ART. IV.—*Notes on a Geological Excursion to Lake Tekapo.*

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DURING the Easter recess of the present year the author paid a visit of several days' duration to the country lying to the east and north of Lake Tekapo, in the Mackenzie country, the visit being primarily to determine the stratigraphical relations of the coal reported to occur in Coal River, and its bearing on the origin of the Mackenzie intermontane basin. The question of the origin of this basin, the greatest in the alpine region of Canterbury, was discussed to some extent by Kitson and Thiele (1910, p. 431), when these authors concluded that it was of structural origin, a conclusion largely based on the observations of McKay on the Tertiary sedimentaries which occur near Lake Ohau and in the lower part of the area. This lower part, however, they do not appear to have visited; while the structural origin of the upper part in the vicinity of Lakes Pukaki and Tekapo, which they did examine, was stated as a probability, without giving distinct evidence. Largely influenced by the great weight of Captain Hutton's opinion, they concluded that the tectonic movements which initiated its formation dated from pre-Cainozoic times; that a depression of the land took place in mid-Cainozoic times, and that the sea then invaded the valleys and deposited marine sediments; that the area was raised at the close of the Cainozoic era with some slight deformation, and that the resulting surface was modified by glacier erosion and deposition. This is a brief summary of the position as far as the origin of the basin is concerned.

Since their paper appeared there has been a general swing of mature geological opinion in the direction of the hypothesis that the chief structural movements in the alpine region of the South Island took place in late Jurassic or early Cretaceous times, when the Alps were raised as a folded mountain-chain and during a subsequent period of stillstand of the land a peneplain was formed as the result of prolonged subaerial erosion; that on lowering this surface below sea-level a more or less continuous veneer of Tertiary marine sedimentaries was laid down on it; and that at the close of the Tertiary era an epeirogenic movement ensued, with attendant faulting, warping, and, in some cases, of folding of the beds, which resulted in the formation of an elevated tract known as the Southern Alps. Included in this are several remarkable intermontane basins, of which the Mackenzie country is one. The second hypothesis is the one favoured by the author, and the visit to the district under consideration was made in order to ascertain if the facts furnished by it fitted in with this hypothesis.

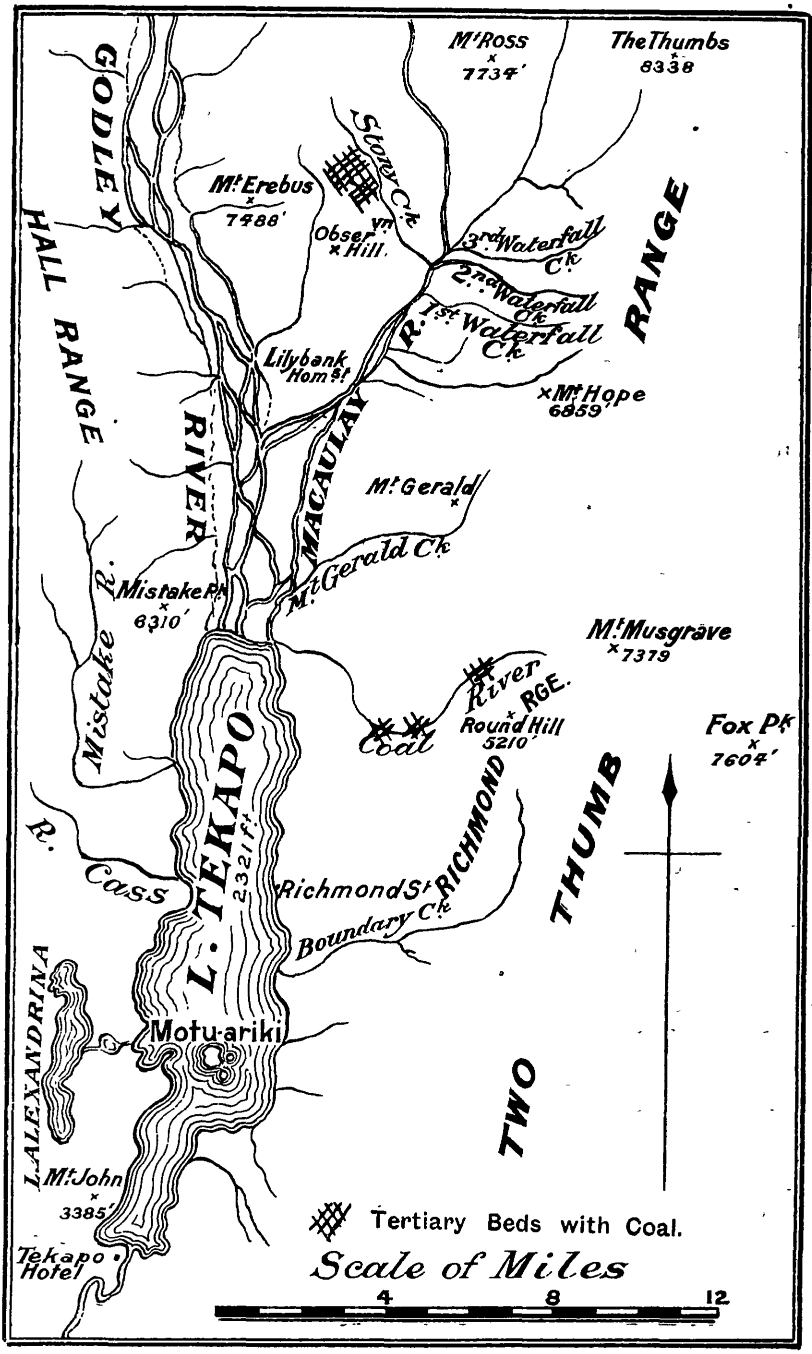
General Physiography. (See map.)

