Morainic Deposits of the Waimakariri Valley.

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Introductory Summary.

THE occurrence of moraine in the valleys of the New Zealand rivers presents certain anomalies, so that it may be appropriate to consider in particular the case of one typical river, viz., the Waimakariri.

The dominant physical features of the upper basin of this river have an important bearing on the distribution of moraine, and therefore it may help in the presentation of the subject to give a brief account of the mode of origin and nature of this basin before the onset of the ice-flood. In a general sense it has been formed by the deformation through down-warping and faulting of an area of the late Tertiary Southern Alps peneplain and its covering beds. The foundered portion is bounded on the west by the Craigieburn Mountains (altitude about 6000 ft.), and is connected in that direction with the Trelissick or Castle Hill basin, already described by the present author (Speight, 1917, and 1935). On the south the intermont is bounded by the Torlesse Range (6553 ft.), along the northern base of which flows the Broken River with a general E.–W. orientation. On the east the boundary is formed by the high continuous ridge of the Puketeraki Mountains (6347 ft.), along the flanks of which runs the main Waimakariri River in a deep, continuous, rocky gorge. It should be noted that the river does not lie in this part of its course on the actual floor of the basin, but has excavated its bed on the slopes leading down thereto, so that there is a well-defined greywacke ridge rising to a height of 3380 ft. in Mount Rosa, between the river and the floor of the basin to the west. On the north side the boundary follows generally the line of the bed of the Waimakariri between the mouth of the Cass and Mount White, with a possible subsidiary basin extending upstream from Cass past Bealey to the Crow River. On this northern boundary spurs from the main divide run down finger-wise to the main stream and separate valleys occupied by the following tributaries:—the Crow, Bealey, Hawdon and Poulter, while further east the Esk River drains a tract of country between the Puketeraki Range and the spurs running east and south from the Candlestick Mountains (6628 ft.), but not reaching the main divide.

The formation of this intermont was the result of diastrophic movements under whose influence a number of structural and landscape elements were developed (1) with N.E.–S.W. orientation, and (2) with N.W.–S.S.E. orientation. To the former may be assigned the valley of the Esk, which occupies a fault angle depression, while to the latter belong the ridges stretching from near Cass towards Broken River, which determine the Grasmere-Pearson-Winding Creek valley and that occupied by Slovens Creek right from St. Bernards

Saddle to Broken River. In addition to these, and not obviously structural, are a number of subordinate valleys lying to the east of Slovens Creek which drain either to the Puketeraki section of the Waimakariri River or to Broken River, the chief of which rises near Trig I, while smaller ones still run from Lake Blackwater—when it overflows—and past the old Avoca homestead. A special feature of these streams so oriented is that however open their upper and middle courses may be they discharge to Broken River or to the Waimakariri by deep, rock-bound gorges.

In this part of the intermont the floor lies at an elevation of about 2000 ft. and shows a somewhat uneven surface, though the irregularities have been smoothed by ice action so that flowing contours are characteristic, ridges are frequently cut into sections, and detached hills are common. Some of these last must have always maintained their summits above the ice-level in the form of nunataks (e.g. Mount St. Bernard), but most of them must have been completely submerged when the ice was at a maximum, for scoured surfaces extend at times right over their summits. The south bank of the Waimakariri below the Cass is marked by isolated remnants of such a ridge—e.g. the elevations known as the Sugarloaf, Gog, Magog, and that marked Trig. I are the results of such a dissection, and through the gaps between them the ice crowded at one stage to deploy on the flat, open floor of the upper part of the Slovens Creek area.

North of the broken barrier just referred to stretches for some 25 miles a trench, now occupied by the main stream, whose base is depressed below the general level of the floor of the intermont by between 300 and 400 feet. This hollow is veneered almost completely with gravels brought down by the main stream and its tributaries whose lower reaches are masked in the same way, and enter the main stream at grade. The lower part of this trough is structural in origin, for just above the junction with the Esk, Tertiary limestones show through the gravel floor. It has, however, been modified by glacial erosion, for here the ice reached a great thickness, the trough acting as a great collecting and distributing area, and the ice persisting in mass long after the floor of the intermont to the south had been completely evacuated. When the ice retreated up the main valley and the lower part of the Poulter valley from the junction of the Esk, their floors were occupied by a lake in which varved silts were deposited, and as this condition demands that a barrier existed on the downstream side, it is reasonable to assume that the great Puketeraki gorge of the river was only partly cut at that stage and that a barrier still remained behind which an extensive lake could be ponded.

This brief summary has been given so that the situation of the morainic deposits may be more fully appreciated, for it will be seen that they occur in general where some accident in topography has facilitated deposition and the preservation of what has been deposited. An important point to be noted is the relative absence of morainic deposits in parts of these valleys where the other physiographic evidence of the former presence of glaciers is conclusive.

Long stretches show no moraine at all, whether terminal, lateral, or stadial, and this suggests that some peculiar condition determines at times the continued existence of moraine. When dealing with special cases of deposition consideration will be given to this aspect of the problem. These will now be taken in turn from the eastern to the western side of the intermont.

Lochinvar. (Photos 1, 2.)

The most extensive morainic deposit in the valley of the Waimakariri is that which lies west and north-west of the old Lochinvar station, now an out-station of Mount White. This occupies part of the Lochinvar Plain, a flat area bounded on the north by the outskirts of the Candlestick Mountains, and on the south by the mountain mass of which Mount White and Mount Peveril are the dominant peaks. The area is probably structural in origin, being a strip of country which has been faulted down, but it has been modified by the flood of ice which once occupied the region. In pre-glacial, and perhaps during early glacial times, the Cox River, formerly known as Cox's Poulter, now a tributary of the main Poulter, discharged south-east to the Esk River by way of the Lochinvar Plain and the lower course of Nigger Creek, but at one stage in the glacial history a great moraine was piled across the western end of the Lochinvar Plain and the Cox was diverted south-west through a rough, rocky gorge to the main Poulter. The area covered by moraine is remarkable, and it impressed Haast in the early days (1879, p. 151). Extending over several square miles of flat are large irregular dumps deposited by the Cox Glacier with lakelets lying in the hollows (Photo 1), and fronting this in tongue-like form is an area in which the hummocks are much smaller (Photo 2). This last must have been deposited in a comparatively short space of time, whereas that required for the deposition of the great dumps must have been somewhat lengthy. It should be noted that Nigger Creek which now drains this area, after flowing for a considerable distance in an open, ill-defined, and swampy channel—perhaps the floor of an old, shallow lake—passes through a deeply incised gorge to reach the Esk River. The landscape forms in its vicinity prove that the ice reached a long distance past the Lochinvar moraine at one stage, and the moraine itself marks a halt in a retreat from this advanced position, or a readvance from a line much further back and nearer the main divide.

