Art. XXXVI.—*The Intermontane Basins of Canterbury.*

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[For important places mentioned in this article, see accompanying map.]

In his admirable paper on the "Physiography of the Middle Clarence Valley," published in the *Journal of the Royal Geographical Society*, September, 1913, Mr. C. A. Cotton discusses the origin of the Kaikoura Mountains, and considers that their main features have resulted from the following sequence of events: (1) Denudation of a deformed mass of Triassic rocks; (2) deposition of the covering strata; (3) orogenic uplift; (4) a cycle of erosion which he terms the "great denudation"; (5) regional uplift of relatively small amount; (6) renewed denudation.

From this it is apparent that the author considers the area now occupied by the Kaikouras to have been covered by the sea in early Tertiary times, and that during this submergence a veneer of relatively weaker beds was laid down over these older rocks which had previously been either partially or wholly reduced to a peneplain. Subsequently an orogenic uplift took place, and the relatively weak beds were removed from the higher exposed ridges, and were preserved at lower less-exposed levels, where they now form strips occupying the floors of the main valleys and part of the flanks of the adjacent ridges, or form a fringe on the seaward side of the outer range of this mountain mass.

As the author of the paper referred to applies this explanation to the country to the south-east of the Kaikouras on the borders of North Canterbury, and suggests a similar origin for various important physical features of that district, the present paper has been written with the object of examining how far these principles may be applied to the country farther south, and what modifications, if any, must be made to frame a satisfactory explanation of those features. As most of the evidence bearing on the question will be furnished by an investigation of the conditions obtaining in the case of the intermontane basins of the province, a consideration of their features is a requisite before a proper conclusion on the point can be arrived at.

We find in various parts of the mountain region of Canterbury and its adjacent districts small outliers of sedimentaries of Cretaceous and Tertiary age, consisting of members of the following sequence, which in its complete form comprises the following, starting from the top:—

7. Calcareous gravels, sands, and shell-beds.
6. Sands more or less consolidated and passing downward into—
5. Grey Marl.
4. Limestone, glauconitic in its higher parts, and argillaceous in its lower; the lower member frequently absent.
3. Greensands.
2. Sands and clays, the former frequently sulphur-bearing, and with large numbers of rounded concretions containing saurian remains.
1. Clays and conglomerates with coal.

These rest everywhere in the Canterbury region on folded sedimentaries of Trias-Jura age or on volcanics which have penetrated and overlie these sedimentaries. It must be noted, however, that the sequence just quoted is rarely complete, and that, as is natural in a country which has been exposed to active erosion for a considerable period, it is the lower members which are most frequently in evidence. The number of remnants of these beds is somewhat large, and they are usually placed in basins either partially or wholly surrounded by the Trias-Jura rocks. The chief of these basins are the following: Hanmer Plains, Culverden Plain, Castle Hill basin, the Mid-Waimakariri, the Upper Rakaia, Lake Heron, Mid-Rangitata, Upper Pareora; but there are others of small size which have an important bearing on the problem.