The district under special consideration lies to the north-east and north of Lake Tekapo, which occupies the most easterly of the three main valleys leading from the highest section of the Southern Alps out on to the sloping plain region of the Mackenzie country, which owes its formation largely to the aggrading action of the great rivers which formerly flowed from the fronts of glaciers issuing from those valleys. The basin is bounded on the east by the Two Thumb Range, which branches off the main divide of the Southern Alps in the vicinity of McClure Peak (8,192 ft.), and runs south without a break until it reaches the Ashwick Saddle and Burke's Pass, whence it continues southward as the Hunters Hills. The range is highest at its northern end, where it is dominated by the great mass of Mount d'Archiac (9,279 ft.); but high peaks are found farther south, such as Mount Chevalier (7,910 ft.), the Thumbs (8,338 ft.), and Fox's Peak (7,604 ft.); while for long distances it is over 7,000 ft., and rarely sinks below 6,000 ft. It thus forms a thoroughly effective divide between the north-eastern part of the Mackenzie basin and the valleys of the Rangitata and Opihi, which lie to the east. From this range important ridges stretch down towards Lake Tekapo, such as the Sibbald Range, which divides the Godley Valley from that of the Macaulay, with Mounts Sibbald (9,181 ft) and Erebus as its leading peaks, and the Richmond Range, which reaches south-west towards the middle of the eastern shore of Lake Tekapo. To the south of the Macaulay lies Mount Gerald, which, though not very high, is a noteworthy feature of the landscape.

The chief rivers feeding the lake are the Godley and the Macaulay, the former rising in the main divide and the latter draining the country between the Sibbald Range and the Two Thumb Range. On the western side of the lake the chief streams are the Cass River and Mistake River; while on the eastern side the most important streams are Coal River and Boundary Creek, both of which flow first of all south-west and then west. The former follows along the northern flank of the Richmond Range and enters the lake at its extreme north-eastern corner, while the latter follows along the southern side of the range and enters the lake about the middle of the eastern shore.

The surface of Lake Tekapo is 2,321 ft. above sea-level, and it is therefore the highest of the great lakes of New Zealand. It has a length of about fifteen miles and a breadth of about three and a half in its widest part, and is somewhat quadrangular in shape. Its general surroundings are monotonous, and the country is now treeless except for the plantations in the neighbourhood of station-homesteads. The shores, too, are flat and wanting in bold features Only on the western side, in the vicinity of Mount John and the Mistake Range, do hills closely approach the lake; and in these cases they rise precipitously from the water's edge, and exhibit all the features of valley-walls whose bases have been sapped back by lateral glacial erosion.