Junction of the Poulter and Waimakariri. (Photos 3, 4.)

An extensive area of moraine is located in the angle between the Poulter and Waimakariri Rivers at the base of Mount Binser. This owes its presence partly to the Waimakariri and partly to the Poulter Glacier, material having been dumped from the sides of both on a kind of no-man's-land lying between them as they issued each from its own valley, and being preserved after deposition, since it was not exposed in its somewhat sheltered position to the erosive action of ice or of the rivers issuing from the front of each glacier whether combined or not.

There is also a thin veneer of moraine distributed discontinuously on the country near the Mount White station and on in the direction of the junction of the Esk with the Waimakariri, but this was exposed to the action of the streams issuing from the front of the Poulter Glacier and so the deposit is of no great magnitude.

Another extensive area of deposit is that on the south bank of the Waimakariri opposite its junctions with the Poulter and Esk, around Lake Blackwater, and on the northern base of Mount Rosa, with an extension south-west of the lake through a trough leading towards the head of Puffers Creek, a tributary of Slovens Creek. Half a mile south-west of the lake this trough is crossed by a stream which rises between Trig. I and the Craigieburn homestead, runs first of all in a narrow, deeply incised channel for a mile and a half, then in an open bed flanked by moraine and river terraces (Photo 3) past the northern end of the Mount Rosa ridge to enter the Puketeraki reach of the main river by a deep, wooded gorge. Other crescentic morainic ridges, evidently deposited by a glacier coming from the north-east, cross this trough, and dumps occur on the shoulders of spurs facing the same direction, while scattered blocks lie on the slopes above. The lake, which is little more than a large pond, lies among morainic heaps (Photo 4) and north of it these deposits cover an area of some three square miles. They lie at two definite levels, the upper with large and irregular mounds, the lower with smaller and more subdued heaps of debris. The material has come from both the main glacier and that of the Poulter valley, the latter in all probability contributing most, for its valley is almost equal to the former in size, and its glacier had not been diminished to any great extent by distributaries, the only one of importance coming down Andrews Creek. The preservation of these moraines can be attributed to their having been deposited in a locality not exposed to the action of powerful streams issuing from an ice-front. It may be mentioned that the trough just referred to is perhaps structural in origin, for it lies in a direct line with the fault-angle valley of the Esk and only a short distance from where the Tertiary limestone has been faulted down into the bed of the main stream. If this line be followed south-west it will coincide after very slight variation in direction with that of the fault which bounds the Tertiary beds on the lower part of Slovens Creek on their eastern side.

Lake Sarah–St. Bernard Saddle Area.

A very interesting area of deposit occurs near Lake Sarah, south of the Sugarloaf, continuing on to the St. Bernard Saddle and the slopes of Gog. Near the lake itself to the north-east of the railway the deposit is entirely moraine showing characteristic hummocky topography. Some of this has been deposited by a glacier which came from the north-west and the direction of the lake and other has been deposited by the main glacier which has come round the southern face of the Sugarloaf and dropped its load in this somewhat sheltered locality. An outflow channel from the glacier front drains towards the lake indicating that the Waimakariri Glacier invaded territory which hardly belonged to it, so this moraine is to be credited to two ice fronts. Then there are

the fluvio-glacial moraines which lie on the south-western side of the railway, covering the St. Bernard Saddle, and extending east on to the northern slopes of Gog. These have been described by Gudex (1909, p. 33). They can almost certainly be attributed chiefly to a distributary of the main Waimakariri Glacier, which crowded through the gap between the Sugarloaf and Gog.

Slovens Creek Area. (Photo 5.)

Patches of moraine occur in the upper part of the basin of this stream on the slopes of Gog; on the northern slopes of St. Bernard; in the gap between Magog and Trig. I, near the Craigieburn homestead; and on the rising ground to the east in the direction of Mount Rosa. However, the most striking feature of this area is the flood-plain of a river which once issued from the front of a distributary of the main glacier when it reached about a mile below the present Craigieburn homestead. This has an accordant surface stretching across the middle portion of Slovens Creek from Puffers Creek on the east right to the neighbourhood of Vagabonds Inn on the west. The bed of Slovens Creek has been incised in this flood-plain to a depth of some 300 ft. (Photo 5).

The basal beds of the area are greywacke with some overlying coal measures, and in the upstream direction they present a steep face directed north, and crossing the bed of the creek. Behind this barrier a shallow lake was ponded at one time, remnants of which are the small lake Marymere to the west of the railway, and the swampy ground to the east which contains near the railway station a somewhat extensive deposit of diatomaceous earth. The former lake was emptied as Slovens Creek lowered its bed subsequent to the glaciation.

On the surface of the barrier lies a veneer of moraine which extends on the eastern side of the stream over a considerable area where it merges into outwash plain. At first sight this appears flat and regular, and so it is in its distal portion, but in the upstream direction the regularity is broken to some extent by roughly crescentic low morainic dumps, of which three—perhaps four—lines are preserved, separated by small outwash plains in which are remnants of dumps. No doubt moraine once extended as far as the junction of Puffers Creek with Slovens Creek, near which definite moraine is exposed, but it has been subjected to the wash of glacial streams forming the plain, so that the dumps have been scattered, buried, or removed in the downstream area, and all that is left to indicate their former presence is a very occasional large block that the streams were incompetent to remove entirely or to bury. This is an excellent example of the ability of a powerful stream issuing from an ice-front on to an outwash plain to remove all surface evidence of moraine from its vicinity.

As mentioned previously this flood-plain extends across Slovens Creek towards the eastern slopes of Mount St. Bernard, but west of Vagabonds Inn (2052 ft.)—an old camping ground for trampers—moraine extends in the same direction, and south of it lies an outwash plain at a slightly higher level than that of Slovens Creek.

Near the Inn itself are hummocks mantled with moraine, and in my opinion they are not formed entirely of transported material, but this is merely a veneer over rock in situ, either of greywacke or of the Cretaceous coal measures exposed in places on the northern slopes of Noman's Land.

