# The Gravels of the Mackenzie Intermont.

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## A. INTRODUCTORY.

A REMARKABLE feature of the later Tertiary and Quaternary sequence within the province of Canterbury and a little beyond it is the widespread occurrence of high-level gravels, which are not connected with those forming the upper layers of the Canterbury Plains. These latter have an accordant surface, which in places on the western margin is covered with morainic deposits, indicating that the last extension of the glaciers occurred after the greater part of the plains had been formed. Certain other older gravels lie at higher levels near the base of the mountains and in some of the mountain valleys, e.g. those in the valley of the Waiau River between the Hanmer Ferry and the Hope River, between the Eyre and Waimakariri Rivers, and on the higher country between Chapman Creek and the Stour in the Mount Somers area. Their relation to the plains can be attributed either to direct uplift or to some agency acting after their deposition, and probably antecedent to the deposition of the material of the plains, which has allowed the rivers intersecting them to cut down to a lower base-level, and thus leave remnants high and dry. This uplift or other cause may be only a phase of that which accounts for the terracing of the plains after the last extension of the glaciers.

In addition to these two categories there are other beds apparently related to the Kowai gravels (Speight, 1919, pp. 269–81), some of which are involved in deformational movements. The most important localities where they occur are as follows: on the foothills west of the Culverden Plain; on the downs between the Waipara and Okuku Rivers; the Mairaki Downs; in the Esk Valley and the Puketeraki Gorge of the Waimakariri; forming the capping of the Homebush Ridge and the downs west of it in the Malvern Hills; at various places in the Mount Somers region, such as that near the Coal Reserve, and on the ridge extending therefrom towards the Brothers; on the downs near Kakahu in South Canterbury; under the dolerite of the Timaru Downs; in the valleys of the Opihi, Hakataramea, and Waitaki in South Canterbury; and lastly forming large areas in the Mackenzie Country, such as those near the Balmoral Station, in the Tasman Valley west of the Tasman River, and the great development near Benmore between the Ohau and Ahuriri Rivers in the western extension of the Mackenzie intermont. Some of these gravels just listed may belong to the second group of high-level gravels rather than the third group.

Also they probably underlie the gravels of the plains, for where the rivers have cut down deep into these near the outlets of the gorges leading on to the plains, an underlying more oxidised series appears, which probably belongs to the second group, although there are indications in some places that they have suffered some dislocation and thus belong to the third series. This association therefore exhibits a wide distribution, and while it is not continuous *at present,* the isolation of different areas may be partly attributable to the dissection of a widespread cover, or to differential changes in land level and the stripping of the veneer from higher elevations.

While there is an admixture of fine material in the form of interstratified sand and silty beds, the dominant constituent of this extensive deposit is gravel, usually rounded or sub-angular, a large proportion less than six inches in diameter, but ranging up to three feet and very occasionally to more. The material is largely greywacke, and it shows signs of decay much more pronounced than that of the pebbles now forming the upper layers of the plains, and this applies also to the gravels of the second category. While these latter show little signs of definite stratification except of the rudest type, the third class as a rule is well stratified, occasionally exhibits foresetting, and contains at times discontinuous layers of low-grade lignite. These features indicate that the beds had been laid down under deltaic conditions on the margin of a lake, or lakes, or of the sea near a land of moderate relief. They also exhibit in many places some deformation as the result of diastrophic changes.

After these introductory remarks detailed reference will be made to the real subject of this article, viz., "The Gravels of the Mackenzie Intermont." It should be explained that the area between the Ohau and Ahuriri Rivers, sometimes known as the Ahuriri Plains, is included in the region under consideration, since it is tectonically a part of the Mackenzie intermont, though not classed as such geographically.

A brief description of the area under consideration has been given by the author (1939, pp. 53–5), and it will suffice for present purposes merely to say that the intermont lies south and south-east of the Southern Alps where the range is highest, viz., in the vicinity of Mount Cook; it is some 50 miles in length and reaches a maximum of 30 miles in breadth, being narrower towards the south-west; it is ringed on all sides by mountains, high and continuous on the western margin, but lower on the east and south-east, where there are several somewhat low breaks in the rim; the floor is in general an outwash plain of formed and present-day glacial rivers, sloping somewhat steeply towards the south, and with a general level of between 1,200 and 2,200 feet; inliers of older rock rise in places 1,000 feet above plain level; and finally glacial moraines cover, discontinuously, large areas on its north-western margin, behind which three somewhat large lakes, Tekapo, Pukaki, and Ohau are ponded.