On the eastern side the country rises gradually from just above lake-level to the foot of the spurs from the Two Thumb Range, such as Mount Gerald and the Richmond Range; and the profile of these slopes is evidently carried down to the bed of the lake, so that it has not the form of a true glacial trough, but rather of a widely open groove or depression. The lake is thus somewhat shallow—387 ft. was the maximum depth obtained by Ayson—and two small ice-scoured islands with outlying reefs near the lower end of the lake emphasize the fact that the solid bottom does not lie far below a large area of the water.



Mt Ross
7734'
The Thumbs
8338
Stony Ck
Mt Erebus
7488'
Obser vn Hill
GODLEY
HALL RANGE
3rd Waterfall Ck
2nd Waterfall Ck
1st Waterfall Ck
RANGE
Lilybank Homst
R.
Mt Hope
6859'
RIVER
MACAULAY
Mt Gerald
Mt Gerald Ck
Mistake Pk
6310'
R.
Mistake
Mt Musgrave
7379
River
RGE.
Round Hill
5210'
Coal
Fox Pk
7604'
L. TEKAPO
2321 ft
R.
Cass
Richmond St
RICHMOND
Boundary Ck
THUMB
L. ALEXANDRINA
Motu-ariki
TWO
Mt John
3385'
Tekapo Hotel
Tertiary Beds with Coal.
Scale of Miles
4
8
12

The whole country in the vicinity of Lake Tekapo has been heavily glaciated. Extensive areas of the lower levels are masked by a veneer of moraine; large travelled blocks everywhere dot the landscape, and some are exposed, partially submerged, along the shores of the lake. Owing to the completeness of this covering, exposures of rock *in situ* are rare below the steep slopes of the mountains. Scoured and grooved surfaces and smoothed landscapes are visible at higher levels. Numerous shelves of comparatively small elevation are characteristically developed as the valley widens out, especially on the section between Coal River and the Macaulay. These are strongly reminiscent of those to be seen near the Potts River in the Rangitata Valley, and near Lake Heron in the valley of the Upper Ashburton. In these cases the type of sculpture is associated with the erosion of a valley which has been at one time filled with non-resistant Tertiary sediments. Farther up-stream, however, a modified form of this sculpture is apparent where the ice has overridden the end of the spur between the Macaulay and the main valley, the rock being entirely greywacke, so that it is not dependent altogether on the presence of easily eroded rocks. A feature similar to this is recorded by Park (1909, p. 19) as occurring near Ben More, in the Wakatipu district. In this case, however, he attributes the feature entirely to glacier erosion, whereas the Tekapo occurrence seems partly due to erosion and partly to the deposit of morainic matter on the shelves so formed.

The extreme freshness of the evidence of ice-action suggests that the retreat of the ice was comparatively recent, a fact which is emphasized by the modifications of the valley-sides. The youthful stage of the drainage of some of the tributary creeks, too, with their deep, narrow, rock-bound gorges incised into the abraded surfaces, so smooth by contrast, strongly supports the hypothesis that the ice has but recently retreated from this region. This feature is specially well exhibited in the Waterfall Creeks, which enter the Macaulay from the east, just at the point where it is emerging from the rocky precipitous country on to the down area which lies on the flank of Mount Gerald.

One somewhat surprising feature is the absence of halting-stages in the retreat. There are no terminal moraines apart from the great one at the foot of the lake, and the coating of angular material seems to be somewhat thin. It is as if the ice disappeared simultaneously from long stretches of the valley and dropped the covering of moraine which then masked its surface. This loose material would be rapidly occupied by plants from the adjoining open spaces, so that the formation of a plant covering should not lag long behind the disappearance of the ice. The rapidity with which a bare shingle river-bed is covered with vegetation shows that no objection can be raised to the hypothesis of a recent rapid retreat of the ice on the ground that plants would not have had time or opportunity to spread and establish themselves on the glacier-swept areas. The evidence of rapid retreat with few or no halting-places is observable in the valleys of the other main rivers of Canterbury, especially the Rakaia and the Waimakariri.