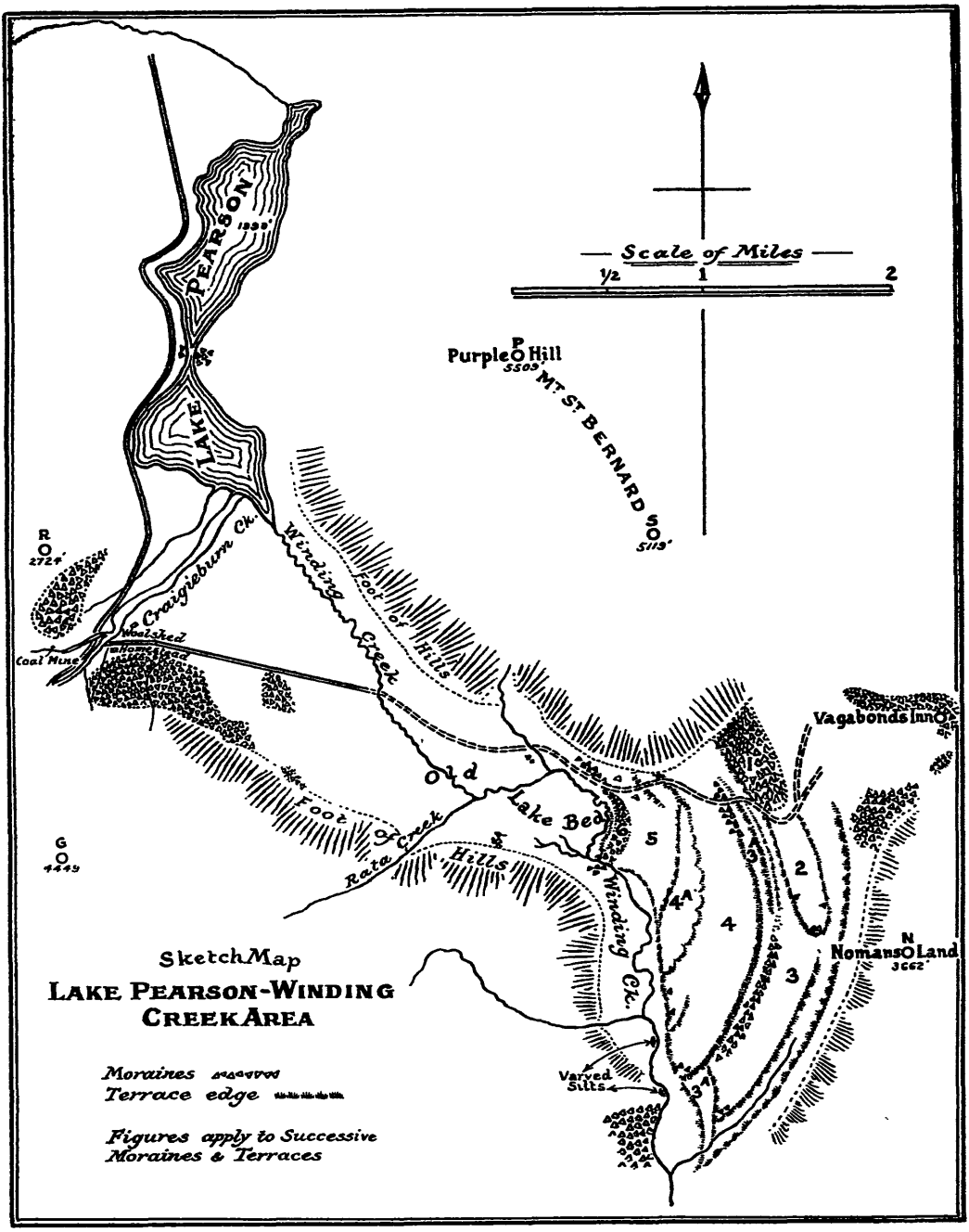
To the east of the Slovens Creek outwash plain moraine occurs on the hillsides, especially where it has been sheltered from erosion in nooks and corners and above the wash of streams. In addition numerous perched blocks lie on the smoothed western slopes of Mount Rosa and of the range of hills extending south from the Craigieburn homestead. The furthest downstream that moraine occurs in the Slovens Creek area is at its junction with Puffers Creek, and it also occurs in the elevated U-shaped trough running south-east from the old Avoca homestead. It forms a fringe to the north-west lip of the trough, and occurs on both sides of the valley leading therefrom towards the reach of Broken River below the bridge. About a mile from the site of the house lies a terminal moraine, with a double row of crescentic hummocks, breached by the stream which issued from the glacier as it was retreating through the trough. A large, high roche moutonnée rising from its floor must have divided the ice-stream into two parts at an advance and at a retreat stage in its history.

Lake Pearson–Winding Creek Area. (Sketch-Map No. 2 and Photos 6, 7.)

An interesting and extensive area covered with moraine lies between the northern end of Noman's Land—an elevated tract of country (3662 ft.) forming a tilted block and lying between the lower courses of Slovens and Winding Creeks—and the southern end of the St. Bernard Range. The deposit is largely due to the dumping of material from the sides of glaciers flowing past the east and west flanks of the range on to ground not directly exposed to erosion by them or to that of the streams issuing from them. As conditions changed, the country to the west was directly subjected to the action of the glaciers which came from the north over the site of Lake Pearson.

The uppermost terrace (marked 1 on the map), which stretches south from the end of the St. Bernard Range, consists of large angular blocks unmodified by stream action, and the same applies to the irregular dumps which mask the lower slopes of the northern end of Noman's Land and lie in all probability on faulted down Cretaceous coal measures as well as on greywacke. These two morainic areas have been separated by a stream which issued from the front of the glacier flanking St. Bernard on the east and discharged to Winding Creek instead of to Slovens Creek as might be expected. The upper end of the channel is now dry, but the lower end has been incised in terrace (3) subsequent to the latter's formation by the drainage it has collected from the adjacent slopes of Noman's Land.

Terrace (2) is oriented in the same direction as (1), the edges of both being in alignment and it too in all probability has been


PEARSON
1899'
LAKE
Scale of Miles
½ 1 2
Purple Hill
5509'
P.O.
MT ST BERNARD
5119'
R.O.
2724'
Craigieburn Ck.
Winding Creek
Foot of Hills
Coal Mine
Coal Shed
Homestead
Vagabonds Inn
Old Lake Bed
Foot of Rata Creek
Rata Hills
Winding Ck.
G.O.
4449
N.
Nomans Land
3662
Varved Silts
1
2
3
4
4A
5
Sketch Map
LAKE PEARSON-WINDING CREEK AREA
Moraines
Terrace edge
Figures apply to Successive Moraines & Terraces

No. 2.

formed by a stream common to the glaciers east and west of St. Bernard. Although formed by water, large blocks show occasionally on its surface, its flanks and on its distal end.

