizontal trunks of these latter. The floor is covered in most places with a tall growth of the fern *Polystichum vestitum*. Moss mantles are abundant on the horizontal trunks and branches.

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‡ Naked stiff stems, often more or less fastigiate; leaves long, grasslike, in erect rosettes at the apices of the twigs, and frequently almost isolateral.

†† Composition.

Tall trees: *Podocarpus Hallii, Libocedrus Bidwillii.*

Moderate-sized and small trees: *Phyllocladus alpinus, Gaya Lyallii,*‡ *Griselinia littoralis, Suttonia divaricata, Veronica salicifolia, Coprosma linariifolia, Olearia ilicifolia, Senecio elaeagnifolius.*

Shrubs: *Polystichum vestitum, Phyllocladus alpinus, Gaya Lyallii, Aristotelia fruticosa, Suttonia divaricata, Coprosma ciliata, C. parviflora, C. cuneata, Veronica salicifolia.*

Lianes: *Rubus schmidelioides* var. *coloratus.*

Epiphytes: *Hymenophyllum sanguinolentum, Asplenium flaccidum, Lycopodium Billardieri, Senecio elaeagnifolius.*

Parasite: *Tupeia antarctica,* on *Gaya Lyallii.*

††† Physiognomy.

The forest is made up of three tiers—viz., the tall trees, their heads of foliage distant; the smaller trees, their heads closer, but the forest-roof as a whole open; the closely growing short-trunked layer of *Polystichum vestitum.* In addition to the above, especially where there is a maximum of light, there is a discontinuous tier of more or less straggling divaricating shrubs. On the ground where there is space there is abundance of seedlings of *Gaya Lyallii* and a few floor-plants—*e.g., Asplenium Richardi, Epilobium linnaeoides, Hydrocotyle novae-zelandiae,* and *Uncinia uncinata.*

The leading physiognomic feature is the horizontal and semi-horizontal thick and most irregular trunks of the small trees, especially the composites (see Plate VII, fig. 2), with their long depending strips of papery bark, their naked branches, which finally branching several times, candelabra-like, form a spreading open greyish-coloured head.

The trunks are frequently much moss-covered, but, although there may be thick masses, these can hardly be called cushions, as compared with those of Westland, Stewart Island, &c.

†††† Ecology.

The soil consists, so far as it was examined, of an upper layer of loose humus some 12 cm. deep and full of roots, succeeded by stones (old shingle-slip), into which a good deal of the finer humus has penetrated. This upper layer holds and stores water, and the network of roots shows how important a part its power to do so plays in the economy of the forest, and how dependent this is on the frequent downpour—that it is, in fact, a true rain forest.

The general more or less horizontal habit of the composite trees and *Griselinia littoralis* is very striking, and doubtless to be correlated with the mechanical action of the wind, though certainly there must be an hereditary tendency to respond to the wind-stimulus, as Cockayne has already suggested from observations on seedlings (1904, p. 254). How greatly the ecology of a formation depends upon the formation itself—that is to say, how a formation when established brings a change in its own environment —is here illustrated by the remarkably luxuriant growth of so many of the components. Thus the usually densely divaricating shrub *Suttonia divaricata* becomes an erect tree at least 6 m. tall and 57 cm. in diameter, branching above into a small head of "weeping" slender twigs. *Coprosma linariifolia* measured in one instance 66 cm.§ in diameter at the base of its

‡ If a plant is mentioned under two heads it means that it has two growth-forms.

§ Kirk (1889, p. 187) gives 9 in. (22·9 cm.) as an extreme size.

FIG. 1.—VIEW OF EXTERIOR OF TOTARA FOREST, UPPER RAKAIA.

FIG. 2.—HORIZONTAL TRUNK OF *Olearia ilicifolia*.

Face p. 364.]

trunk. *Olearia ilicifolia* was noted as quite 12 m. tall, and its trunk 71 cm. in diameter, a truly remarkable size for a tree composite.

The behaviour of *Gaya Lyallii* within the forest is a matter of interest which still requires a satisfactory explanation, our remarks below notwithstanding. In none of the young plants examined, which grew upon the forest-floor, was the main stem at first erect; on the contrary, it was prostrate for many centimetres, putting down roots into the loose substratum. In nearly all the plants examined the apex of this creeping stem was damaged, but it put forth erect branches which ultimately, as examination of many plants at different stages proved, became the final trunk. Leaning trunks of *Gaya* put forth rapidly growing erect stems (suckers), which would finally resemble trunks. How far the floor of moist loose humus and semi-decayed leaves, which certainly would favour the production of adventitious roots, which by their pull would hold the shoot to the ground, is responsible for this primary creeping and rooting habit it is hard to say. Other shrubs of this association show the same phenomenon—*e.g.*, *Aristotelia fruticosa*, "normally" a dense divaricating shrub, an example of which was noted with the basal 4 cm. prostrate and rooting, then the succeeding 5 cm. raised from the ground but still almost horizontal and giving off two vertical branches, and finally 3·5 cm. bending upwards until erect. The cases already cited by Cockayne (1908) of *Styphelia fasciculata* and *Myrtus pedunculata*, both "normally" erect shrubs, but on the moist mossy floor of the subalpine forest of Ruapehu being creeping and rooting plants, not erect at all, are analagous examples.