On the higher country the usual forms resulting from glacial sculpture are to be seen, notably corries in all stages of complete and arrested development and of destruction by present-day ice and frost. The cirques, originally heading them after the retreat of the ice, are attacked by these agencies, the clear-cut walls disappear, the hollows becoming filled with debris. Especially is this the case when they are partially filled with snow. Rocks roll down its frozen surface, especially in winter, and accumulate at the lower margins of the hollows, simulating terminal moraines of the glaciers which once filled them.

A most beautifully developed corrie, fully a mile broad, occurs at the head of Stony Creek, a western tributary of the Macaulay. This is headed by a well-marked amphitheatre or cirque with steep rock walls; at their base are hollows now occupied by small ponds or swamps, the remains of old corrie lakes. The lower part of the basin was once filled by a deposit of Tertiary sands and clays with coal, but a great part of these has been removed, so that now there is a double basin inside the limits of the corrie. On the lower side, too, below the spot where the coal has disappeared, there is the characteristic rock barrier, breached at one point, and through this opening, in a deep narrow notch, the stream draining the basin now flows. Before the coal-measures had been removed it must have presented a thoroughly typical example of a coomb or corrie.

STRATIGRAPHY.

The great mass of the mountains of this region consist of greywackes, argillites, and slates of the Maitai series, to which may be assigned a Trias-Jura age. This time classification is based almost entirely on the similarity of the lithological character of the rocks to those with undoubtedly Trias-Jura fossils. This is, however, supported by the author's finding a fragment of dark-coloured argillite in the high country between the Godley and Macaulay Rivers which shows the unmistakable sculpture of *Monotis salinaria*. Not only the primary and secondary ribs occur, but also the peculiar and regular cross-sculpturing, so that the author has no reasonable doubt but that it belongs to that important Triassic fossil, and the find thus confirms the age of the beds as deducted from their lithological character. The finding of this fossil, and other finds reported lately from Arthur's Pass and the Hawdon River, suggest a wide extension of rocks of this age over the mountain region of Canterbury; but it must not be inferred that all the rocks of that area are of the same age. The presence of heavy bands of conglomerate containing pebbles of greywacke, in close proximity to beds with these fossils and in apparent conformable relations, suggests that there is an older set of beds in the region of similar lithological character which have furnished these pebbles, and therefore lying unconformably under it. The contention of Hutton and others that two distinct series of rocks occur in the mountains of Canterbury is apparently correct, but much more field-work will have to be done before they are definitely separated.

On the east side of Lake Tekapo, especially in the Richmond Range, the rocks show a submetamorphic facies; and slaty shales with a somewhat lustrous surface occur, and in all probability they grade into the true phyllites exposed near Fairlie on the flanks of the Hunters Hills and in the Kakahu Gorge, which resemble closely the phyllites of that belt of Otago east of the schists. I have been informed by Mr. Pringle, owner of Richmond Station, on Lake Tekapo, that marble occurs just over the divide to the east of the lake, on the Rangitata slope; and if the identification of the rock is correct it means that the metamorphic belt extends much farther north than has been recorded previously. Much less is known of the geological features of the western side of the Rangitata Valley than of any part of Canterbury, so that the occurrence of marble may well have escaped observation. The beds to the north and east of Tekapo have, according to the observations of the author, a general north-and-south strike, with directions west of north occurring freely.

Two exposures of Tertiaries are recorded for the first time from this district—(1) that in Coal River, and (2) that occurring on the western side of the Macaulay River on the Sibbald Range.

(1.) *Coal River.*—Exposures of sands and clays with coal occur in several places in the deep gorge which Coal River has incised in the down country to the north-east of the lake, and chiefly in the vicinity of the right-angle bend which the stream makes as it leaves the Richmond Range and runs straight to the north-eastern corner of the lake. The exposures, five in number, occur in places along the two miles of gorge stretching both above and below the bend, but they are so masked by moraine that they cannot be traced away from the stream, and the relations of the individual outcrops to each other are obscure. The exposure lowest in the course of the stream is distant about three miles from the road-crossing. Here are exposed greyish-white sands of uncertain thickness, capped by gravels, brownish owing to the presence of iron-oxide, which are apparently unconformable; above them lies morainic matter.