After a number of small intermediate terrace remnants extending towards the slopes of St. Bernard in a northerly direction on the flanks of (1) and (2), the next important terrace (3) forms a wide outwash plain half a mile in width where broadest, and extending nearly two miles downstream towards the rocky gorge of Winding Creek. Its north-western margin is marked by a row of morainic dumps, sometimes a double row, which becomes indefinite towards the northern end and merges into one of the intermediate terraces just mentioned, but becomes very definite downstream and extends to the west across the gorge of the river on to the slopes of Broken Hill. In places the moraine lies several chains back from the edge of the terrace. The surface of this outwash plain is beautifully accordant and must be attributed to the stream which issued from the glacier front as it reached the moraine just mentioned. Only towards the lower end do large blocks appear, though others no doubt occur buried beneath the accordant surface. Subsidiary terraces (3a) lie along its western front, and towards the northern end one of these is marked by a well defined lateral moraine.

Terrace (4), and also its flanking terrace (4a), at a lower level, give little evidence of the proximity of ice, though they must both have been determined upstream by a former ice-front. The only signs of its proximity are occasional morainic blocks at the proximal end against the slopes of St. Bernard, in scallops on the northern face and along the termination of both on the high banks of Winding Creek. The upper surfaces of both (4) and (4a) are reasonably flat and grade evenly downstream.

At their base lies a flat outwash plain (5) with occasional blocks at its northern end, and bordering it to the north and north-west is a typically developed terminal moraine (6) extending in crescentic form, with convexity directed downstream, from the slopes of St. Bernard right across the bed of Winding Creek towards the slopes of Broken Hill (Photo 6), except where it has been breached by the stream. Low and indefinite terraces, perhaps lake beaches, but more probably of stream formation, lie on the northern side of this moraine. The outwash plain (5) was no doubt formed when the glacier reached this moraine.

The total height involved from (1) to (6) is estimated at approximately 600 feet.

It should be noted as well that two small exposures of varved silts occur between this moraine and the upper end of the gorge, the lower one with well-developed alternations of clay and sand, and the other more sandy, while under moraine (6) on the bank of the stream there are indefinite sandy layers perhaps due to the same cause and laid down close to the ice front. The two undoubted instances are covered first of all by terrace gravels and in one case certainly by moraine as well. They show that at one stage, antedating the deposition of moraine, a lake existed in this area ponded

back on the downstream side by the yet uncut barrier where the gorge is now situated. It is remarkable how the lower courses of Winding Creek, Slovens Creek, and even the main Waimakariri, have all been incised after the retreat of the ice.

This area appears to me the most interesting in its bearing on the glacial problem in New Zealand that it has been my fortune to come across, and it well merits detailed investigation. The following is my interpretation of the sequence of events after several examinations, and it is put forward with all due diffidence, and with the certainty that some day it will be thoroughly revised.

The main glaciation of the area is indicated clearly enough by the general landscape features such as the scoured surfaces of Noman's Land, and the facetted spurs of St. Bernard, Broken Hill, etc., but the special interest is connected with the events following on the deposition of the high-level moraines between St. Bernard and Noman's Land. These appear to me to be as follows:—

1. Glaciers advance or hold their own after a general retreat, eroding a basin in a fault-formed valley, previously modified to some extent by the main glaciation. Note that the valley of Winding Creek has been determined by a fault or faults, the evidence for which is remnants of coal measures which in places occur on the floor of its gorge.
2. Retreat of the ice leaving a hollow with a barrier on the downstream side, not yet incised by the stream, and behind which a lake was ponded in which varved silts were laid down.
3. Advance of streams over this deposit covering it with gravel, the stones being well rounded and the ice-front evidently some distance back.
4. Advance of the ice, formation of the outwash plain (3) and the deposition of moraine along its edge, these deposits being laid down on the lake silts, which were not completely removed by ice or stream erosion.
5. Retreat of the ice, and the deposition of terraces (4) and (4a) with little sign of the presence of ice in the vicinity. It retreated in all probability further upstream than the present position of moraine (6). At this stage the incised gorge of Winding Creek was probably cut, a temporary lake—not the same as that in which the varved silts were laid down—occupying the floor of the valley.
6. Readvance of the ice forming the lowest level moraine (6) and its outwash plain (5). A lake, now occupied by the swampy meander belt of Winding Creek was ponded back by this moraine which was drained when the moraine was breached, and the terraces on its upstream side were then formed.
7. From this onward in time there was the deposition of stadial moraines across the floor of the valley as the ice retreated towards Cass. Reference to these will be made now.

The first of these moraines is indicated by a small hummock on the western side of the mouth of the stream issuing from St. Bernard, and by two larger hummocks lying against the western side of the valley directly opposite, below the tributary called Rata Creek. The second occurs near the Flock Hill homestead, first as a detached collection of hummocks (see map) about a mile from the homestead, and then as an extensive area on both sides of Craigieburn Creek at the outlet from its gorge. Although this occurrence has the hummocky surface characteristic of moraine there is a notable paucity of angular blocks, and such as occur appear to lie on fluvio-glacial material and boulder clay (tillite) with a few scratched stones. In this case at one stage the ice climbed the greywacke barrier in the direction of Castle Hill and the deposition of tillite is a common occurrence on the upstream side of such a barrier. This deposit may date from an early stage of the glaciation, and the blocks that do occur on the surface may be a somewhat late addition. It is best developed on the south side of the Craigieburn between the homestead and the lower slopes of Broken Hill, and also on the opposite side of the stream immediately north of the coal mine, where large blocks occur more frequently.

The next of these almost divides Lake Pearson into two subequal areas, but it has been almost obscured by two shingle fans which come in from opposite sides of the lake at this point. It might be urged that the fans are entirely responsible for the constriction of the lake, but the size of some of the blocks much exceeds those usually brought down by streams forming fans.

The next moraine lies between Lakes Pearson and Grasmere, and has been responsible for the change in the direction of drainage of the area occupied by the latter lake. This now runs to the Cass, a reversal of its former direction. The moraine abuts on the east right against the rocky ridge running in a northerly direction from Mount St. Bernard (Photo 7), while the western end is overwhelmed by the fan of Ribbonwood Creek which issues from the Craigieburn Mountains on the west. Nevertheless a considerable area of the moraine is clearly exposed, showing hummocky ridges arranged in crescentic pattern and the convexity directed towards Lake Pearson.

The last area lies to the west of Lake Grasmere right against the Craigieburn Mountains, and this merges into lateral moraine in the direction of the outlet of the gorge of the Cass River, and it may link up under fan material in the other direction with the moraine between Lakes Grasmere and Pearson.