## B. GRAVELS OF THE MACKENZIE INTERMONT.

### (a) HISTORICAL.

Although brief references to various features of this area were made by von Haast in his reports to the Provincial Government and summaries given in his *Geology of Canterbury and Westland* (1879), the earliest definite reference to the gravels of this area was made by McKay (1882) when he described their occurrence at Benmore and the Ahuriri River. His account was supplemented by Hector in his Progress Report of the same date (pp. xxiv–xxv) when commenting on McKay's report. The next reference to the area is given by Kitson and Thiele (1910) in their account of the geography of the Upper Waitaki Basin in the *Journal of the Royal Geographical Society,* where they maintain that the basin was formed in early Tertiary times with features somewhat resembling those it shows now. The next reference is by the present author (1921) in his account of a "Geological Excursion to Lake Tekapo," but perhaps the most valuable contribution is that by Marwick (1935) in his account of the "Geology of the Wharekuri Basin," an area external to the Mackenzie intermont, yet in fairly close proximity, and with beds there developed analogous in many respects to those typical of the larger intermont, his Kurow Series furnishing a useful stratigraphical level for correlation purposes. Hutton also refers to the Upper Waitaki area in his *Geology of Otago* (1875, pp. 87–8), where he maintains that the basin along with other intermonts was excavated in early Tertiary times. He maps the Benmore beds as of Wanganui age, but gives no account of the strata forming them.

### (b) VARIOUS OCCURRENCES. (See Map, Plate 25).

These will be dealt with in turn, commencing with that referred to by McKay and Hector, viz., what may be called the Benmore Beds, named after the old Benmore Home Station, not after the mountain on the south-east side of the Ahuriri Plain.

i. *The Benmore Beds.* (Plate 21.)

It will be noted that the following description adheres fairly closely to that given by McKay (*op. cit.,* pp. 62–3).

The Benmore Beds form a low and discontinuous range of hills stretching north-east from the Ahuriri River a few miles above Omarama past the old Benmore Station and Table Hill to the vicinity of the Ohau River. They rise to heights of from 2,300 to 2,900 feet above sea-level and from 700 to 1,000 feet above the Ahuriri Plain, presenting a somewhat steep scarp to the south-east, while on the north-west they sink gradually to the plain country lying between the Benmore ridge and the Diadem Range (called by McKay the Quailburn Range). The ridge is intersected at right angles to its general trend at fairly regular intervals by the Hen Burn, the Quail Burn, the Wairepo Stream, and the Ohau River, all flowing south-east, so that cross sections are given, but they have lost a good deal of their diagnostic value by the slumping of the lower beds that are exposed, and the general masking of the slopes by debris from above. In addition to these cross-sections the beds are exposed on the slope facing the Ahuriri River towards the southern end of the ridge.

In the Hen Burn the lowest beds to be seen are sandy clays interbedded with whitish and light greenish-grey sands, striking E.N.E. and dipping N.N.W. at somewhat high angles, sometimes as much as 70°; McKay gives the dip as 45°, but this observation may have been made in some other locality. These beds pass up into gravels interstratified with sands at first, but succeeded by gravel beds containing in their lower levels many small pebbles of quartz. At higher levels the dominant material is greywacke and the colour becomes a rusty-brown; they are very thick, probably exceeding 500 feet. They have the same dip as the underlying sands and do not appear to be unconformable, but no clear contact was seen either between the sands and gravels or with the basement beds underlying the sands and clays. Pieces of coal have been reported as occurring in the lower beds, but McKay says that he saw none, and this is my own experience. South-west of the Hen Burn erosion has exposed a great thickness of the sands, clays, and gravels, especially the latter, on the slopes facing south-east towards the Ahuriri River, and striking earth pillars have developed as a result of the action of the weather and gullying erosion on the coloured gravel and clay beds (Plate 21).

In Quail Burn, which lies north-east of the Hen Burn and parallel to it, an apparently similar sequence has been cut by the stream, and white sandy clays and sands are exposed on which rest massive beds of brownish gravel.

The next good exposure occurs on the bluff which terminates Table Hill and faces the Ohau River. The beds here consist of whitish sandy clays and sands, much slipped and covered with gravels, the last of great thickness, rusty-brown in colour, some layers with well-rounded and others with angular pebbles, among which quartz is a notable constituent. These beds probably extend to the north side of the Ohau River, for the low ridge near the Ben Ohau Station is in line with that south of the Ohau and is apparently composed of gravels; it was, however, not examined closely.

These beds now form a monoclinal ridge, and they as well as the basement greywackes and argillites on which they rest were certainly subjected to folding and tilting movements after the Benmore beds had been deposited. The more recent plain-gravels on either flank show no sign of deformation. It is impossible to say what area of the basin was formerly covered with these beds and what was their structure, but the existing ridge was no doubt at one time more extensive in breadth if not in length, for considerable areas must have been removed by the Ohau and Ahuriri Rivers or by rivers which preceded them. It is probable that the Ahuriri was the most potent erosive agent, since it perhaps flowed north-east along the base of the present scarp and junctioned with the Ohau directly before it cut its present rock-bound gorge to join the main Waitaki. There is no indication that even a part of this erosion is to be credited to glacial action.