On the north side of the river, at the bend, occur sands and sandy clays weathering white or stained brown. The strike is apparently N. 10° W., and the dip to the east 35°, but there is some doubt about this observation. On the south side of the river, about 100 yards up-stream, are sandy clays with carbonaceous shales; and farther up still, at the mouth of a small creek coming from the Richmond Range, there is a patch of much-slipped country showing sands and sandy clays, some with distinct greenish tint.

After the intervention of a barrier of greywacke, capped in places by white sands, similar beds to those just mentioned occur nearly a mile up-stream on the south side. The following sequence occurs here, in ascending order: (1) White sandy clay, 4 ft.; (2) clays with reddish tinge, 8 ft.; (3) impure lignite, with carbonaceous shale, 2 ft. 6 in.; (4) argillaceous sands, stained brown in the lower part, yellow above, 15 ft.; (5) whitish sands, thickness uncertain. These are capped by brownish gravels, which may be conformable, but the exposure is so limited that it cannot be determined for certain These are succeeded unconformably by moraine.

The strike of the beds is north, with a dip to the east of 45°. This patch of sedimentaries has a fault-contact on the south-east margin with the older beds, the fault running north-east and south-west, and its continuation may account for the presence of the beds in the bend of the creek, as their south-eastern border has the same line as the fault. This patch owes its preservation, in all probability, to having been faulted down, and having thus been preserved from erosive agents. How far it extends under the morainic material to the north and south of the river is quite uncertain, but brown gravels similar to those occurring near the stream are exposed farther north on the western slope of Mount Gerald, which suggests a continuation of the beds in that direction.

(2.) *Stony Creek Beds.*—These beds lie on the floor of a corrie on the western side of the Macaulay Valley, which is drained by Stony Creek. They lie about 4,000 ft. above the sea. There are two occurrences, separated by a barrier of greywacke. The lower one consists of the following beds, in ascending order: (1) White argillaceous sand; (2) greenish sandy clay; (3) brown coal, 2 ft. 6 in. thick, striking north and south, and dipping west 35° (the coal contains pieces of ambrite); (4) whitish sand, with yellow stain; (5) white sand, very fine in grain, with small amount of clay; (6) grey sandy clay.

The country is much slipped and the deposit comparatively thin, so that the true relations of the beds are uncertain, and their enumeration is in all probability quite incomplete. This is emphasized by the fact that pebbles of quartz, like those from the quartz drifts of Otago, occur in other parts of the basin, but they were not noticed in the series given above.

About 200 ft. higher in elevation there is another outlier of uncertain size, consisting of several seams of coal. This has a pitchy lustre, conchoidal fracture, blackish-brown colour, and contains numerous pieces of ambrite. Several of the seams are 2 ft. in thickness, and may be more. They are interstratified with carbonaceous shales, and lie on green sandy clays, which in turn lie on greywacke. The whole thickness of the beds is at least 100 ft., and may be much more, as the surface is masked by debris. The strike is north-east, and the dip north-west about 35°. It was just below this occurrence that the fragment of rock was found showing the sculpture of *Monotis*. The greywacke here strikes north-west.

These two patches are evidently the remnants of a much larger deposit which filled a considerable part of the cirque, the great size of which is evidently due to the fact that it was an area of easily eroded beds. The remnant is a very small one, and is rapidly disappearing. This observation is confirmed by the experience of Mr. Pringle, who accompanied us on our visit to the spot and stated that since he last saw it, some twenty years ago, the floor of the basin had completely changed and a great deal of the beds containing coal had disappeared. In the great snow winter of 1895 he had packed down half a ton of this coal for use at the Lilybank Station when supplies were short owing to the break in communication, and he said that it burnt excellently. If it were not in such a remote locality no doubt the deposit would have been used up long ago.

On both sides of the Macaulay between this and the lake are extensive deposits of brownish gravels antedating the glaciation. The pebbles are chiefly greywacke, but quartz is also an occasional constituent, although no quartz-bearing rocks are now found in the locality. These are evidently remnants of a much more widely extended sheet which has been swept away by glaciation.