These moraines were no doubt formed during halting stages in the last retreat of the ice. The distributary of the main Waimakariri Glacier responsible for them crossed the Mount Misery-Goldney Saddle ridge near Cass and the ice-stream was of relatively small importance. The grade of the valley was also low, and in fact at its northerly end the grade was reversed. Also, it was formerly even more completely occupied by lake than at present. The moraines, therefore, owe their preservation in such perfect form to not having been exposed to the full force of a powerful stream issuing from the main front of a large valley glacier, and especially so since the grade of the valley was comparatively flat.

Other Moraines.

In addition to these deposits, moraines of small size are found near the heads of some of the main valleys, for example, the Upper Bealey, the Hawdon, and the basins at the head of the Craigieburn and Broken River, but they are absent in other cases where they might be expected. It should be noted too that deposits which look like moraine are in some cases due to rock falls consequent on earthquake or without that agency. An excellent example occurs in Thompsons Creek, a tributary of the Poulter, and the barrier behind which Lake Minchin is ponded at the head of this river is probably attributable to such a fall. Even if such deposits are glacial, it is remarkable what great lengths of the valleys contain no deposit even simulating moraine.

Mention might be made here of the presence of moraine in the valley of the Kowai, a tributary of the Waimakariri entirely outside the intermont, and rising on the south-eastern slopes of the Torlesse Range. First of all, moraine occurs at the head of Macfarlanes Creek, a tributary of the Kowai rising just south of Porters Pass, but this is more probably attributable to an offshoot of the Rakaia Glacier, which entered the basin of the Kowai over a somewhat low saddle. There are also two occurrences in the main Kowai, lying at the mouths of tributary streams coming directly from the Torlesse Range, one of which is certainly moraine, and the other probably so. They are additional to deposits which might be attributable to rock falls associated with a recent earthquake rent passing through Porters Pass and which are almost certainly not glacial; these lie nearer the pass.

Absence of Moraine.

The only trace of the former presence of ice in many localities is that furnished by the form of the landscape as cut from the solid. What then has become of the moraines or have they ever existed in these places? It should be noted that many of our present-day glaciers have no terminal moraine. Those at the end of the Tasman Glacier are small when the amount of debris on the surface of the glacier is considered. The Lyell Glacier at the head of the Rakaia has little or no terminal moraine, and the same is true of the Franz Josef and Fox Glaciers on the West Coast. In all these cases the rivers issuing from the glaciers are competent to carry the moraine away as fast as it is delivered at the ice-front, and the same conditions may have obtained in bygone times. There is no such thing in the case of a retreating glacier as an annual moraine such as can be seen in Sweden, whose precise date can be assigned in the Swedish time scale. Stadial moraines, such as have been mapped in various glaciated regions occur in the Waimakariri basin only in the Cass-Pearson-Winding Creek valley, and even these are not precisely regular or typical.

Their absence may perhaps be explained on the Flint hypothesis (1929, pp. 256–89) that glaciers disappear from long stretches of the valley during retreat by wastage from the sides, and especially is this likely if for any reason tributary glaciers fail as well, owing to the decline of the névé fields at their heads, to maintain connection

with the trunk glacier. Such might well occur in the case of the Waimakariri trough, if the tributary glaciers from the Hawdon, Poulter, Bealey, and other valleys failed at their heads. The moraine covering the trunk glacier would then be deposited as a mere veneer on the valley floor and would soon be dispersed or buried by river action. This would account for its absence in certain cases, and it may be concluded that existing moraines in the Waimakariri Valley, and perhaps in the valleys of other rivers of Canterbury, apart from the great terminal moraines, have in most cases been deposited and preserved where they have been protected by some accident in topography, etc., from the erosion and transporting action of powerful streams. In some cases, however, existent moraines have been covered and concealed in the fans of tributary streams.

Length of the Waimakariri Glacier.

The question of the maximum length of the Waimakariri Glacier during the glacial period is bound up with the presence or absence of moraine in critical localities. The furthest distance from the divide that undoubted moraine occurs in the Waimakariri intermont is near the old homestead at Avoca, there being no signs of it on the sides of the gorge down which the railway passes towards Springfield. The chief suggestion of its extension on to the plains is the presence of mounds, perhaps morainic in origin, near the Springfield and Sheffield railway stations, and at Racecourse Hill, some 5 miles further on, and distant from the mouth of the gorge about 13 miles. Such an extension implies a wide spreading of the ice as a piedmont on both sides of the present position of the river, and even if it were of moderate thickness, the maintenance of the supply through a somewhat narrow gorge would be a matter of extreme difficulty unless the ice reached far up the slopes on either side. This seems to me a serious objection to an extension as far as Racecourse Hill, and, to a lesser degree, if Sheffield be considered the limit. However, both Haast (1879, map) and Hutton (1884, pp. 449–54) were of the opinion that the glacier reached as far, or nearly as far, as these mounds. It will be appropriate, therefore, to consider the evidence, inconclusive though it may be.

Little can be said concerning the mound near Springfield since it is now covered completely with close-growing gorse and broom, and an adequate examination is impossible, but no large blocks are visible on the surface. Hutton (loc. cit., p. 449) gives a description of the Sheffield mound, sometimes known as Little Racecourse Hill. He says, " it contains large, angular, erratic blocks washed out of some former morainic deposit, and now completely mixed with river shingle, but there is no boulder clay." The mound is now covered with soil and cultivated nearly all over, so there are no good exposures, but about the middle of the western face a collection of angular and sub-angular blocks shows on the surface with little small material among them. The largest block measured was 5ft. by 4ft. by 4ft., and there is a fair proportion of slightly smaller sizes. At one spot a mass shows just level with the surface, strongly suggesting rock *in situ*, and if this be correct, it no doubt forms a connecting link between the solid greywackes of Gorge Hill on the Waimakariri

and the slopes of Abners Head about a mile to the west of the mound. If it is not in position, then it implies a larger mass than any exposed. It seems reasonable for both Hutton and Haast to maintain that the ice extended nearly as far as this mound or actually reached it, since the blocks have retained angularity and therefore had not been carried any considerable distance by stream action.