The lithological character of the beds of the Benmore ridge enables them to be correlated with reasonable certainty with the Kurow Series of Marwick (*op. cit.*, pp. 329–30) as it exists in the Wharekuri Basin, and it is noteworthy that he cites a substantial thickness, viz. 600 feet, as being shown by them in this locality. Thus there is no important difference in thickness or composition of the beds developed in these two areas, nearly 40 miles apart, and now separated by a wide extent of mountainous country, with heights rising to over 5,000 feet. It is not impossible that at one time they formed parts of a single continuous veneer.

ii. *The Glentanner Beds.* (Plates 22, 23, 24.)

The area near the Glentanner Homestead furnishes the most interesting of the gravel deposits of the Mackenzie intermont. These are found flanking the Tasman Valley from Fred's Creek, some six miles upstream from Glentanner, to Jack's Creek, some eight miles downstream, and they probably extend as far as the head of Lake Pukaki, and it is just possible that they underlie the veneer of lateral moraine on the west side of the lake. However, their relations are best seen in the slips near the Glentanner Homestead and in Bush Creek and Fred's Creek. They form a definite shelf on the western side of the Tasman Valley, which reaches a height of just over 4,000 feet above sea-level and 2,500 feet above the floor of the valley. This shelf is such a remarkable physiographic feature that it merits particular reference (Plate 23).

There is little doubt that its mode of formation is analogous to that of the *albs* of the Swiss Alps, and the upper portion, which shows well-marked evidence of glacier erosion in the form of ice-cut shelves parallel to the trend of the main valley, may be credited to the erosive action of a somewhat ineffective glacier, with little powers of excavation, probably moving on a gentle grade. The deep trough which has been incised into the floor of the shallow valley has been formed at a later date by a more active glacier, of which the present Tasman, Hooker, and Mueller are remnants. On the opposite side of the Tasman Valley the land forms are analogous (Plate 24), though not so definite, for the eastern side of the valley was less confined, and the ice streams had more opportunity to dissipate their energy in lateral rather than vertical erosion. When traced downstream towards Lake Pukaki these two valley features grade into one another, no doubt owing to the decline in erosive power of the later glacier as the cross-section of the valley widened in its lower reaches.

It is possible that the upper and wider cross-section may be due initially to the modification of a shallow stream valley by glacier action before the deepening of the main valley occurred, this itself having been eroded by stream action antecedent to the onset of the second ice-flood, but it seems clear that the two separate glacier advances are necessary to account for the complete cross-section of the valley. It will be pointed out later that some of the gravels of the Mackenzie Plain are definitely overlain by the last great moraine, and it is possible that these gravels represent an outwash from the glaciers of the first episode or they may represent an interglacial stage.

After this explanation of the mode of formation of the shelf to the west of the Tasman some account will be given of the beds composing it. Their composition and structure are well displayed in the great slip behind the Glentanner Homestead. This shows an alternation of whitish conglomerate with beds coloured a rusty brown, the latter being dominant. The whitish layers peter out laterally, and pass into brown either abruptly or by gradual thinning; they are frequently lens-shaped, and then again they may continue for several chains without diminution in thickness. They appear to be just as common towards the top as near the base of the slip. The material of which they are composed consists of rounded and sub-angular stones up to 2 ft. 6 in. in length included in a finer matrix. Fine-grained sands and gravels, both as a constituent of the more massive beds and as independent layers form a subordinate percentage of the total material. These are more important in the lowest beds exposed. I am not prepared to express any opinion as to why some of these beds are red and some whitish in colour; the latter may have been whitish always or they may in some way have been subjected to bleaching, and may not represent a change in the conditions of actual deposition. The total thickness of beds exposed exceeds 1,000 feet, and it may actually be much greater, as at no place was the basement seen. They strike N. 15° W., and have a westerly dip of 45°. Occasional fragments of poor lignite are to be seen in the lenses of finer material.

In a neighbouring gully to the south of the one just mentioned there is a similar sequence, and some of the beds are very coarse. with boulders up to three feet in length. Then again some of the beds are composed of angular masses with no indication of rounding whatsoever. Some of these suggest a glacial origin, but no scratched stones were seen in position, those occurring in the slip having been shed no doubt from the veneer of glacial debris capping the shelf. It seems much more reasonable to consider these angular beds as a scree deposit, analogous to some of the rough "shingle slips" characteristic of the present Southern Alps. The finer beds give evidence of foresetting. Brownish beds are dominant, while whitish also occur, some persisting right across the slip. and others again terminating abruptly or thinning out gradually. Stems of trees turned to lignite are reported as occurring in this slip. but I saw none during my visit. The beds strike N. 30° W., and dip westerly at angles of about 40°. It is probable that the exposures in these two slips form the eastern wing of an acute syncline, and even if this is not the case the inclination of the visible beds is too high to be due solely to circumstances of deposition, and its direction has no relation whatsoever to the present topography.

It should be noted that while the front of the valley shelf facing the Tasman River is composed of gravels, a parallel strip at the rear has been cut in pre-Tertiary (Mesozoic and perhaps Palaeozoic) greywackes and argillites of the Ben Ohau Range.