The divaricating shrubs are not nearly so dense as in the open. *Coprosma parviflora*, for example, has in this forest several stems which are quite without branches for the lower two-thirds, when they arch downwards and branch abundantly, this growth-form reminding one of the usual mesophytic habit of *C. foetidissima*, plants generally quite dissimilar in form.

The moss-clad horizontal trunks favour the presence of epiphytes, *Senecio elaeagnifolius* especially following this manner of growth, and attaining a remarkable size. As the plant increases in bulk the moss no longer supplies enough water, and the roots lengthen, pass downward, and enter the soil. Finally such roots may grow together and make a trunk. Many of the trees of *Griselinia littoralis* and *Olearia ilicifolia* have also originated in this manner.

The two tall trees may both be considered xerophytes. Both can tolerate physiologically dry stations—*e.g.*, wet peaty soil; but *Podocarpus Hallii*—nor *P. totara*, for that matter—does not appear capable of enduring a steppe climate, or, in other words, they are not found at present under such xerophytic conditions as is *Nothofagus cliffortioides*. So far as form, leaf-structure, and so on, are concerned, there seems no reason why the totaras should differ in their requirements from the beech. Certainly the *Nothofagus* is more plastic; it can more readily change its form according to circumstances; it is on the borderland of the deciduous habit; and as a forest it has wonderful powers of rejuvenescence, thanks to the shade-tolerating power of its seedlings. The above would give it an advantage over *P. totara* or *P. Hallii*, but in addition, as in many other plants, there are physiological distinctions not recorded, or not yet estimated, in form or structure which determine the habitat-range of a species.

As for the totara forest of the Rakaia Valley as a whole, it is altogether more mesophytic than is the *N. cliffortioides* association, and must be classed with rain forest.

4. THE FLORISTIC BOTANY.

(A.) Notes on various Species.

The number of species noted (357) most certainly does not represent *nearly all* that must occur in an area so large and diversified, and future observers cannot fail to much extend the list. At the same time, it may be pointed out that the steppe, owing partly to its climate and partly to the constant grass-fires, is distinctly barren, while the adjacent subalpine and alpine belts consist chiefly of dry rock and shingle-slip, stations hostile to plant-life. Further, so far as that part of the district with a forest climate is concerned, only the sunny side of a small portion of the Rakaia Valley, the poorest in both flora and vegetation, was examined, while the examination was but a cursory one.

(1.) **Luzula ulophylla** (Buchen.) sp. nov. = *L. racemosa* Desv. var. *ulophylla* Buchen. in Oesterr. Bot. Zeitschrift, p. 245, 1898.

An excellent description is given in Cheeseman's Manual, p. 738. The plant can be recognized at a glance, and certainly is one of the most distinct forms of the genus in New Zealand, as Cheeseman has already pointed out.

(2.) **Bulbinella Hookeri** (Col.) Benth. and Hook. f., var. **angustifolia** var. nov.

In omnibus partibus typo minor, non autem glaucis, superiore superficie folii concava, racemo quam typi breviore, densioreque.

South Island: Common in the east of Canterbury and Otago.

This is the common form of the steppe climate of the South Island. The leaves are concave on the upper surface, green, thicker and narrower (1·1 cm. at base) than those of the North Island and western Nelson plant (the type), which are flat, broad (3 cm. at base), and glaucous. The raceme is altogether less open than in the type, and the flowers are smaller. Seen side by side the two plants are most distinct, and can be separated at a glance. We are indebted to Mr. T. Keir, of Rangiora, for first pointing out the great difference between the two forms; in fact, he considered—and with much justice—that they were distinct species, but we hesitate so to treat them in the absence of a large series of specimens.

(3.) **Epilobium confertifolium** Hook. f.

The above name was restricted to the plant of the New Zealand subantarctic botanical province by Cockayne in 1904, and Cheeseman in 1909 has come to the same conclusion. This leaves the New Zealand forms hitherto referred to this species without a name. Of these forms there are probably more than one to which we are inclined to accord specific rank, but think it best to defer so doing until examining more abundant material, and, above all, testing their fixity by cultivation.

(4.) 1. **Anisotome Haastii** (F. Muell.) comb. nov. = *Ligusticum Haastii* F. Muell. ex Hook. f. in Handbk. of N.Z. Flora, p. 95, 1864.

2. **Anisotome filifolia** (Hook. f.) comb. nov. = *Ligusticum filifolium* Hook. f. in Handbk. of N.Z. Flora, p. 95, 1864.

3. **Anisotome carnosula** (Hook. f.) comb. nov. = *Ligusticum carnosulum* Hook. f. in Handbk. of N.Z. Flora p. 96, 1864.

4. **Anisotome pilifera** (Hook. f.) comb. nov. = *Ligusticum piliferum* Hook. f. in Handbk. of N.Z. Flora, p. 96, 1864.