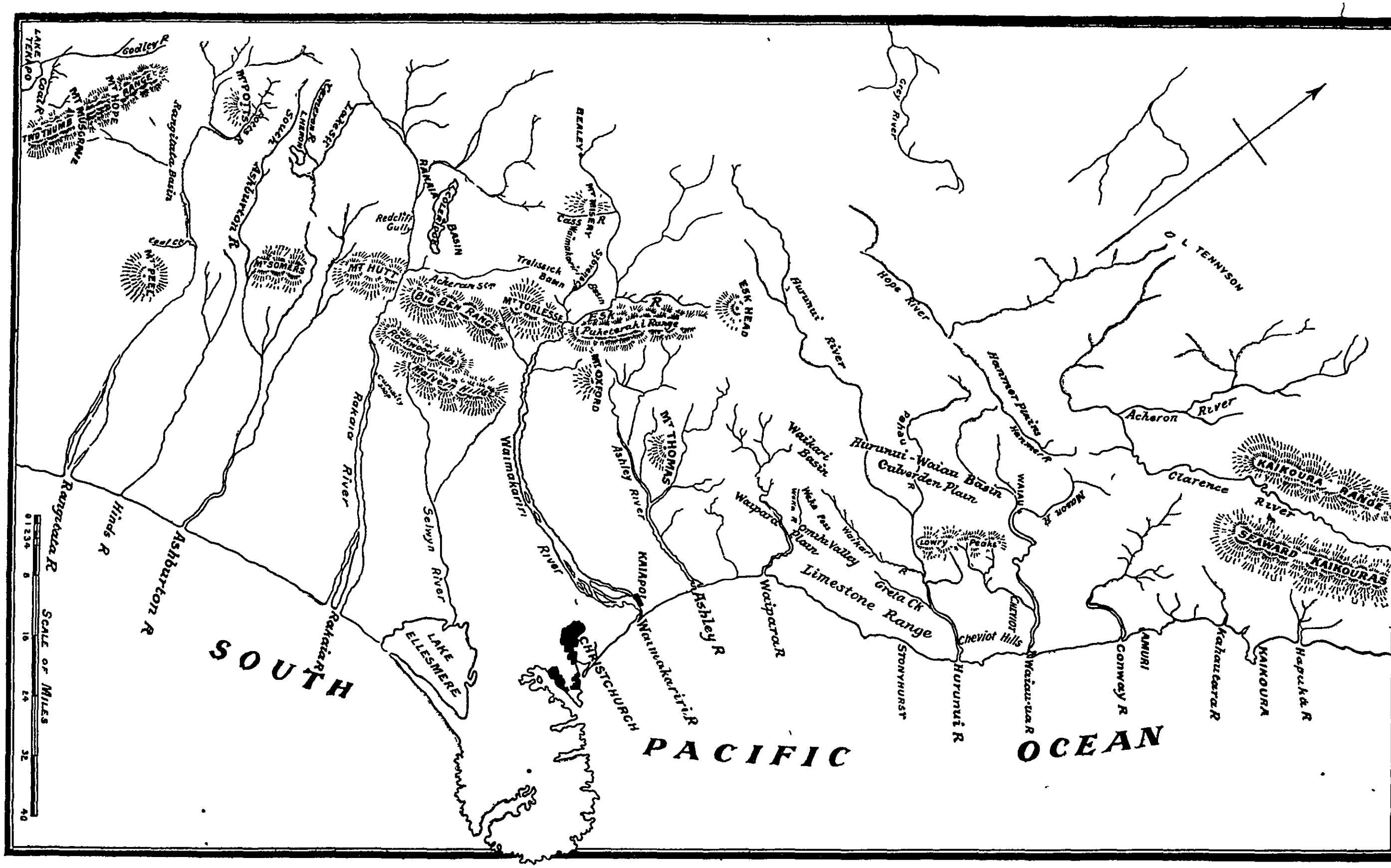
The two suggestions that have been put forward to explain their occurrence are,—

1. They are the remnants of a widely distributed cover of Tertiary beds which once masked the greater part of the surface of the country. Since they were weak structurally, they have been removed from the higher and more exposed parts of the country by ordinary erosive agents, such as frost and rain, but more especially by the abrasion of the great glaciers which in Pleistocene times filled the valleys. The isolated fragments of this covering are only to be found in positions where they were more or less shielded by the form of the ground from these erosive agents.

2. They have always been in the form of discontinuous deposits, and represent materials which have been laid down in isolated areas which were invaded by the sea, the basins having been eroded in pre-Tertiary times, and were, during the time of deposition, bays, gulfs, or straits belonging to a more open sea; and these basins had even at the time of deposition a form closely approximating to that which they have at present.

The first suggestion has found its strongest support up to the present from Cotton. There are suggestions, however, in the writings of others that the idea had occurred to them. Cox, for instance, in his "Report on the Geology of the Clent Hills District" ("Report of Geological Explorations," 1877, p. 107), notes the wide extent of the Cretaceo-tertiary series in that district, and concludes that they have not filled valleys of erosion owing to their presence at higher levels. Later, however, he departed from this opinion, for in his report on the same district in 1884 ("Report of Geological Explorations for the Year 1884," p. 43) he evidently regards the basins in which the Awamoa and Pareora beds were laid down as having much the same form as at present, for he considers the sea had access to the basin by way of the Rangitata River and the Pudding-stone Valley, and neither by way of the Rakaia nor by the Ashburton Gorge, which was not cut at that time.