In Bush Creek, which lies about three miles north of the homestead, a similar series is exposed on the southern side of its valley. The lower slopes are composed of greywacke and argillite, but unfortunately they are much slipped so that contacts cannot be seen nor the relations of the lower members of the series to the basement beds or to one another accurately determined. Also obscurity masks the contact of the conglomerates, etc., with the greywackes, slates and phyllites of the Ben Ohau Range to the west; that is, it cannot be determined whether the contact is one of normal unconformity or a fault contact.

The lower members of the Tertiary series appear to be composed of small, angular, and sub-angular pebbles of sandstone and greywacke, well cemented, and definitely interstratified with layers of finer material. In the higher levels brownish gravels predominate, though the whitish layers also occur as in the vicinity of Glentanner. In the lower levels the beds lie fairly flat, strike east approximately, and dip to the south at angles of about 10°, but in the higher levels they are bent up into a syncline which pitches south. The estimated thickness of the Tertiaries in Bush Creek is about 700 feet. Between here and Glentanner the beds are also synclinal, and strike west-north-west. Coal was reported in the '70's of last century as occurring in Bush Creek, but I understand from a resident of long standing that it was not reported again, and I saw none during my visit.

On the northern side of Bush Creek these beds do not show, for, as far as can be seen, the hillsides are composed of pre-Tertiary rocks; but a notch in the spur running from the Ben Ohau Range perhaps indicates that the syncline once carried across to the north side of the valley. About three miles further on is an outcrop of sands and brownish gravels in Fred's Creek, striking where observed approximately east, and dipping south at moderate angles. This is the furthest upstream that I have seen these beds occurring in the Tasman Valley. They probably extended formerly much further, but they have been removed by lateral glacier erosion, and they perhaps owe their preservation near Glentanner to the protection afforded by the solid mass of Round Hill (4,330 feet) on the north side of Bush Creek, which formed a strong bastion protecting from erosion the somewhat soft and incompetent beds on its downstream side.

It is unfortunate that the beds have yielded no fossils on which their age can be based, and we can only rely on their lithological resemblance to the Benmore Beds which are fairly close and in analogous stratigraphical position, these in turn being correlated with the Kurow Series of Marwick, considered by him to be of Mio-Pliocene age. The fact that the Glentanner Beds are steeply tilted, and in places folded, shows that diastrophic movements which affected this part of the Southern Alps had not ended by that time, and as they must be subsequent to the time of deposition of the beds, the deformation indicates that such diastrophic changes persisted into later Pliocene or even into early Pleistocene times.

Also when one considers the coarseness of the pebbles contained in the white and brown gravels, it seems certain that an area of considerable relief lay close to the place of deposition of the beds, perhaps not as pronounced as that now existing, but certainly of the same order.

iii. *The Balmoral-Irishman's Creek Beds.*

Stretching south-west from the vicinity of Balmoral Station and Little Mount John, across the gorge of Irishman's Creek, and on towards the northern end of Lake Pukaki, lies an analogous series. This forms hills just over 3,000 feet in height, capped with thick beds of gravel. The lowest beds visible are exposed in the bed of the creek generally below water level, so that they cannot be examined closely, but they appear to consist of light-coloured sandy clays and sands, the last sometimes of a light green colour; their dip is uncertain in amount, but they appear to strike north-east. These pass up into beds composed of angular and sub-angular pebbles in a finer matrix which includes numerous pebbles of jasper and lenses of sandy material which contain stems of trees turned into lignite. These beds dip S.E. at angles which vary about 70°. Further downstream brown and blue-grey gravels interstratified occur, the pebbles being sub-angular and rounded in a finer matrix, and in the lower levels of the gravels many of the pebbles have the characteristic beach form as if they had been deposited on the shore of the sea or of a lake washed by fairly heavy waves. This cannot be taken as definite proof of the situation where they were deposited, for river gravels often take this form, but when it is noted that they occur in connection with stratified sands and sandy clays, the possibility that they were laid down on the margin of a sheet of water is greatly increased. I saw no exposure of greywacke or related rocks in position associated with these beds, either forming a basement or outcropping on the hillsides.

The relations of the Irishman's Creek Beds to the higher gravels could not be seen owing to obscurities caused by the glacial veneer and the slumping of material from higher on the hillside, but the whole occurrence indicates that in the middle of the Mackenzie intermont lies a series analogous, especially as to its gravel content, to those developed near Glentanner and Benmore. The beds are also inclined at high angles and must have suffered marked tilting.

iv. *Coal Creek* (Lake Tekapo and Waitaki River). See Map.