In none of these occurrences of Tertiary sediments were any marine fossils found which might definitely prove that the beds themselves were of marine origin. They resemble very closely the deposits described by McKay (1882, p. 62) as occurring in the lower part of the Mackenzie country near Lake Ohau and in the Wharekuri basin, and classified by him as "Pareora," or of Lower Miocene age. As far as the deposits at Wharekuri are concerned, considerable doubt has been thrown on McKay's account by both Park (1905, p. 499) and Marshall (1915, p. 380)—which is unfortunate, seeing that the Wharekuri basin is in the same river-valley as the Mackenzie basin, and the explanation of the origin of one might support that of the other. However, the deposits laid down in the basins of Central Otago, as described by Hutton (1875, p. 64) and Park (1906, pp. 15–19, and 1908, pp. 31–33), are so similar that a common origin is suggested. Hutton (*loc. cit.*, p. 64) notes the similarity of the Otago deposits to those at Lake Ohau, and thus incidentally confirms the resemblance of the Tekapo beds to those of Central Otago. He classifies the latter as of Pliocene age.

There is thus a possibility that the beds occurring in the Tekapo district are of Pliocene age, though it is possible that the age of the Otago lacustrine (so called) beds has not been definitely determined up to the present, and that this opinion may have to be revised.

McKay was correct in suggesting (1884, p. 62) that considerable areas of his Pareora gravels and clays underlay the moraine which covered a considerable area of the plains, seeing that remnants of this deposit have now been located near their upper margin. Up to the present the valley of the Tasman River has yielded no positive evidence of the existence of these beds, but the character of the slopes about Braemar is such that similar Tertiaries might be located beneath them.

There is thus direct evidence of the structural origin of the basin, apart from that suggested by its form; but the special point left to consider is the date at which it took on this form—that is, whether it antedates or postdates the time of deposition of the beds contained therein.

Hutton (1875, p. 64) was firmly convinced that the areas were basin-shaped before the deposits were laid down in them—that is, they were of pre-Pliocene origin—just as he maintained that the Canterbury intermounts were pre-Tertiary (1885, p. 91). In this he was followed by McKay (1884, pp. 76–81) and by Park (1905, p. 523; 1906, p. 9; 1908, pp. 17 *et seq.*), who restated his position in his *Geology of New Zealand* (1910, pp. 141–44). The latter evidently dates the formation of his block-mountain system of Otago and the Wharekuri basin to pre-Pliocene times, although he gives in numerous places instances of the beds concerned having been involved in faults and other deformations which may well have originated or have been attendant features of the formation of the basins.

On the other hand, Marshall (1915, pp. 380–81) has expressed the opinion that some of the basins, such as that at Wharekuri, were formed after the deposition of the Tertiary sediments, and that the landscape as it now exists has no resemblance whatsoever to the form of the surface when deposition was going on. This opinion has been strongly supported by Cotton (1916, pp. 316–17, and 1917, pp. 249 *et seq.*), who points out that the evidence for the basins being filled with lacustrine sediments is extremely slight, and that they were subjected to deformational movements after deposition, and that the dominant surface-features result from the faulting-down of blocks covered with a non-resistant veneer of Tertiary sediments which were preserved in the low-lying basins resulting from this faulting, whereas on the higher elevations it was completely or almost completely removed by erosive agents. In this paper, too, he endorses the statement that the upper course of the Waitaki River occupies a broad tectonic depression, and apparently accepts Kitson and Thiele's explanation of its origin, although this conflicts somewhat with his explanation of the origin of the basins of Central Otago.

The most important piece of geological evidence, apart from the physiographical, is that furnished by the character of the deposits themselves. There is a widespread absence of coarse sediments in the basal beds of the basin—sediments suggesting a mature topography and the absence of high land in the vicinity of the area of deposit; and if this contention is correct the landscape must have been entirely different from what it is now. It is inconceivable that sediments could have been laid down in basin-shaped hollows as at present existing without, in some parts of the area, coarse conglomerates forming an important element in the lower members of the series. Again, the presence of numerous quartz pebbles in conglomerates like those in the Macaulay Valley, evidently strangers to the district, cannot be easily explained unless the drainage directions were considerably different at the time of deposition from what they are at present. These geological features are not explained on the hypothesis that the "lake-basins" were formed before they were loaded up with sediments.