Park apparently occupies a middle position, which results from his division of the Cretaceo-tertiary sequence of beds into two great series with an unconformity between them. This he places finally between the glauconitic limestone (Weka Pass stone) and the argillaceous limestone (Amuri limestone). He regards the series closed by the latter beds as his Amuri system, which was laid down in basins of previous formation, for he says ("Geology of New Zealand," p. 88), "The Cretaceous beds, although deeply involved in the faults that follow the foothills of the Inland Kaikouras, take no part in the tectonic arrangement of the rocks of the Hokonui system, but rest against them as marginal deposits that follow the strand


SOUTH PACIFIC OCEAN
LAKE TEKAPO
Godley R
Coal R
MT HOPE RANGE
MT MUSGRAVE
TWO THUMB
Rangitata Basin
MT POTTS
South Ashburton R
Lake Stt
Lake Heron
Redcliff Gully
LAKE COLERIDGE
BASIN
RANGE
Coal Ck
MT PEEL
MT SOMERS
MT HUTT
Acheron St
BIG BEN RANGE
MT TORLESSE
Rockwood Hills
Malvern Hills
Trelissick Basin
ESK R
Puketeraki Range
ESK HEAD
MT OXFORD
BEALEY
MT MISERY
Cass R
MT THOMAS
Rangitata R
Hinds R
Ashburton R
Rakaia River
Rakaia R
Selwyn River
Waimakariri River
Ashley River
LAKE ELLESMERE
CHRISTCHURCH
KAIAPOI
Waimakariri R
Ashley R
Waipara R
Waipara
Waikari Basin
Omihi Valley Plain
Limestone Range
Greta Ck
STONYHURST
Hurunui River
Hurunui R
Hurunui-Waiau Basin
Culverden Plain
Lowry Peaks
Cheviot Hills
Waiau-ua R
Hope River
Grey River
Hanmer Plains
Hanmer R
Mason R
O L TENNYSON
Acheron River
Clarence River
KAIKOURA RANGE
SEAWARD KAIKOURAS
Conway R
AMURI
Kahautara R
KAIKOURA
Hapuku R
SCALE OF MILES
0 1 2 3 4 8 16 24 32 40

of the pre-Cretaceous sea, invading even the narrow tortuous fiords that stretched far back among the mountains of that date, as, for example, into the Trelissick basin and along the ancient rift-like Clarence Valley."

Again, on page 98, he says, "The marginal distribution of the rocks of the Karamea system; the manner in which they ramify into and around the narrow fiord-like valleys in Nelson and Otago; and the mantling sheet they form in western Nelson, gradually ascending from sea-level up to 4,000 ft. on the higher slopes of the main divide, seem to afford indubitable evidence that the main tectonic features of the country were already determined before the advent of the Cainozoic epoch." However, when referring to the folded limestones at Bob's Cove, Lake Wakatipu, he says (page 100), "Here we have a portion of a marine littoral involved in a great crust fold, and elevated to a height exceeding 5,000 ft. above the sea, affording clearest proof that a sea-floor existed in the early Miocene where the Richardson Mountains now stand."

Later, on page 144, he points out that marine conditions extended over a great portion of Central Otago, and that the block mountains were formed not by the subsidence of the portions of an elevated plateau, but by the uplift of the adjacent strips of territory.

It is apparent from these statements that Park certainly regarded Central Otago as a sea-bottom in Tertiary times, and that the marine deposits of Canterbury were laid down in arms of the sea, and were not the remnants of a widely extended overlying sheet.

McKay, in his report of the Trelissick basin (Geological Reports for 1879–80, p. 59) regards this basin as the result of movements accompanying the elevation of the surrounding mountains. Elsewhere in his reports McKay appears to consider that the Tertiary sequence of beds was more widely distributed, and that the remnants occurring in other places, such as in the Clarence Valley, were due to strips being preserved owing to their being let down along the lines of fault to levels where they were less exposed to eroding agents.

In connection with this, Hector states in his progress report for the years 1888–89, p. liv, "The evidence collected is, it must be admitted, strongly corroborative of the theory that the Cretaceo-tertiary and Amuri rocks once spread over the whole district, from the mountains on the north-west side of the Awatere Valley to the eastern seaboard, and have only disappeared from the higher elevations of the two intervening mountain ranges on account of the intense denudation that must have taken place, and is still taking place."

And in connection with the Trelissick basin, Hector remarks (Progress Report, 1885) that "the presence of fault lines in other parts of New Zealand is shown by structural movements that have isolated areas of Cretaceo-tertiary and Upper Tertiary strata, such, for instance, as the Trelissick area, which has been erroneously described as a basin."

Marshall gives no definite pronouncement as to the origin of these basins, but in his "Regional Geology," page 41, he insists on the presence of land of considerable extent, bold coast-line, and small rivers, while the glauconitic members of the middle of the Tertiary series were being laid down, with the sea in the area of deposition of approximately 200–300 fathoms deep. He notes, too, the extreme variability of the character of the deposits, the great thickness of conglomerate on the west coast of the island, the remarkable changes in the thickness of such beds as the Grey Marls, but concludes that the land-surface was depressed after longcontinued erosion. He makes no statement as regards the condition of deposition from which one could conclude that the land-surface was even approximately resembling that which exists now.