The case of Racecourse Hill presents more serious difficulty. Hutton says that it is composed of rounded shingle like that of the plains. In my opinion it resembles in degree of weathering the older pre-glacial gravels of the Malvern Hills and elsewhere in North Canterbury rather than that of the plains, and, further, the mound is capped near the trig. station and on its northern end by concentrations of large angular and subangular blocks not as large as those of Little Racecourse Hill near Sheffield, but still up to four feet in length. The form of this hill suggests that it might be a remnant of a latero-terminal moraine of a glacier reaching so far, but Hutton says that it reminded him of the Eskers of Ireland or Kames of Scotland. It does certainly show a striking resemblance to the historic esker near Upsala in Sweden, especially as regards the concentration of large blocks on its summit. The concentration in the Swedish case is attributed to the action of the sea, but this agency is hardly possible in the New Zealand cases, though Hutton maintained that the plains in the vicinity of the mounds had been planed by the sea; he did not suggest that their summits had been planed and the large blocks concentrated by its agency.

Although no moraine to support the former presence of ice occurs on the lower slopes of the hills near Springfield, where it might be expected to occur on the analogy of the perched blocks on the slopes and summit of the Rockwood Hills near Rakaia Gorge, an assemblage of large blocks lies on the north-eastern slopes of Abners Head just above the level of the Hawkins River, and these, if of glacial origin, might be attributed to the Waimakariri Glacier if it had reached as far as Racecourse Hill, and even if it had reached Sheffield, but it is also reasonable to credit them to a distributary of the Rakaia Glacier which came down the upper Selwyn valley past the Dalethorpe homestead.

It may be urged that if a glacier extended on to the plains some definite remnant of terminal moraine should have survived. This, however, is not necessary since the glacier may have had no terminal or a very scanty one. In the latter case the blocks comprising it would be dispersed and buried like those in the outwash plain of Slovens Creek. Hutton mentions the presence of erratics in the high gravel banks near the junction of the Kowai with the main river, an observation confirmed by the present author, for an accumulation of angular masses up to 6 ft. by 4 ft. by 3 ft. in size with a large number of smaller sizes with angular and rounded edges lies at the base of the terrace in the angle between the rivers, and one especially massive boulder, 10 ft. by 10 ft. by 12 ft., with edges well rounded, lies near the top of the terrace surrounded by others of smaller size. A wash-out nearby discloses that the lower beds are composed of finer more thoroughly cemented material with a layer of coarser

material on top of it, and on this latter, or in it, occur the large masses. I have noted a tendency elsewhere in this area—and it happens also in the case of the large concrete blocks in protective works on the Waimakariri lower down the plains—for large blocks lying on loose gravel and exposed to the wash of water, to sink till they reach solid rock or a layer of more consolidated material, and this may account for the concentration of larger masses from what were originally mere sporadic occurrences in a mass of shingle, and would explain the gradual disappearance of moraine if it had been laid down on the gravel of the upper part of the plains. Moraine resting on gravel does occur now at the outlets of the Rakaia and Rangitata valleys.

The question, therefore, of the presence of ice in this vicinity depends on the power of rivers to move such large blocks. If they cannot, then under the conditions obtaining, ice must have been the only agency responsible for their position, and we must agree with Haast and Hutton that the glacier came down nearly to Sheffield, though hardly as far as the vicinity of Racecourse Hill. I have seen blocks up to 15 ft. in length in the bed of the Harper River, where it is over half a mile in width and composed of gravel, but these may have been residuals of moraines such as occur in the vicinity and are not transported blocks. The experience of engineers carrying out protective works on the Waimakariri River is in the direction of conceding the river power to move concrete blocks of similar size, and with this possibility always existent it seems dangerous to use their presence as definite proof of the extension of the glacier into the area under consideration, although it does not appear reasonable that such large blocks can have been carried far. The angularity of many of these masses also supports the contention that they have been ice-borne from some spot in close proximity to that where they are now situated.

The evidence from the north bank of the river is as unsatisfactory. If a glacier had reached as far down as Sheffield one would expect to find some remnant of moraine in the form of perched blocks on the slopes of View Hill, and I have not been able to find any either on the greywacke or on the dolerite, where the presence of foreign greywacke would be easily detected, and if found, would be convincing. Large angular blocks up to 6 ft. in diameter have been washed out of the high terrace between Woodstock and the Eyre River, and occur on its margin and on the sides of the Airlie Creek which intersects it; these are analogous to those on the south bank of the Waimakariri near the Kowai. But this terrace is not composed of ordinary river gravel for it has an important matrix of clay with angular, sub-angular, and rounded stones. None of these were observed to be scratched and the texture was not as tenacious as that shown by a typical boulder-clay or tillite, so it cannot be assigned definitely to that class of glacial deposit. Its uniform and accordant surface suggests that it has been planed from a pre-existing deposit. The terrace extends for several miles down-stream towards the Eyre River, and gradually increases in width till it is over a mile broad. It is the highest terrace in this part of the plains, and its occurrence

supports Hutton's contention that a veneer of gravel has been stripped from their surface, the mounds at Racecourse Hill, etc., being remnants of it. Although it is not analogous in character to these, it does indicate that a river issuing from the gorge or its vicinity once ran at a higher level than that of the present general surface of the plains. On the solid greywacke slopes rising from this terrace there are accumulations of large angular stones which do not appear to have been shed from the slopes above and which resemble those of the terrace just referred to. Judging from the smoothed contours of the hills in their vicinity, a distributary of the main glacier must have crossed a low part of the ridge east of Trig. Q, in the direction of the middle course of the Eyre River, and these blocks may be part of a lateral moraine of this distributary, but since they are entirely of greywacke and rest on greywacke as far as can be seen, there must be some doubt concerning their character as a glacial deposit. A stream from this portion of the ice-front certainly ran towards the Eyre.

To sum up the position as to the possible extension of the Waimakariri Glacier on to the plains, it can only be stated that either rivers are competent to move for considerable distances the large blocks occurring in the terraces, or, in the event of this competency being denied, glaciers came down nearly as far as Sheffield; but that it is extremely improbable that they came as far as Racecourse Hill. In my opinion, which after all is largely impressionist, they came as far as the line of the Kowai River and may have reached further. The problem is thus left unsolved, and awaits more detailed future investigation.

The only indications from the gorge itself that it was once occupied by ice are (1) the wide, open trough in which the present bed of the river is deeply incised, (2) the smoothed surfaces of the slopes alongside of it, and (3) the occasional triangular facets of spurs—usually a somewhat indefinite feature. The trough itself probably dates from pre-glacial times, since some stream must have discharged through this gap from the Waimakariri intermont, and it probably reached a sub-mature stage. Its form would be modified by ice-scour into its present cross-section, and on the retreat of the ice the floor would be covered from the gorge upstream with a thick veneer of gravel, remains of which now survive on the rocky shoulders above the present incised gorge. So thick is this deposit at times that many of the railway tunnels are driven in it entirely. These gravels date in all probability from the epoch of the Slovens Creek outwash plain and they grade into it. The streams issuing from the ice-front at this stage would be so heavily charged with waste that they would have little energy left over to modify the form of the ice-scoured trough by vertical or lateral corrosion. The deeply incised gorge within the gravel-masked trough is a later feature, whose formation, as well as that of the other incised gorges of the river in its vicinity, is perhaps connected in some way with an isostatic modification of the earth's crust following on the disappearance of the load of ice.