Gravel beds covering sands and clays with carbonaceous shale have been recorded by the present author (1921, p. 42) as occurring in the vicinity of Coal Creek, which enters Lake Tekapo on its eastern side. Sands also occur in another Coal Creek on the opposite side of the intermont, just above the spot where the Waitaki River enters its rocky gorge, but when I visited the spot two years ago I saw no coal.

v. *Hakataramea Pass.*

The last locality of importance in this connection is the northern approach to the Hakataramea Pass by way of the valley of Snow River. This was examined in order to see if any signs of the former presence of ice existed in its vicinity, since they should certainly show here if the whole basin had been filled with ice and distributary tongues had overflowed the low places in its eastern and southern rim, as had been postulated by Haast, Park, and others. If the basin had been thus filled with ice, there should be recessional moraines, marginal lakes with varved silts and old shore-lines, boulder-clay, etc., on the slopes facing the basin, but none were seen. All the stream terraces were inclined down the grade of Snow River, whereas some should have been directed towards the pass, also some of the spurs should be truncated, but they are long and trailing and entirely without facets where these might be expected had they been subjected to glacial erosion. The only phenomenon suggesting ice-action is a ridge about a mile from the summit of the pass, composed of blocks up to three feet in length, but no really large masses were visible such as might be expected if the ridge were of glacial origin, and the blocks present might well have been brought down from adjacent mountain slopes, for they are no larger than some now carried by tributaries of the Snow River. I conclude therefore that there is no reason to believe that ice overflowed from the basin at this point or, indeed, at any, except perhaps across gaps in the Two Thumb Range north of Burkes Pass, and I support the contention of Hector, Marshall, and others who maintain that the great moraines at the lower end of the lakes of the region mark the limits of glacier advance during the Pleistocene.

However, the northern slope of the pass is noteworthy, since, on the sides and in the beds of the streams issuing therefrom are numerous exposures of whitish, greenish, and brownish sands, striking north, that is, in a line with the pass itself, and where seen dipping west at moderate angles. In places they contain fragmentary marine shells, and they may possibly be correlated with the slightly glauconitic sandstone of Marwick's Wharekuri Series (*op. cit.*, pp. 327–29). I saw no coal or rusty-brown conglomerate associated with these beds, but one or other may occur all the same. There is little doubt that the pass itself has been determined by faulting, probably by trough faulting, associated with the Kirkliston Fault of Marwick. The occurrence here is specially noteworthy since it furnishes the sole example of definitely marine beds within the intermont.

By the kindness of Mr. F. Langbein, District Engineer, Public Works Department, Christchurch, I have been allowed to examine the logs of the trial bores put down in order to test the foundations for a dam to be built across the Tekapo River in connection with a proposed hydro-electric installation. Their location follows approximately the line of the river for about 500 yards from the lake, and the records appear to indicate that under a comparatively thin veneer of moraine lie glacial silts, and below them consolidated and unconsolidated gravels interstratified with yellow clay, which pass down in turn into yellow gravels. A trial drive some distance further downstream is entirely in greyish gravels, which evidently underlie the Tekapo terminal moraine. So nothing analogous to the older red-brown facies of Benmore and Glentanner was encountered in the fifty feet or so that the bores were sunk nor in the drive.

vi. *Pleistocene and Recent Gravels.*

The floor of the intermont is in general covered with gravels which may be classified as follows:—

1. Outwash from rivers which either issued from the earliest ice-front or were interglacial; perhaps they belonged to both categories. These are definitely overlain by the last great moraines.

2. The outwash of rivers which issued from the ice-front responsible for these moraines. These grade upstream into moraine and perhaps into ground moraine and other glacial deposits.

3. The gravels deposited by the present rivers.

Those classified as 1 and 2, as well as the morainic deposits associated with 2, have been deeply channelled by the streams responsible for 3 just below the outlets of the lakes. However, the depth of this channelling becomes progressively less downstream till there is little difference in the height of the terraces of streams responsible for 2 and 3; that is, the grades intersect and the present rivers become aggrading streams.

The upstream channelling is no doubt due to the fact that where the streams issue from the lakes they are not clogged with debris, so they have considerable energy available for corrosion, but in their lower reaches, where the load of waste has considerably increased, the energy is required for transportation, and none is left over for lowering the grade of the river.

## C. THE ORIGIN AND PROBABLE HISTORY OF THE INTERMONT.

There is finally the consideration of the bearing of these gravels, especially the earlier *Kurow Gravels,* on the question of the origin of the intermont and its probable history.

1. The first point to consider is the lithological character of the pebbles composing the beds. It is unfortunate in this connection that the accurate geology of the mountain area in proximity, and specially of the country to the west of the Tasman, is practically unknown. This militates against a decision as to the locus of origin of the pebbles and boulders contained in the gravels. Greywacke and argillite appear to be the dominant constituents, but sandstone, phyllite with and without veins of quartz, greywacke with interlacing quartz veins, and undetermined dark green rocks also with veins, appear in the slips. Some of these masses may have been

actually included in the gravels, but others have been derived from the overlying mantle of coarse material of glacial origin.