Cockayne, following Bentham and Hooker, has in all his recent papers referred the New Zealand species of *Ligusticum* to *Aciphylla.* But, as Cheeseman points out (1909, p. 408), this latter genus is best limited to the *Aciphyllae* proper, a most distinct group, and if it be thought correct to limit *Ligusticum* to the northern species, then Hooker's genus *Anisotome* might well be revived for the reception of the southern species. This course we have taken, since we consider *Anisotome* a true antarctic genus, notwithstanding, as in the cases of *Nothofagus, Nothopanax,* and *Celmisia,* it has a strong northern affinity.

(5.) Nertera species.

The species of *Nertera* in the list, which occurs also on bogs in the Waimakariri Valley, differs from *N. depressa* in its orange-coloured pyriform drupe, that of the latter being globose and red; but we have no material, and are writing from memory, so are unable to give a name and description to the plant. Probably it has hitherto been mistaken for *N. depressa,* since the drupes on being dried would lose their distinctive shape.

(6.) Olearia arborescens (Forst. f.) comb. nov. = *Solidago arborescens* Forst. f. in Prodromus, p. 298, 1786.

This is the well-known *O. nitida* Hook. f. in Handbk. of N.Z. Flora, p. 125, and it is a great pity the name has to be changed in accordance with the rules of botanical nomenclature.

(7.) Celmisia spectabilis Hook. f.

A very distinct form was common on Prospect Hill. This is distinguished from the type by the leaves being not "entire or minutely serrulate" (Cheeseman, 1906, p. 308), but coarsely and distantly toothed almost to the base. Young leaves on a cultivated example exhibit the same toothing.

(B.) LIST OF SPECIES.

Species, Family, &c.	Plant-association.
PTERIDOPHYTA.	
FILICES.	
Hymenophyllum sanguinolentum (Forst. f.) Sw. ..	Totara forest.
——— *villosum* Col.	Rock, subalpine.
——— *tunbridgense* (L.) Sm.	Totara forest.
——— *multifidum* (Forst. f.) Sw.	Rock, subalpine.
Alsophila Colensoi Hook. f.	Subalpine scrub ?
Cystopteris fragilis (L.) Bernh.	Stony *débris* in montane belt of steppe climate.
Hypolepis millefolium Hook.	*Nothofagus* forest.
Histiopteris incisa (Thunb.) J. Sm.	Subalpine scrub, where it had been burned.
Pteridium esculentum (Forst. f.) Cockayne.	
Blechnum penna marina (Poir.) Kuhn	*Nothofagus* forest; steppe; fan.
——— *capense* (L.) Schlcht.	*Nothofagus* forest.
Asplenium flabellifolium Cav.	Totara forest.
——— *Richardi* Hook. f.	Rock (steppe climate); totara forest.
——— *flaccidum* Forst. f.	Totara forest.

List of Species—*continued.*

Species, Family, &c.	Plant-association.
Polystichum vestitum (Forst. f.) Presl.	*Débris* below rock (steppe climate); totara forest; *Nothofagus* forest.
—— *cystotegia* (Hook.) J. B. Armstg.	Stony *débris* (stable and large), alpine.
Polypodium Billardieri (Willd.) C. Chr.	Totara forest.
—— *pumilum* (J. B. Armstg.) Cockayne ..	Rock, subalpine.
Ophioglossum coriaceum A. Cunn.	Steppe.
LYCOPODIACEAE.	
Lycopodium Selago L.	Fell-field.
—— *varium* R. Br.	Totara forest.
—— *scariosum* Forst. f.	Steppe, but local.
SPERMOPHYTA.	
TAXACEAE.	
Podocarpus Hallii T. Kirk*	Totara forest.
—— *nivalis* Hook.	Subalpine scrub (Cameron Glacier); *Nothofagus* forest, on outskirts.
Dacrydium Bidwillii Hook. f.	*Sphagnum* bog; lake, margin of, on bank.
Phyllocladus alpinus Hook. f.	Totara forest; subalpine scrub.
PINACEAE.	
Libocedrus Bidwillii Hook. f.	Totara forest.
TYPHACEAE.	
Typha angustifolia L. var. *Muelleri ?* (Rohrb.) Graebn.	Lake.
GRAMINEAE.	
Microlaena Colensoi (Hook. f.) Petrie	Rock, alpine.
Hierochloe redolens (Forst. f.) R. Br.	Fell-field.
—— *Fraseri* Hook. f.	Steppe; river-bed, subalpine.
Agrostis subulata Hook. f.	Rock, alpine.
—— *Dyeri* Petrie	Steppe; fell-field.
Deyeuxia setifolia Hook. f.	Fell-field.
—— *avenoides* (Hook. f.) Buch.	Steppe.
Dichelachne crinita (Forst. f.) Hook. f.	Steppe.
Trisetum antarcticum (Forst. f.) Trin.	Steppe; fell-field.
—— *Youngii* Hook. f.	Steppe of subalpine river-bed.
—— *subspicatum* Beauv.	Rock, alpine.
Danthonia Raoulii Steud.	Steppe.
—— *flavescens* Hook. f.	Steppe; fell-field.
—— *semiannularis* R. Br.	Steppe; rock, montane and subalpine.
—— —— var. *setifolia* Hook. f.	Steppe; fell-field.
—— *Buchanani* Hook. f.	Steppe.
Arundo conspicua Forst. f.	River-bed, montane.
Triodia exigua T. Kirk	Steppe.
Poa novae-zealandiae Hack.	Rock, subalpine.
—— *anceps* Forst. f. (?) var.†	Fell-field; coarse and fairly stable shingle-slip; steppe of river-bed.