Comparison with Mackenzie Country.

Although there is some resemblance between the circumstances of the Waimakariri and those of the Rakaia and Rangitata, there is a closer parallel with those of the Mackenzie Country. In both cases there is an intermontane basin which is drained through a narrow gap in the southern or south-eastern border. Both were fed with snow and ice from valleys rising in the main divide and converging on the floor of the basin; in both cases there is opportunity for the dissipation of declining glacier energy on its floor; moraine has been formed at the end of mountain valleys when they reach the true structural boundary and where distributary tongues of ice have deployed through gaps in a broken range of hills rising from its floor (e.g. west of the road from Tekapo to Simons Pass); an outwash plain fronts the moraines in both cases; and there is a relative paucity or uncertainty of evidence, apart from smoothed outlines, to prove the extension of the ice beyond the limits of the basin. Although Haast and Park have maintained that moraine occurs in the Upper Opihi and Hakataramea Valleys as a result of the ice lapping over the south-eastern edge at the height of the glaciation, Hector and McKay considered that such moraines were not directly connected with it, but arose from independent glaciers on the outer flanks of the basin. Personally, I have seen no definite evidence that ice extended beyond its limits.

The great moraine or complex of moraines that stretches discontinuously from the lower end of Lake Tekapo in a south-westerly direction past Lake Pukaki and on to the vicinity of Lake Ohau seems to correspond in time and conditions of deposit to those of the Waimakariri near its junction with the Poulter, and those along Slovens Creek, judging from their external form, state of preservation, and degree of weathering of the morainic dumps. Both indicate a prolonged halt in the position of the terminal face, whether it be in a general retreat or in an advance from a position further back and nearer the divide.

Recession of the Waimakariri Glacier.

As the Waimakariri Glacier retreated within the intermont, it would first of all evacuate the country lying along the eastern border, approximately the belt along the line of the Puketeraki Gorge and the Esk Valley, for this part would be the first to feel the effect of any failure in the supply of snow and ice near the main divide, and especially so, seeing that no part of the Esk Valley reaches so far. Even if we include the Cox, the length drained to the Esk will be small and of little account as a feeding ground. So the valley of the Esk would feel an ice famine even while large glaciers occupied the Waimakariri and Poulter Valley, and distributaries reached to the slopes of Mount Rosa and Noman's Land. Perhaps to this time belong the high level gravels of the Puketeraki reach of the main river, those near the outlet of Slovens Creek and also the thick, flat-lying gravels of the Esk Tableland. The outwash gravel terrace of Slovens Creek belongs to a later date, after the slopes of the hills just mentioned were freed from ice. It is somewhat difficult to

indicate exactly the order in which different areas were evacuated, but it seems reasonable to place the high-level moraines between the southern end of the St. Bernard Range and Noman's Land earlier than the Slovens Creek outwash terrace, and the outwash plain south-west of Vagabonds Inn with its morainic dumps in an intermediate position, probably contemporaneous with the outwash plain in Winding Creek which is margined with moraine on its upstream side. Retreat from the junction of the Poulter began about the same time, and the fluvio-morainic deposits of St. Bernards Saddle were laid down later and the moraines south of the Sugarloaf near Lake Sarah later still. The low-level moraines at the lower end of Lake Pearson probably date from the period before the evacuation of the lower end of the Waimakariri trough had begun, but this cannot be stated for certain. The Winding Creek-Lake Pearson-Cass area would no doubt be free from ice or but lightly occupied in its northern portion, while the Waimakariri trough was still well filled, since the latter would have important feeders direct from the main divide while the former would have its supply obstructed by the Mount Misery-Goldney Saddle ridge just north-west of Cass. That this area was partly, if not entirely, freed from ice while the main Waimakariri was still occupied is proved by the position and features of the moraines south of the Sugarloaf for they clearly indicate that ice came round the southern flanks of this hill from the direction of the main river. The moraines which cross the above-mentioned valley are stadial of one episode of glacier retreat or of retreat after a re-advance, most likely of the former.

The further retreat to the present position must have been very rapid, since there are no moraines in the upper reaches of the valleys tributary to the Waimakariri till near their heads. This rapid retreat is perhaps contemporaneous with that of the ice margin through Southern Sweden from the Weichsel (Würm) moraine of northern Germany. It should be pointed out that the present glaciers do not necessarily mark a halting stage in the retreat from the Pleistocene position, but really indicate an advance from a line further back than that occupied now, since there is definite evidence that following the Pleistocene glaciation there was a time when the climate of southern New Zealand was much milder and more rainy than at present (Lucy Cranwell and F. von Post, 1936, pp. 308–47). In this respect the sequence of events corresponds closely with that obtaining in Scandinavia following on the great recession of the ice.

Apart from this, the only definite evidence of more than one ice advance after retreat is furnished by the Winding Creek Valley. In this case there are certainly two, perhaps three, episodes of glacier advance, for the fact that moraine rests above varved silts is definite proof of retreat and re-advance. The great moraines indicate that the ice-front was stationary for long periods, but these may have been for periods during a general retreat when the ice was holding its own, and do not indicate an advance from a position further back towards the divide.

The only other evidence of more than one period is furnished by the shelves cut in the sides of the valleys, usually in series of two

or three as along the flanks of Noman's Land. Sometimes there are more, as for example on the hillsides south-east of the Craigieburn homestead, where there are four, perhaps five. These may, however, have been cut during one glacial episode and do not indicate several advances and retreats.

In concluding this account I have to express my sincere appreciation of the assistance rendered to me on many occasions by Mr. William Izard, of Enys, Castle Hill, for without his help the examination of the area concerned would have been most incomplete. I have also to thank Mr. Les. Hill, of Kaiapoi, for the print of Lake Blackwater and its associated moraines.