2. The next point is the size and shape of the pebbles. A substantial increase in their size does appear as the present area with high mountains is approached, e.g., the case of the Glentanner Beds, but none of the pebbles or boulders included even in these beds is so large that it could not have been moved by a stream issuing from an area of only moderate relief. There is thus no reason to postulate that the relief of the land at the time of deposition was as pronounced as that now existing, though it may have been. Also many of the boulders are not water-worn or but slightly so, indicating that the pebbles could not have come far. Even the rounded masses are rarely so smooth as to demand a long transport in water. All the same, the beach form in some cases does perhaps indicate a substantial period when they were exposed to stream action. However, an examination of the greywacke pebbles in the bed of the Opuha River as it issues from its gorge, discloses that a large proportion have a characteristic beach form, so this shape cannot be relied on as a criterion for the position of the area of deposition.

3. The presence of sands and sandy clays under the gravels and the definite stratification of the lower members of the gravel series indicate deposition in an area of fairly still water, either a lake or the sea. Since no marine fossils occur, it is reasonable to assume that they were not laid down in the sea, though this is not conclusive. The sands with fossils near the Hakataramea Pass evidently belong to an earlier age.

4. While the stratification of the lower gravel beds and their occasional foresetting indicate that they were laid down under deltaic or related conditions, the irregularity of the stratification of the higher beds and the variation in their character when traced laterally indicate that they were laid down on a land surface.

The next point to consider is the form of this surface. Owing to the strong tilting and occasional folding of these beds, with various orientation, and their widespread marginal and medial distribution within the intermont, it is apparent that its form must have been quite different from that now existing. There is no clear evidence that it was then in existence *as an intermont,* and if one did exist when the gravel beds were laid down, its form could hardly have resembled that which obtains now. It is known that diastrophic movements continued in the vicinity down to fairly recent times reckoned geologically, as, for example, the faulting associated with the later phases of the history of the Wharekuri basin (Marwick, *op. cit.*, pp. 332 *et seq.*), which is considered to have occurred in the Pliocene or more recently still.

Another instance of recent earth movement on a considerable scale is furnished by the area near Fairlie which lies just beyond the eastern border of the Mackenzie intermont. An excellent example of diastrophic changes influencing the regime of a river but failing to change its direction is here given by the Opihi and Opuha Rivers, both of which rise in the eastern rim of the intermont, flow for some miles across an open plain, and then pass by deep narrow gorges through a barrier of greywacke which rises from 600 to 800 feet directly across their path, whereas they would have had no difficulty if they had followed along the western flank of this ridge through the open valley which stretches from Sherwood Downs past Fairlie to the vicinity of Cave. Throughout this stretch there is no serious obstruction to the course of the stream, the only difficulty—and that a slight one—being the low downs lying just south of Fairlie and occupying nearly the whole breadth of the valley. Park thought that they were the remnants of a moraine, but I do not think they are glacial at all (1939, p. 55). Why, then, have these two rivers taken such a remarkable course? It can hardly be that the drainage is superimposed, and it is almost certain that it is antecedent, that is, the two streams maintained their old courses across the grain of the country as it was then, in spite of the rise of the barrier of greywacke across their paths. The youthful form of the gorges suggests that their formation, and the uplift of the block which necessitated their cutting, took place in very recent times. The position of the Tertiary limestone near Fairlie demands that faulting took place along the line indicated, so it is merely the question of the date of this movement. This case and that of Wharekuri, both associated with areas close to the Mackenzie intermont, lend support to the thesis that the region as a whole was in an unstable condition in Late Tertiary times, and I can see no reason why the formation of the large intermont should not be assigned to Late Pliocene or even to the earliest Pleistocene times.

The occurrence of coal at a height of over 4,000 feet above the sea in the angle between the Godley and Macaulay Rivers at the head of Lake Tekapo should be mentioned in this connection, although it is not possible at present to place it in its proper stratigraphical position with any degree of certainty (Speight, 1921, pp. 42–3). It may belong to the early Tertiary Coal Measures of Marwick's Wharekuri succession, and, if so, its significance as an indicator of deformation in the Late Tertiary in the Mackenzie area is not of any special value, although it seems improbable that incompetent beds like coal measures should have persisted so long in such an exposed position; this seems to be against their being of Eocene age. But if the coal belongs to the measures sometimes associated with the rusty-brown gravels, then it clearly indicates that important diastrophic movements occurred in this region at the close of Tertiary time.