* Our notes regarding the species of totara are quite insufficient, nor have we any specimens beyond one piece of bark which is evidently that of *P. Hallii*. On the other hand, *P. totara* may also be present, especially at the lowest altitude of the forest.

† This grass is possibly an undescribed species. It is probably common on the wet mountains of the central Southern Alps.

LIST OF SPECIES—*continued.*

Species, Family, &c.	Plant-association.
Poa caespitosa Forst. f.	Steppe; rock; fell-field.
——— *Colensoi* Hook. f.	Steppe; rock; fell-field.
——— ——— var. *intermedia* (Buch.) Cheesem.	Steppe.
——— *Kirkii* Buch.	Steppe.
——— *Lindsayi* Hook. f.	Steppe.
——— *maniototo* Petrie	Steppe.
Festuca ovina L. var. *novae-zealandiae* Hack.	Steppe; river-bed, subalpine.
——— *rubra* L. var.	Steppe.
Agropyron scabrum (R. Br.) Beauv.	Steppe; rock.
CYPERACEAE.	
Elaeocharis Cunninghamii Boeck.	Swamp; lake; *Sphagnum* bog.
Schoenus pauciflorus Hook. f.	*Sphagnum* bog; swamp.
Oreobolus pectinatus Hook. f.	*Sphagnum* bog.
Uncinia compacta R. Br.	Steppe; river-bed, subalpine.
——— *uncinata* (L. f.) Kükenth.	Totara forest.
——— *fusco-vaginata* Kükenth.	Fell-field.
——— *rubra* Boott	Steppe.
——— *filiformis* Boott	Totara forest.
Carex kaloides Petrie	Wet ground.
——— *diandra* Schrank	Swamp.
——— *Colensoi* Boott	Steppe.
——— *stellulata* Good	Swamp.
——— *subdola* Boott	Swamp.
——— *Gaudichaudiana* Kunth.	Swamp; *Sphagnum* bog.
——— *ternaria* Forst. f.	Swamp.
——— *wakatipu* Petrie	River-bed.
——— *Buchanani* Berggr.	Stream, margin of.
——— *Petriei* Cheesem.	River-bed, in damp ground.
——— *breviculmis* R. Br.	Steppe.
——— *Oederi* Retz var. *catarractae* (R. Br.) Kükenth.	Swamp.
JUNCACEAE.	
Juncus effusus L.	Lake; swamp.
——— *bufonius* L.	River-bed, montane.
Luzula pumila Hook. f.	Fell-field, alpine.
——— *campestris* D. C. var.	Steppe; river-bed, subalpine.
——— *racemosa* Desv.	Steppe.
——— *ulophylla* (Buchen.) Cockayne and Laing	Steppe; river-bed.
LILIACEAE.	
Astelia montana (T. Kirk) Cockayne	Fell-field.
——— *Petriei* Cockayne	Fell-field.
Phormium Cookianum Le Jolis	Subalpine scrub; fell-field.
Bulbinella Hookeri (Col.) Benth. & Hook. var. *angustifolia* Cockayne and Laing	Steppe; bog.
ORCHIDACEAE.	
Microtis unifolia (Forst. f.) Reichenb.	Steppe.
Prasophyllum Colensoi Hook. f.	Steppe.
Pterostylis mutica R. Br.	Steppe.
Corysanthes (*macrantha* Hook. f.) ?	Totara forest.
FAGACEAE.	
Nothofagus cliffortioides (Hook. f.) Oerst.	*Nothofagus* forest; bank of streams as occasional scattered clumps.
URTICACEAE.	
Urtica incisa Poir.	Totara forest; *Nothofagus* forest.