The strongest supporter of the theory that these beds were laid down in pre-Cretaceous-formed inlets is Captain Hutton, for he nowhere expresses any doubt as to their origin. The only exception to this statement is in connection with the Hanmer Plains, which he attributed to a local subsidence, and not due to the erosive action of glaciers (Geological Reports for 1874, p. 54). In the same report he accounted for the formation of the Hurunui Plains by the erosive action of the sea on beds which were relatively weak. He attributed at one time the basins at Wharekuri and at Castle Hill to erosion of glaciers, but he afterwards abandoned this idea. His most definite statements, however, are made in his paper on the "Origin of the New Zealand Fauna and Flora," which appeared in the *Annals and Magazine of Natural History*. He there maintains (page 91) that the erosion of our mountain valleys such as the Rakaia was more profound in pre-Cretaceous times that at present, and that the patches of Tertiary rocks were formed in them when they were inlets of the sea. Again (Trans. N.Z. Inst., 1886, p. 411), he attributes the formation of the Trelissick basin to a pre-Cretaceous river, not to glacier erosion, and suggested that the sea entered the basin not by way of the Rakaia and the Acheron River, but by the Waimakariri and Craigieburn.

In vol. 43 of the "Transactions of the New Zealand Institute" (1911) there is a paper by Henderson on "The Genesis of the Surface Forms and Present Drainage-systems of West Nelson," which has some bearing on the question, since the author refers therein to the whole mountain region of the South Island. The arguments are somewhat difficult to follow, since all the grounds on which the conclusions are based are not fully stated, but the author evidently regards the Cretaceous and Tertiary deposits of the restricted area which he describes as having been laid down in rift valleys. He says (page 312), "The land seems to have been above sea-level till Tertiary times, when depression permitted the inroads of the sea into rift valleys which had already been formed. Deposits accumulated in these rift valleys. . . . When these last [limestones] were formed the land-surface of what is now west Nelson was represented by a series of base-levelled islands; to the east what is now the long line of the alpine peneplain rose from the shallow sea. Elevation now took place."

According to this statement, Henderson evidently regarded the limestone as laid down in rift valleys, but that the land was gradually reduced to the peneplain form, and the absence of detrital sediments in the limestones was due to the low relief of the land. He further suggested that the elevation which succeeded the deposition was differential, that blocks were elevated unevenly, and that the pre-Tertiary lines of fault again became active.

The question of the origin of these intermontane basins is discussed very briefly by Kitson and Thiele in a contribution to the *Geographical Journal* of the year 1910, dealing with the origin of the Upper Waitaki basin. Their conclusions are thus stated:—

The past geological history of the lake region in general of the South Island is probably as follows:—

1. Middle Mesozoic alpine folding, accompanied by fracturing, probably of a radial character. Some faulting along these lines.

2. Pre-Cainozoic dissection; valleys formed principally along lines of fracture of fault. Some features of many of the existing valleys and basins impressed.

3. Early Cainozoic subsidence, with infilling of valleys; marine transgression, the sea invading some of the depressions.

4. Middle Cainozoic uplift started, continuing with minor fluctuations to the present time. Faulting, with probably some warping, during middle and late Cainozoic times. Many of the old lake basins modified.

5. Advance of glacier conditions in late Cainozoic; existing lake basins and valleys modified by erosion and deposition.

The final summary of the authors suggests that the Waitaki basin is due to pre-glacial erosion, faulting, with probably some warping, modified by glacial action.

After a careful consideration of the opinions of these authors thus expressed, one must come to the conclusion that they have regarded this basin as chiefly formed in early Tertiary times, and that the Tertiary deposits were laid down in arms of the sea which penetrated it at a later date.

Seeing that there has been this discrepancy of opinion, it has been considered advisable by the present author to consider the evidence now available which bears on the question, and to bring forward additional facts which may help to elucidate the matter.

In all probability the best course to pursue will be to take the case of several of these basins in turn, and point out their special features. As the most distinctive of these is the Castle Hill or Trelissick basin, it will be considered first, and then reference will be made to the other areas in turn that may be considered as likely to furnish facts of importance.

TRELISSICK OR CASTLE HILL BASIN.

This basin lies behind Mount Torlesse, between it and the more westerly Craigieburn Mountains, and is perhaps the most remarkable of all of the intermontane basins. It forms an enclosed roughly oval-shaped space of about five miles long by three broad, surrounded on all sides by mountains which reach a general height of between 6,000 ft. and 7,000 ft. It is only towards the north-east that this ring is at all broken; in that locality there is a low saddle, composed of Trias-Jura rocks, which separates it from the Craigieburn district and the adjoining Mid-Waimakariri basin.