After the area had taken on the form of an intermont, it was modified by ice action, at first somewhat slightly—if we adopt the explanation of the origin of the cross section of the Tasman Valley near Glentanner given earlier—and then by stream action. This was followed again by much more active glacial erosion, which modified the valleys, deepening and widening them, covering their sides with a veneer of lateral moraine, and depositing diagonally across the middle of the basin the morainic complex which stretches south-west from the south-eastern corner of Lake Tekapo, past Balmoral and the Irishman's Creek to the southern end of Lake Pukaki, and after a break resuming at the southern end of Lake Ohau, and continuing

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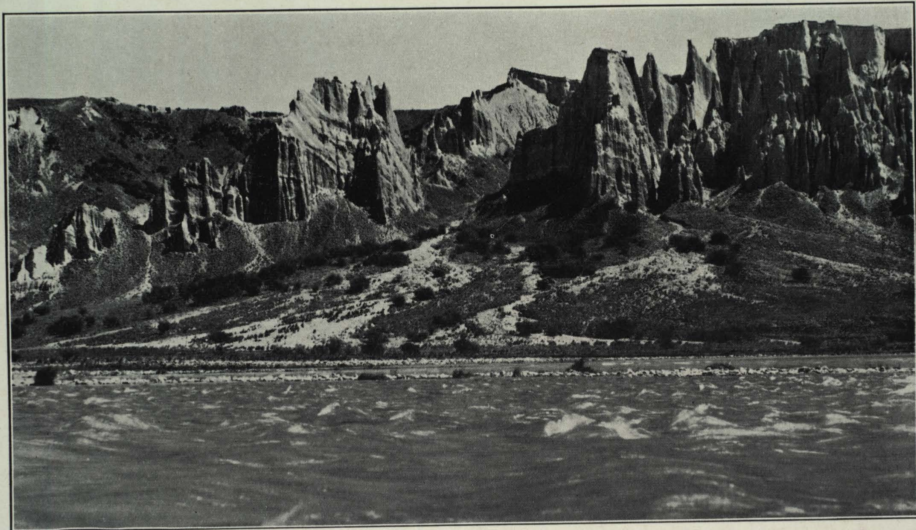
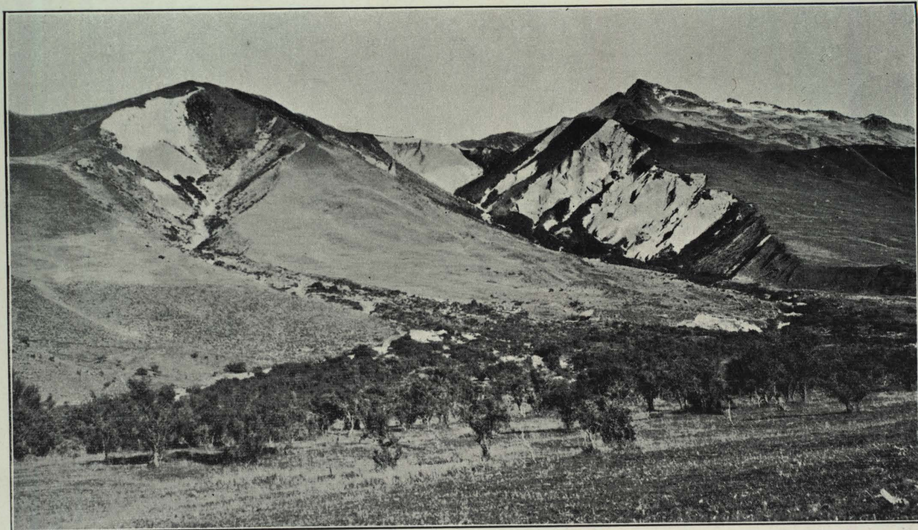