LIST OF SPECIES—*continued.*

Species, Family, &c.	Plant-association.
LORANTHACEAE.	
Elytranthe flavida (Hook. f.) Engler	*Nothofagus* forest.
Tupeia antarctica (Forst. f.) Cham. & Schlcht. ..	Totara forest; subalpine scrub.
POLYGONACEAE.	
Rumex flexuosus Sol.	Steppe.
Muehlenbeckia australis (Forst. f.) Meissn. ..	Totara forest.
——— *complexa* (A. Cunn.) Meissn.	Totara forest; scrub of river-bed.
——— *axillaris* Walp.	River-bed; steppe.
——— *ephedroides* Hook. f.	Steppe.
PORTULACACEAE.	
Claytonia australasica Hook. f.	Shingle-slip; stream.
Montia fontana L.	Stream.
CARYOPHYLLACEAE.	
Stellaria Roughii Hook. f.	Shingle-slip.
Colobanthus quitensis Bartl.	Steppe.
——— *Billardieri* Fenzl.	Steppe.
——— *brevisepalus* T. Kirk	Steppe.
——— *acicularis* Hook. f.	Rock.
Scleranthus biflorus (Forst.) Hook. f.	Steppe; river-bed.
Hectorella caespitosa Hook. f.	Rock, alpine.
RANUNCULACEAE.	
Clematis australis T. Kirk	Subalpine scrub.
——— *marata* J. B. Armstg.	
Ranunculus Lyallii Hook. f.	Fell-field.
——— *Godleyanus* Hook. f.	Fell-field; bank of stream on river-bed.
——— *Monroi* Hook. f. var. *dentatus* T. Kirk ..	Rock, subalpine; fell-field.
——— *Haastii* Hook. f.	Shingle-slip.
——— *crithmifolius* Hook. f.	Shingle-slip.
——— *hirtus* Banks & Sol.	Steppe.
——— *lappaceus* Sm. var. *multiscapus* Hook. f. ..	Steppe.
——— *foliosus* T. Kirk	Steppe of subalpine river-bed.
——— *Cheesemanii* T. Kirk	River-bed, in wet ground.
——— *macropus* Hook. f.	Swamp; stream.
——— *rivularis* Banks & Sol.	Swamp.
Caltha novae-zelandiae Hook. f.	Fell-field.
CRUCIFERAE.	
Nasturtium palustre D. C.	River-bed, moist.
Cardamine heterophylla (Forst. f.) O. E. Schultz.	
——— *depressa* Hook. f.	Rock, subalpine.
Notothlaspi rosulatum Hook. f.	Shingle-slip.
DROSERACEAE.	
Drosera arcturi Hook.	*Sphagnum* bog.
CRASSULACEAE.	
Crassula Sieberiana Schultz	Rock.
SAXIFRAGACEAE.	
Carpodetus serratus Forst.	Totara forest.
PITTOSPORACEAE.	
Pittosporum tenuifolium Banks & Sol.	Totara forest.

LIST OF SPECIES—*continued.*

Species, Family, &c.	Plant-association.
ROSACEAE.	
Rubus schmidelioides A. Cunn. var. *coloratus* T. Kirk	Totara forest.
——— *subpauperatus* Cockayne	Totara forest; scrub of river-bed.
——— *australis* Forst. f.	Totara forest.
——— *cissoides* A. Cunn.	
Geum parviflorum Sm.	Fell-field.
——— *urbanum* L. var. *strictum*	River-bed.
Potentilla anserina L. var. *anserinoides* (Raoul) T. Kirk	Swamp.
Acaena Sanguisorbae Vahl. var. *pilosa* T. Kirk* ..	Steppe; fell-field.
——— *inermis* Hook. f.	Steppe.
——— *microphylla* Hook. f.	Steppe.
LEGUMINOSAE.	
Carmichaelia Enysii T. Kirk	Steppe.
——— *uniflora* T. Kirk	Steppe.
——— *nana* Col.	Steppe.
——— *Monroi* Hook. f.	Steppe.
——— *grandiflora* Hook. f.	Subalpine scrub; river-bed, subalpine.
Swainsona novae-zealandiae Hook. f.	Shingle-slip.
Sophora microphylla Ait.	Totara forest.
GERANIACEAE.	
Geranium microphyllum Hook. f...	Steppe; *Sphagnum* bog.
——— *sessiliflorum* Cav.	Steppe.
OXALIDACEAE.	
Oxalis corniculata L.	Steppe.
——— *magellanica* Forst.	Fell-field.
CORIARIACEAE.	
Coriaria ruscifolia L.	Steppe.
——— *thymifolia* Humb. & Bonpl.	River-bed, steppe; fell-field.
——— *angustissima* Hook. f.	River-bed, steppe; fell-field.
STACKHOUSIACEAE.	
Stackhousia minima Hook. f.	Steppe.
RHAMNACEAE.	
Discaria toumatou Raoul	Steppe; river-bed; rock.
ELAEOCARPACEAE.	
Aristotelia fruticosa Hook. f.	Subalpine scrub.
MALVACEAE.	
Gaya Lyallii (Hook. f.) J. E. Baker	Totara forest; subalpine scrub.
——— *ribifolia* (F. Muell.) Cockayne	*G. ribifolia* association.
GUTTIFERAE.	
Hypericum gramineum Forst. f.	Steppe.
VIOLACEAE.	
Viola Cunninghamii Hook. f.	*Sphagnum* bog; fell-field.
Hymenanthera dentata R. Br. var. *alpina* T. Kirk ..	Fell-field; *débris* below cliff.

* This is probably *Acaena Sanguisorbae* subspecies *caesiiglauca* Bitter.