Again, the height at which these sediments occur in the Tekapo region is most striking. In Coal River they are 3,500 ft. above sea-level, and in Stony Creek 4,200 ft.—that is, 2,700 ft. above the floor of the lake. These deposits, especially the latter, could not have been deposited were the form of the Mackenzie basin at all like that at present existing. If the basin had been filled up to this level it would imply the removal of an enormous amount of material by glacier erosion subsequent to deposition, and this amount is too great to have been removed without leaving more than two slight traces of its former presence in the Tekapo area, even if we grant that glaciers have great powers of erosion. Some remnants other than those would be present, tucked away in some sheltered corner of the mountains out of the line of action of the ice-flood. If warping be called in to modify the form of the basin this argument falls to the ground. It is remarkable, however, that the remnants occur in a region where the mountains are highest.

If due regard be paid to the character of the deposits it will be evident that the Mackenzie country looks rather to Otago for its nearest relatives, though similar areas occur farther north in Canterbury. In these, limestones are a dominant geological feature; whereas in Otago they are almost absent, the occurrence of patches like that at Bob's Cove, on Lake Wakatipu, being quite exceptional. The occasional occurrence of marine shells, however, shows that the sea extended over the area. The presence of conglomerates at the close of the cycle of deposition indicates that fairly high land was in existence at that time; and, as similar gravels are found closing the Tertiary sequence over a great extent of country to the east (*e.g.*, the Kowai* series of North Canterbury) and to the west of the Alps, as described in various bulletins of the Geological Survey, it is reasonable to think that the movements which resulted in the final formation of the Alps commenced towards the close of the Pliocene period and continued into the Pleistocene, and therefore that the intermounts date from that time. The final form of the landscape resulted largely from the influence of glaciation on the structural features then formed.

Little evidence of the direction of the axes of deformation is afforded by the Tekapo district. There is nothing to support the contention of Edward Dobson that the orientation of the valley of the Godley was initially determined by tectonic movements, although I came across nothing against it. The axis of the valley, however, seems to correspond with the general strike of the greywackes and associated rocks.

The latest observed deformational movements that the district experienced are on north-east and south-west lines. The strike of the coal-beds in Stony Creek, and also the fault-line which bounds the occurrence in Coal River, have this direction. From the limited and unsatisfactory nature of the exposures in the latter locality the general strike of the beds cannot be accurately determined, but the even and regular slope of the north-west side of the Richmond Range suggests that it corresponds with some fault-line; and, further, if such a line be granted to exist, and its direction

* NOTE.—I have retained the spelling for this term in the form as applied originally by myself to the series developed in North Canterbury, although Dr. J. A. Thomson has criticized it and replaced it by another spelling in his paper on the "Geology of the Middle Waipara and Weka Pass District" (*Trans. N.Z. Inst.*, vol. 52, p. 334, 1920). The spelling used by me is that originally used by Haast, and is also that in official use for the past thirty years not only for the river, but for the district, now merged into a county. It is that which appears on all recent maps issued by the Survey Department. Further justification is, I think, unnecessary.

be followed into the Rangitata Valley, it is found that the steep tent-sided face of the Ben Macleod Range, which forms the southern boundary of the Forest Creek valley, is in actual alignment with it. This striking surface-feature cannot be accounted for as the result of stream or glacier erosion, but if faulting be granted it would also explain the subdued character of the surface which lies to the south of the Mesopotamia homestead, this having been lowered as a result of the earth-movement, and it would also help to account for the form of the Rangitata intermount. Further, if the line of the north-west face of the Richmond Range be continued to the south-west across Lake Tekapo it will pass along the north flank of the isolated Mount John, and bound the considerable area of flat country which lies between that elevation and the Mistake Range, which may also owe its form to having been faulted down. This is a pure speculation, but the peculiar position of Mount John requires some explanation, and it seems impossible to account for it as the remnant of a spur or extension of the Mistake Range, with the connecting-ridge removed entirely by normal glacial erosion.

In concluding, I should like to express my indebtedness to Mr. James Pringle, of Richmond Station, who not only gave valuable information with regard to the district, but also kindly provided means of transport so that the most was made of the time at my disposal.

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