The structure of the Trelissick basin has been dealt with by both Hutton and McKay, but unfortunately neither of these geologists examined all parts in detail, and there are several discrepancies between the descriptions of these observers and the actual facts. In general, it appears to me that McKay's account is the more correct of the two.

The general sequence of beds, in descending order, is as follows, according to Hutton, and is confirmed with slight modifications by the observations of McKay and of the present writer:—

Pareora—
- Blue shales (plant-beds).
- Soft grey sandstone.
- Grey sandy clays and shales.
- Lignite.
- Grey sandstone full of Lamellibranchs.
- Grey sandstone, current-bedded.

Oamaru—
Limestone.
Volcanic grit.
Tufaceous greensands, calcareous tuff.

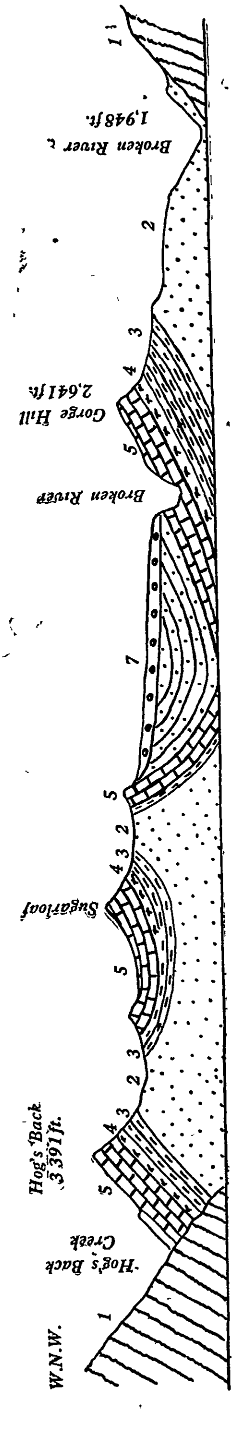
Waipara—
Argillaceous limestone.
Greensands.
Grey Marl.
White sandstone.
Green sandstone with concretions.
Sandstones, with *Ostrea* and *Conchothyra*.
Sandstone with lignite.

The approximate thickness of the Pareora beds is 500 ft., of the Oamaru beds 150 ft., and of the Waipara beds about 1,600 ft.

Unconformities have been put in various places by different authorities, but it appears to me that the beds are physically conformable throughout, the only dislocations being those attributable to volcanic action or to faulting or folding movements; in some places, however, obscurities occur, the elucidation of which may ultimately lead to a revision of this statement. I have specially in my mind the absence of the upper limestone over considerable areas. The general lithological nature of the beds indicates that the sea of the region gradually became deeper, the maximum being reached during the deposition of the limestones, after which shallowing succeeded, whether by uplift of the bottom or by aggradation has not been determined. This shallowing was followed by a slight deepening towards the close of the period of deposition, and when the land finally emerged at the close of this cycle of deposition it probably remained permanently above the sea.

The most striking feature of the beds is the absence of coarse sediments such as would occur were the conditions of the surrounding country, or even the height of the land relative to the basin, at all similar to those now existing. The actual presence of land is proved by the sandy beds and by the lignites, the last-named being also noteworthy as they occur at two distinct horizons. This shows that at least on two occasions shore-lines were near the area. A somewhat interesting constituent of the coal-bearing beds in the Craigieburn Gully (which is a small outlier of the basin across a low pass to the north-east) are rolled fragments of rhyolite. Now, no occurrence of rhyolite *in situ* has been found inside the basin or nearer than the Rakaia Gorge and the Malvern Hills. Between these localities and Craigieburn, which are nearly twenty miles apart, there lies a continuous ring of mountains rising at times to a height of 6,000 ft., and it seems impossible, as noted by Hutton, that these pebbles could be transferred under present conditions of relief. In confirmation of the movements of these pebbles I have recently been given a pebble of rhyolite of similar nature picked up in the bed of a small creek near the outlier of coal in the Acheron River in the Rakaia basin, which has been carried in some similar way. It could not have been carried under the present conditions. Hutton was fully aware of this difficulty, as may be seen from a reference to his report on the Trelissick basin.