List of Species—*continued.*

Species, Family, &c.	Plant-association.
THYMELIACEAE.	
Pimelea Traversii Hook. f.	Rock, subalpine.
——— *laevigata* Gaertn. var. *repens* Cheesem. ..	Steppe.
——— *Lyalli* Hook. f.	Steppe; fell-field.
Drapetes Dieffenbachii Hook.	Steppe; fell-field.
MYRTACEAE.	
Leptospermum scoparium Forst.	Steppe.
ONAGRACEAE.	
Epilobium chionanthum Hausskn.	Swamp.
——— *pubens* A. Rich.	Totara forest; rock.
——— species*	Fell-field.
——— *Hectori* Hausskn.	Steppe.
——— *chloraefolium* Hausskn.	*Sphagnum* bog; fell-field.
——— *nummularifolium* R. Cunn.	Rock, in shade.
——— *pedunculare* A. Cunn.	River-bed; steppe.
——— *macropus* Hook.	Stream.
——— (*crassum* Hook. f.) ?†	Rock.
——— *pycnostachyum* Hausskn...	Shingle-slip.
——— *melanocaulon* Hook.	River-bed.
——— *rostratum* Cheesem.	River-bed.
——— *microphyllum* A. Rich.	River-bed.
——— *glabellum* Forst. f.	River-bed.
——— *elegans* Petrie	Steppe.
Fuchsia excorticata L. f.	Totara forest; *Nothofagus* forest.
HALORRHAGACEAE.	
Halorrhagis unifolia T. Kirk (= *H. depressa* Walp. var. *unifolia* (T. Kirk) Cheesem. in Trans. N.Z. Inst., vol. 42, p. 203, 1910)	Steppe.
——— *micrantha* R. Br.	Bog.
Myriophyllum elatinoides Gaud.	Stream; lake.
Gunnera (*monoica* Raoul) ? var.	Bog.
——— *dentata* T. Kirk..	Stream.
ARALIACEAE.	
Nothopanax simplex (Forst. f.) Seem.	Totara forest; subalpine scrub.
——— *parvum* (T. Kirk) Cockayne	Subalpine scrub of river-bed.
——— *Colensoi* (Hook. f.) Seem.	Subalpine scrub; totara forest.
Pseudopanax crassifolium (Sol.) C. Koch var. *unifoliatum* T. Kirk	Totara forest.
UMBELLIFERAE.	
Hydrocotyle novae-zelandiae D. C.	Steppe.
——— *americana* L.	Steppe.
Schizeilema nitens (Petrie) Domin.	Stream.
Oreomyrrhis andicola Endl. var. *Colensoi* (Hook. f.) T. Kirk	Steppe.
——— ——— var. *ramosa* (Hook. f.) T. Kirk ..	Steppe.
Crantzia lineata Nutt.	Bog.

* = one or more of the series of forms hitherto included by J. D. Hooker, T. Kirk, Cheeseman, and others with *E. confertifolium* Hook. f. of the New Zealand subantarctic islands.

† Specimens poor; it may be *E. brevipes*.

LIST OF SPECIES—*continued.*

Species, Family, &c	Plant-association.
Aciphylla Colensoi Hook. f.	Steppe.
——— ——— var. *maxima* T. Kirk	Subalpine scrub.
——— *squarrosa* Forst.	Steppe.
——— *Monroi* Hook. f.	Rock, subalpine; fell-field.
Anisotome Haastii (F. Muell.) Cockayne and Laing ..	Fell-field.
——— *filifolia* (Hook. f.) Cockayne and Laing ..	Shingle-slip; steppe.
——— *carnosula* (Hook. f.) Cockayne and Laing ..	Shingle-slip.
——— *pilifera* (Hook. f.) Cockayne and Laing ..	Rock; fell-field.
——— ——— var. *pinnatifida* T. Kirk	Fell-field.
——— *aromatica* Hook. f.	Steppe; fell-filled; *Sphagnum* bog.
Angelica Gingidium (Forst. f.) Hook. f.	Fell-field; steppe; river-bed.
——— *decipiens* Hook. f.	Steppe.
CORNACEAE.	
Griselinia littoralis Raoul	Totara forest; subalpine scrub.
ERICACEAE.	
Gaultheria depressa Hook. f.	Steppe; *Sphagnum* bog.
——— *perplexa* T. Kirk	Subalpine scrub of river-bed.
——— *rupestris* (Forst. f.) R. Br.	Rock; fell-field.
Pernettya nana Col.	Steppe.
EPACRIDACEAE.	
Pentachondra pumila (Forst. f.) R. Br.	Fell-field.
Styphelia acerosa Sol.	Fell-field.
——— *Colensoi* (Hook. f.) Diels	Fell-field; steppe.
——— *Fraseri* (A. Cunn.) F. Muell.	Steppe; river-bed; fell-field.
Archeria Traversii Hook. f.	Subalpine scrub.
Dracophyllum longifolium (Forst. f.) R. Br. ..	Totara forest; subalpine scrub.
——— *Urvilleanum* A. Rich. var. *montanum* Cheesem.	Subalpine scrub.
——— *Kirkii* Berggr.	Rock, subalpine.
——— *uniflorum* Hook. f.	Fell-field.
——— *rosmarinifolium* (Forst. f.) R. Br.	Rock; fell-field.
MYRSINACEAE.	
Suttonia divaricata Hook. f.	Totara forest; subalpine scrub.
——— *nummularia* Hook. f.	Rock, subalpine.
GENTIANACEAE.	
Gentiana Griesbachii Hook. f.	Steppe.
——— *bellidifolia* Hook. f.	Fell-field.
APOCYNACEAE.	
Parsonsia capsularis var.	Subalpine scrub of river-bed.
BORRAGINACEAE.	
Myosotis Traversii Hook. f.	Shingle-slip.
——— species (perhaps a form of *M. antarctica* Hook. f.)	Fell-field.
——— *australis* R. Br.	Steppe.
——— *Forsteri* Lehm.	Shady bank, subalpine.
LABIATAE.	
Mentha Cunninghamii (A. Cunn.) Benth.	Steppe; bog.
SCROPHULARINACEAE.	
Mazus radicans (Hook. f.) Cheesem.	Bog.
(*Glossostigma elatinoides* Benth.) ?	Swamp.