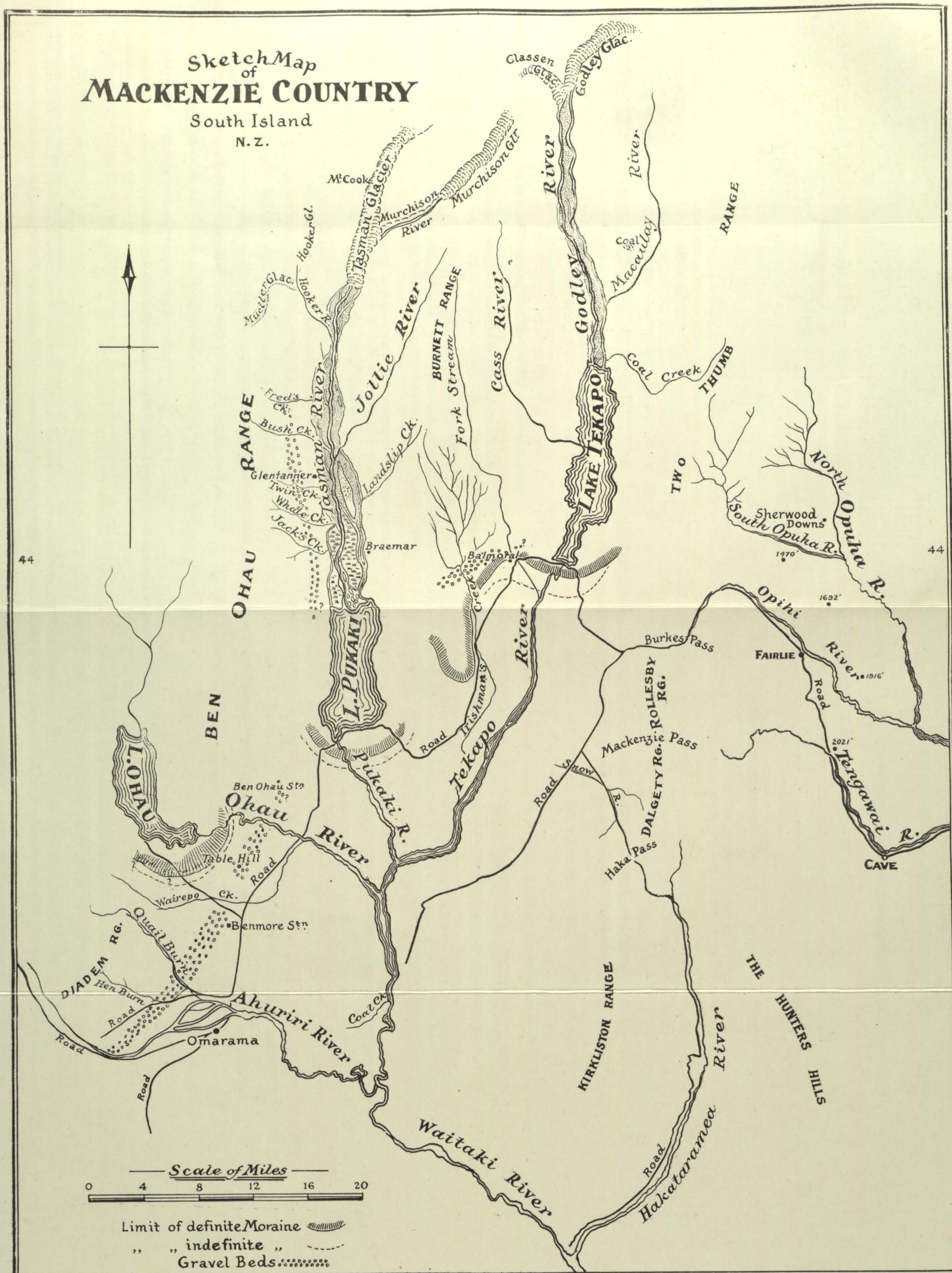
21. Benmore Beds at the south-west end of the Benmore ridge, showing pillars due to erosion and weathering of the gravels; view looking north-west across the flooded Ahuriri River.



22. Glentanner Beds, view looking west from near the homestead; the westerly tilt of these beds is shown in the slip on the right. The top of the shelf forms the base of the *alb;* Ben Ohau Range in the background.

23. View across the Tasman riverbed from Landslip Gully; Twin Creek (three miles below Glentanner) on the left. Gravel beds show in the slips on the lower slopes. The surface of the *alb* shows in the middle distance, with Ben Ohau Range in the background.

24. View from near Glentanner homestead across the Tasman riverbed; the valley of the Jollie River shows on the left, and the glaciated slopes of the side of the valley and of the *alb* above are visible in the middle and the right of the picture.




25. Map of the Mackenzie region and country to the east, showing the position of localities mentioned in the text.

*To follow plate 24]*

for some distance along the foot of the Diadem Range. Behind this front lie large areas covered with moraine, and mention should be made in this connection of the area between Lake Tekapo and the Tasman Valley near Braemar, to the north of the hills near Balmoral. Here is a deposit partly lateral and partly terminal of the former greater Tasman Glacier at one stage in its history; this is nearly as impressive as the great Pukaki moraine.

The modification of the outwash plains formed on the glacier front has been mentioned earlier. It is stressed here also that I have seen no signs of modification by ice-action of that part of the intermont which lies south and south-east of the outlying dumps which mark discontinuously the external fringe of the great morainic complex.

If this outline of events be correct, it perhaps indicates that the rusty-brown gravels of the intermont have been formed under conditions closely resembling those which obtained when similar gravels were deposited outside this area on the country now occupied by the foot-hills and downs flanking the base of the Southern Alps on the east, and they may really be outliers of a once fairly continuous sheet, the component parts of which were not necessarily deposited contemporaneously. This suggestion is merely an extension of the thesis advanced by the present author (1915, pp. 336–53), in which it is maintained that the Tertiary limestones and associated beds which occupy the floors of the various intermontane basins in the Canterbury area were laid down on a peneplained surface, subsequently deformed by folding and faulting, especially the latter, and that fragments of the cover were preserved in the lower-lying areas where they were less exposed to erosive agents. The contention here advanced is that similar changes took place in the Mackenzie region at a later date, viz., at the very end of the Tertiary era. It is probable that the peneplain on which the gravels were laid down is not the same as that just cited, but one cut across the existent Tertiary beds as well as the earlier Mesozoics, though the planation was not so complete as in the earlier case, since sufficient high land must have been left close to the area of deposit to furnish debris of a coarseness corresponding to that of the gravel beds.

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