Then, again, if we assume, with Hutton and others, that physical breaks occur, we should expect, were the relief the same as now existing, or if it resembled it to some degree even, that basal conglomerates and other relics of the existence of land should occur in some parts of the basin at the points where discordance occurred. The limestones are of a resistant nature, and fragments of them should certainly appear in the overlying beds. Their absence furnishes either strong probability of the continuous deposition of sediments in the area or positive proof that the relief of the land relative to the basin was far different from that existing now. So that one at least of Hutton's hypotheses appears to be untenable.



SECTION FROM HOG'S BACK ALONG WATERFALL CREEK AND BROKEN RIVER, TRELISSICK BASIN.
1. Greywacke. 2. Greensands and coal. 3. Marls and sands. 4. Tuff. 5. Limestones. 6 Calcareous sands and shell-beds. 7. River-gravels.
Length of section, four miles (approx.).

The structural evidence is also somewhat important. There is definite proof that the rocks of the area have been subjected to decided folding movements, the general result being analogous to what would happen were a layer of plastic clay placed flat on the palm of the hand and the palm closed slightly. The harder and more resistant limestones show this admirably, faulting, both normal and reversed, the latter exhibiting decidedly flat fault surfaces, and overturned folds show the intensity of the lateral pressure. This is clearly seen on the western side of the area, between the upper part of Broken River and the Hog's Back Creek, but especially so in the country between the latter and Waterfall Creek. Where the limestone band crosses Broken River, about a mile above the ford on the road, it has been tilted till it stands almost vertically, and a portion has been displaced towards the centre of the basin relatively to the lower member, the plane of rupture being almost horizontal. Farther up the river the line of outcrop of the limestone takes the form of a letter S, and in the deep, narrow, precipitous gorge of Waterfall Creek there are several small faults at points where the strain was probably the greatest when the folding took place. In the Hog's Back Creek the limestone is slightly overturned, but on following the outcrop north the dip slowly diminishes till it becomes a moderate one to the west when the Waterfall Creek is reached (see accompanying section). It must be noted that the interpretation of the structure, advanced by Hutton on hearsay evidence as to the locality, is not borne out on a closer examination on the spot. Farther south in the basin, in the upper portion of Whitewater Creek, there is a detached mass of limestone, dipping to the west, whose presence can only be explained by supposing that a fault has been run along the western margin of the area, in close proximity to the Trias-Jura rocks, and isolated this remnant from the main mass of limestone which forms the crest of Castle Hill. This line of fault can be traced up Coleridge Creek to the extreme south-west corner of the area, as is evidenced by the blocks of limestone with westerly dip left in isolated positions high up on the western side of the valley of this stream. The straight alignment of its walls is strongly suggestive of glacier action, but there is no doubt its original form was determined largely by the fault-line.

The centre of the basin is masked by an overburden of Recent shingle and other river deposit, and on the eastern side the dip of the beds is inwards as a general rule, but in one or two cases, as at the gorge of the Porter River, it is almost vertical; on the whole, however, the folding is less pronounced on the eastern margin of the basin than on the west.

Farther east, in the lower part of the Broken River Valley, are outliers of the coal-measures belonging to the lower part of the Tertiary or the Upper Cretaceous series, as is clear from the presence of *Conchothyra* and other fossil molluscs. These have evidently been folded on axes running in a general north-and-south direction, and the surface on which they were laid down shows evidence of considerable warping. The coal-measures usually occupy the lower levels of deep valleys, where they have been protected from denuding agents. There is some evidence of faulting, and in one case at least, in the bed of Sloven's Creek, the Trias-Jura rocks have been bodily pushed over the Tertiaries from the eastward. It is extremely probable that both of the parallel valleys of Sloven's and Winding Creek have been determined by faulting. In one or two places there occur, intercalated in the greensands which overlie the coal, irregular beds of angular greywacke pebbles up to 3 in. in diameter which cannot have travelled far from some exposed rock-surface; but, judging from the lie of the coal-beds, the surface did not resemble that which now exists.

The remaining portion of the Waimakariri basin, with whose features I am not at present as well acquainted as I should like, is no doubt of similar origin to the Castle Hill area. Fragments of coal-measures are found in various portions of it, and there is a great mass of limestone in the valley of the Esk River near Mount White, and, judging from its presence, as well as that of occasional small remnants of sedimentaries similar in character to the Pareora beds of the Broken River basin, it seems clear that these Tertiaries once covered the floor of this Waimakariri basin more or less completely, but have been removed almost entirely by erosive agents which were especially active in that locality in Pleistocene times and later. The Esk River limestone owes its preservation to being out of the sphere which was especially subject to glaciation, since there are everywhere signs that the intensity of ice-action fell off on the eastern side of the great mountain valleys, especially where their heads do not reach as far back as the main divide, but belong rather to the drier mountain region to the east. The boundary of this area on the eastern side is the great ridge of the Puketeraki Mountains, whose steep western faces and even alignment suggest an origin dependent on some great structural feature such as faulting. This would be quite in keeping with the features exhibited by other basins, where the eastern margin is determined by fault-lines while their western side exhibits folding.