List of Species—*continued.*

Species, Family, &c.	Plant-association.
Veronica salicifolia Forst. f.	Subalpine scrub; totara forest.
——— ——— var. *Kirkii* (J. B. Armstg.) Cheesem.	Subalpine scrub ?
——— *leiophylla* Cheesem.	Scrub on limestone, montane.
——— *subalpina* Cockayne	Subalpine scrub.
——— *buxifolia* Benth. var. *odora* T. Kirk ..	Steppe, near stream.
——— *anomala* J. B. Armstg.	Habitat ? (Rakaia Gorge, E. Stead !).
——— *amplexicaulis* J. B. Armstg.	Fell-field.
——— *pinguifolia* Hook. f.	Fell-field.
——— *pimelioides* Hook. f. var. *minor* Hook. f. ..	Steppe.
——— *tetrasticha* Hook. f.	Rock, subalpine.
——— *lycopodioides* Hook. f.	Fell-field.
——— *Armstrongii* T. Kirk	Habitat ?*
——— *cupressoides* Hook. f.	Habitat ?†
——— *Haastii* Hook. f.	Shingle-slip.
——— *epacridea* Hook. f.	Shingle-slip; rock.
——— *macrantha* Hook. f.	Fell-field.
——— *pulvinaris* (Hook. f.) Benth. & Hook. f. ..	Fell-field.
——— *loganioides* J. B. Armstg.	Fell-field.
——— *Lyallii* Hook. f.	River-bed, subalpine.
——— ——— var. *suberecta* Cheesem.	Rock, shaded, subalpine.
——— *Bidwillii* Hook. f.	River-bed.
Ourisia macrocarpa Hook. f.	Fell-field.
——— (*Colensoi* Hook. f.) ?	Fell-field.
——— *sessiliflora* Hook. f.	Fell-field.
——— *caespitosa* Hook. f.	Fell-field.
Euphrasia Monroi Hook. f.	Fell-field.
Lentibulariaceae.	
Utricularia monanthos Hook. f.	*Sphagnum* bog.
Plantaginaceae.	
Plantago Brownii Rapin	Bog, subalpine.
——— *spathulata* Hook. f.	Steppe.
——— *triandra* Bergg.	Bog.
Rubiaceae.	
Coprosma serrulata Hook. f.	Fell-field.
——— *rhamnoides* A. Cunn.	Subalpine scrub.
——— *ciliata* Hook. f.	Subalpine scrub; totara forest.
——— *parviflora* Hook. f.	Subalpine scrub; totara forest.
——— *ramulosa* Petrie	Fell-field.
——— *brunnea* (T. Kirk) Cockayne	River-bed.
——— *rugosa* Cheesem.	River-bed, subalpine; subalpine scrub.
——— (*propinqua* A. Cunn.) ?	*Nothofagus* forest.
——— *linariifolia* Hook. f.	Totara forest.
——— *cuneata* Hook. f.	Rock, alpine; fell-field.
——— *Petriei* Cheesem.	Steppe.
Nertera species (probably distinct from *N. depressa* Banks & Sol.)	Bog.
Galium umbrosum Sol.	Habitat ?
Asperula perpusilla Hook. f.	River-bed; bog.
Campanulaceae.	
Pratia angulata (Forst. f.) Hook. f.	Steppe; bog.
——— *macrodon* Hook. f.	Fell-field.

* Not seen by us, but the original description gives the Upper Rangitata.
† Probably fairly common originally, but now destroyed for the most part by fire.