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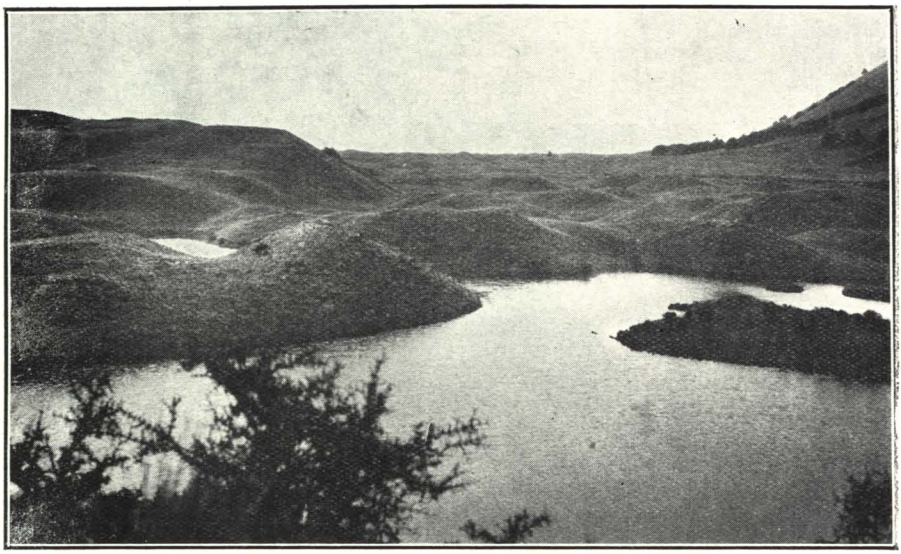

PHOTO. No. 1.—Lochinvar Moraine, showing glacial dumps, with Lake Gracie ponded in the hollows.

PHOTO. No. 2.—Lochinvar Moraine, frontal portion, with smaller morainic dumps; valley of the Cox in background, slopes of the Candlestick Mountains on right.

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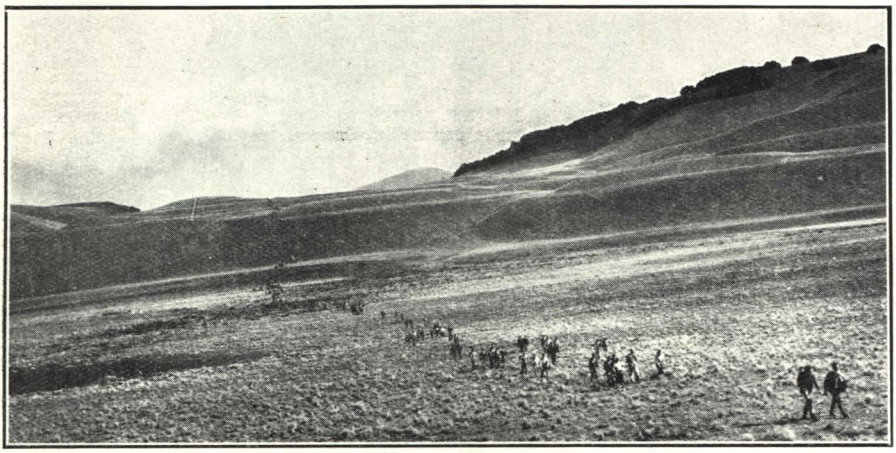

PHOTO. No. 3.—Moraines south-west of Lake Blackwater, in foreground bed of old glacial stream flanked with river terraces, the bed now carrying little water; on right are ice-scoured slopes.

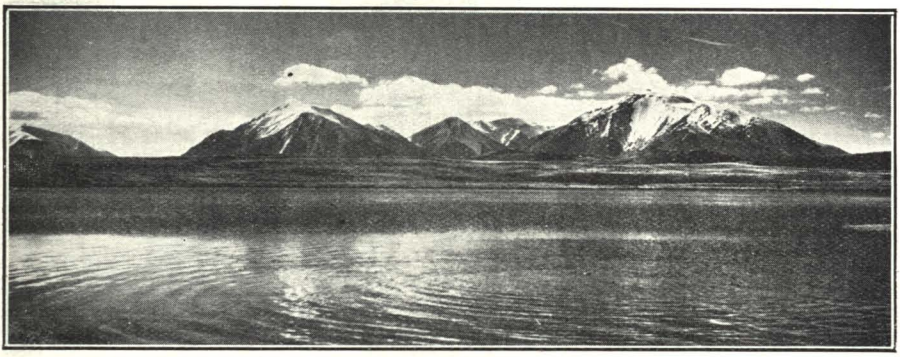

PHOTO. No. 4.—Lake Blackwater in foreground, moraine in middle distance; Poulter Valley, Mounts Peveril and White in distance.

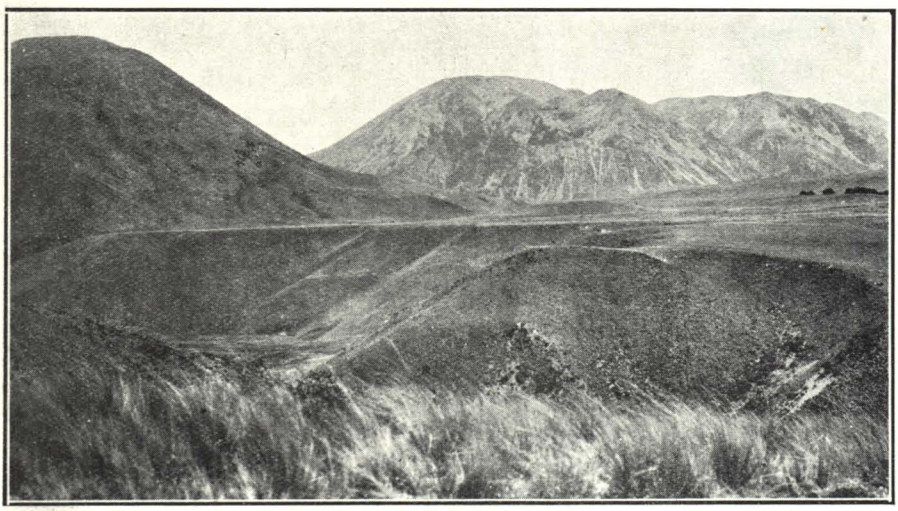

PHOTO. No. 5.—Outwash plain of Slovens Creek in middle distance; Nomans Land on left; Vagabonds Inn and moraine on right; incised bed of Slovens Creek in foreground; moraine covered flats on right.

PHOTO. No. 6.—Looking up Winding Creek towards St. Bernard Range; high level morainic terraces against mountain on right; arcuate younger moraine in middle distance; breached by stream on left; ends of spurs clearly facetted.

PHOTO. No. 7.—Moraine between Lakes Pearson and Grasmere; St. Bernard Range with ice-scoured slopes on right; the ridge on the left has also been scoured by ice.

To follow plate 23.