The general results of this statement of the conditions governing the formation of the Broken River and its associated basins are,—

(1.) That land existed in the neighbourhood of the area at the beginning of the period of deposition, and that it also existed subsequently, although on some occasions the sea grew deeper.

(2.) That the land did not supply coarse sediments, and probably was of low relief.

(3.) That it was different in form from that now existing.

(4.) That the rocks of the basin have been subjected to faulting and folding.

(5.) That the Tertiary sediments are the remains of a once much more widely extended sheet.

(6.) That the general character of the beds and their structural features are those which might arise if the beds had been laid down on an old peneplain or plain of marine denudation, and that certain areas had been subject to either faulting or folding movements which depressed them below the level of this old surface, and that when elevation of the land took place these deposits occupied the basins of relatively less height far below the general level of the mountains.

(7.) This surface has been dissected by stream and glacier action as well as by other denuding agents, and the relatively weaker beds have only been preserved where the form of the ground sheltered them from these destructive agencies.

RAKAIA VALLEY.

In the main Rakaia Valley there are five outliers of the Tertiary beds if we neglect those in the valley of the Cameron River and near Lake Heron, which belong more properly to the Upper Ashburton and Rangitata occurrences. The former include coal-measures at the Acheron River, at Mount Algidus, at the Rakaia Gorge, all of which are now without limestone. These and the overlying sandy beds with shell-remains, similar to those in the Trelissick basin, are, however, preserved at Redcliff Gully, where, owing to their position, they have been out of the line of action of the ice-stream which once operated in the Rakaia Valley. Similar beds are also exposed at the Curiosity Shop, where the river has cut through the gravel of the plains about three miles below the gorge itself. These isolated fragments, occurring as they do in widely separated parts of that valley, are probably remnants of a sheet which once occupied it completely. They do not, however, furnish much evidence as to the circumstances of their deposition, the lower exposed members of the series being sands or clays, with the exception that at the Rakaia Gorge there are fairly coarse conglomerates, composed chiefly of fragments of rhyolite, similar to that which lies underneath the Tertiary series and forms the volcanoes of the Rockwood Hills and their various extensions. In the Redcliff Gully the beds have been subjected to faulting and folding of an intensity similar to that in the Trelissick basin. The limestone also has been elevated, till it now exists at a height of 3,700 ft. above the sea.

ASHBURTON-RANGITATA REGION.

There are in this district two areas which may be designated intermontane basins. These are the Lake Heron Valley, which extends from the vicinity of Lake Heron across the middle course of the South Ashburton River, and is bounded on the north-west by the high country stretching from Mount Arrowsmith, and on the south-east by the range which extends from the Rakaia River towards the Ashburton, and includes the following elevations: Mount Hutt, Mount Alford, Taylor Peak, Mount Somers, and the Clent Hills. This valley has connection with the Rangitata area by means of the Pudding-stone Valley and by the wide valley extending from Hakatere towards the Potts River.