List of Species—*continued.*

Species, Family, &c.	Plant-association.
Lobelia linnaeoides (Hook. f.) Petrie	Fell-field.
——— *Roughii* Hook. f.	Shingle-slip.
Wahlenbergia gracilis (Forst. f.) A. D. C.	Steppe.
——— *saxicola* (R. Br.) A. D. C.	Steppe; fell-field.
Stylidiaceae.	
Phyllachne Colensoi (Hook. f.) Bergg.	Fell-field.
Donatia novae-zelandiae Hook. f.	Bog, subalpine.
Forstera Bidwillii Hook. f.	Fell-field.
——— *tenella* Hook. f.	Steppe.
Compositae.	
Lagenophora petiolata Hook. f.	Steppe.
——— *Barkeri* T. Kirk	Habitat ?
Brachycome pinnata Hook. f.	Steppe.
——— *Sinclairii* Hook. f.	Steppe.
Olearia arborescens (Forst. f.) Cockayne and Laing	Subalpine scrub.
——— *macrodonta* Baker	Subalpine scrub.
——— *ilicifolia* Hook. f.	Totara forest; subalpine scrub.
——— *moschata* Hook. f.	Subalpine scrub.
——— *Haastii* Hook. f.	Subalpine scrub.
——— *oleifolia* T. Kirk	Subalpine scrub.
——— *nummularifolia* Hook. f.	Subalpine scrub.
——— *cymbifolia* (Hook. f.) Cheesem.	Subalpine scrub.
——— *avicenniaefolia* Hook. f.	Subalpine scrub.
——— *virgata* Hook. f.	Steppe.
Celmisia Walkeri T. Kirk (not typical, but nearer this than to *C. discolor*)	Rock, subalpine.
——— *discolor* Hook. f.	Fell-field.
——— *Sinclairii* Hook. f.	Fell-field; rock.
——— *Haastii* Hook. f.	Fell-field, alpine.
——— *petiolata* Hook. f.	Rock, subalpine, on raw humus; fell-field.
——— *spectabilis* Hook. f.	Steppe; fell-field.
——— *pseudo-Lyallii* (Cheesem.) Cockayne	Fell-field.
——— *coriacea* (Forst. f.) Hook. f.	Fell-field.
——— *Lyallii* Hook. f.	Fell-field.
——— *viscosa* Hook. f.	Fell-field.
——— *longifolia* Cass.	Steppe; bog.
——— *laricifolia* Hook. f.	Fell-field.
——— *sessiliflora* Hook. f.	Fell-field.
——— *bellidioides* Hook. f.	Rock, subalpine
Vittadinia australis A. Rich.	Steppe.
Haastia Sinclairii Hook. f.	Shingle-slip, alpine.
Gnaphalium Traversii Hook. f.	Steppe.
——— *paludosum* Petrie	Bog.
——— *luteo-album* L.	Steppe; river-bed.
——— *japonicum* Thunb.	Steppe.
——— *collinum* Lab.	Steppe.
Raoulia australis Hook. f.	River-bed.
——— *lutescens* (T. Kirk) Cockayne	River-bed; steppe.
——— *tenuicaulis* Hook. f.	River-bed.
——— *Haastii* Hook. f.	River-bed.
——— *Monroi* Hook. f.	Steppe.
——— (*apice-nigra* T. Kirk) ?	Steppe.
——— *subsericea* Hook. f.	Steppe.
——— *eximia* Hook. f.	Rock, alpine.
——— *grandiflora* Hook. f.	Fell-field.

LIST OF SPECIES—*continued.*

Species, Family, &c.	Plant-association.
Helichrysum bellidioides (Forst. f.) Willd.	Steppe; fell-field.
—— *filicaule* Hook. f.	Steppe.
—— *grandiceps* Hook. f.	Rock.
—— *depressum* (Hook. f.) Benth. & Hook. f. ..	River-bed.
—— *microphyllum* (Hook. f.) Benth. & Hook. f. ..	Rock.
—— *Selago* (Hook. f.) Benth. & Hook. ..	Rock.
Cassinia Vauvilliersii (Homb. & Jacq.) Hook. f. ..	Steppe.
—— *fulvida* Hook. f.	Steppe.
Craspedia uniflora Forst. f. var.	Steppe; river-bed.
—— *alpina* Backhouse	Shingle-slip.
Cotula atrata Hook. f.	Shingle-slip.
—— *pyrethrifolia* Hook. f.	Fell-field.
—— *perpusilla* Hook. f.	Steppe.
—— *squalida* Hook. f.	Steppe.
Erechtites glabrescens T. Kirk	Totara forest.
Senecio bellidioides Hook. f.	Steppe.
—— *scorzoneroides* Hook. f.	Fell-field.
—— *lautus* Forst. f. var. *montanus* Cheesem. ..	Shingle-slip.
—— *cassinioides* Hook. f.	Subalpine scrub.
—— *elaeagnifolius* Hook. f.	Subalpine scrub.
—— *Bidwillii* Hook. f. var. *viridis* (T. Kirk) Cheesem.	Subalpine scrub.
Microseris Forsteri Hook. f.	Steppe.
Crepis novae-zelandiae Hook. f.	Rock.
Taraxacum glabratum (Forst. f.) Cockayne ..	Fell-field.

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Art. XXXVIII.—*The Younger Rock-series of New Zealand.*

By P. Marshall, D.Sc., F.G.S., Professor of Geology, Otago University; R. Speight, M.Sc., F.G.S., Lecturer on Geology, Canterbury College; and C. A. Cotton, M.Sc., Lecturer on Geology, Victoria College.

[*Read before the Otago Institute, 1st November, 1910.*]

Plate VIII.

[Note.—This paper has been mainly written by the first author. The observations upon which it is based were made conjointly by the three authors in the typical districts of North Canterbury. Other districts referred to have been examined by only two or by one of the authors, but in each case the observations made have been referred in detail to the others, and the authors are in complete agreement in regard to all the critical points set forth in the paper. The critical account of the stratigraphical relations of the Waitemata series has been kindly furnished by Mr. E. de C. Clarke, of the University College, Auckland, and the authors are specially indebted to him for the description of this important locality.]

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