The basin of the Rangitata includes the Mesopotamia country, and extends down the river to about eight miles above the Mount Peel Station. Both these basins are in all probability of structural origin, but have been modified extensively by glaciation. They contain numerous remnants of the Tertiary series, which, as originally pointed out by Cox, has no relation to the present form of the country. They are almost entirely of sands and clays with coal-seams, and only near Lake Heron and at Coal Creek, on the south bank of the Rangitata, are any covering limestones present The former limestones were classified as Miocene by Cox, and put in the Oamaru formation by Haast, and the latter, judging from its fossils, is of the same age as the Mount Brown limestone of North Canterbury, which may be correlated with the Mount Somers limestone. They are, therefore, in all probability of later date that the Malvern beds, and represent the gradual extension of the coal conditions over central and southern Canterbury. Remnants of the coal-measures are now found in the Cameron Valley; near Lake Heron; in the valley of the Smite Creek; near Clent Hills Station; in the valley of the Potts River. The last-mentioned outlier occurs at an elevation of about 3,000 ft to the north of the ice-swept and moraine-covered downs which stretch from Mount Potts in a south-easterly direction towards the river of the same name. The total length of the exposure is about 25 chains, with a maximum breadth of about 7 chains. The beds consist of sands and clays about 200 ft. in thickness, with several seams of brown coal, one of which is 18 ft. thick. They have a general strike in a north-west to south-west direction, with a dip to the south-west at an angle of about 60°; in some places this is a little flatter, but the variation may be due to slip. There is no capping of limestone present, nor was I able to discover any fossils, but from the general circumstances it is evident that the coal belongs to the same series as that at Mount Somers. The beds owe their preservation to having been faulted down and brought into such a position that they have not been subjected to the full intensity of the glacial erosion which other parts of the same valleys have experienced. A similar occurrence exists in the valley of a tributary of the Godley River, in the Mackenzie Country basin, which lies just across the Two Thumb Range, the dividing ridge between the Rangitata and Waitaki basins. In the country immediately to the west of the Lake Stream coal-measures are found up to levels of between 4,000 ft. and 5,000 ft., and these fragmentary occurrences are evidently the remains of a once widely extended sheet. As a rule they do not show much signs of dislocation, though there is no doubt that their position points to certain of them having been faulted down, and their persistence may be due to their having been thus removed from the operation of active erosive agents. Their frequent distribution at high levels, associated with occurrences at lower levels, is strong evidence that the sheet was extended over a surface unlike that now existing, and that the surface has been subject to serious dislocations. The evidence from this locality is strongly in favour of the wide distribution of a mantle of Tertiary beds, and is remarkably analogous to the conditions obtaining in Central Otago, where the quartz drifts and associated beds of Tertiary age are found at times depressed in hollows and again in close proximity acting as a capping to the flat-topped schist ridges.

WAIAU-HURUNUI BASIN.

This basin lies across the middle courses of the Waiau and Hurunui Rivers, and is perhaps the most typical of all those within the Canterbury area. The rivers have cut deep gorges through the barrier which bounds it on the east, and furnish a most interesting example of anomalous drainage. Cotton has suggested that the rivers were antecedent to the present land-surface, and that the gorges were cut as the surface was warped upwards. The other explanation, which was originally advanced by Hutton, is that it is a case of superimposed drainage.

The basin through which these rivers run extends for nearly thirty miles in a south-west to north-east direction, and has a maximum breadth of about eight miles, its elevation above the sea lying between 500 ft. and 800 ft. The greater part of its surface is formed by the combined aggraded flood-plains of the Waiau, Pahau, and Hurunui Rivers, but at one or two places the Tertiary beds rise through this covering. An extension of this basin lies on the south side of the Hurunui River, and reaches the Waipara River in the neighbourhood of Heathstock, with outlying portions in the Upper Okuku and Ashley Rivers; and another connection with it lies toward the upper head of the Waikari Creek, the dividing ridge being quite low, and constructed entirely of Tertiary rocks.

The general sequence of beds exposed in the area is as follows:—

(1.) Sands and clays, with beds of greywacke, gravel, and very occasionally impure coal. These are well exposed in the banks of the Pahau, on the western side of the basin, in the valley of the Mason River to the north-east, and in the deep gorges cut by the various tributaries of the Waipara River near Heathstock.

(2.) Limestones, frequently interstratified with volcanic tuffs. These are typically developed on the north-west side of the area between the Pahau and Waiau Rivers in the valley of the Mason, and near Heathstock. In the central portion, on the south-east flanks of Mount Culverden, they dip steadily to the south-east at angles of about 15°; farther west they have been folded into an anticline, and in the lower part of the gorge of the Pahau River the dip is to the north-west, but the directions are much disturbed by volcanic action. The limestone outcrop can be traced round the north side of the basin, across the Hurunui, and on the flanks of Mount Mason, but the outcrop is not continuously visible. In this last-mentioned locality the limestone is folded back sharply where it abuts against the Trias-Jura rocks of Mount Mason, although the general dip appears to be towards the south-east. On the south side of the basin, along the Hurunui River, the limestone has evidently been faulted down and covered up by gravels, but farther west it reappears, the fault grading into a fold, and the outcrop follows round the western end of the Trias-Jura mass forming the Mount Alexander Range and joins on to the Weka Pass stone near Waikari, which, when followed north-east down the Waikari Creek, forms one of the strips of limestone in the floor and on the north-west flanks of fault valleys which are so characteristic of this region of Canterbury. This fault also grades into a fold in the upper part of the Waikari Creek basin. There is a marked difference, however, in the fossil-content of the limestones in the Culverden area from those of the Weka Pass stone, for the former seem to accord more closely with those of the Mount Brown beds, which lie above the Weka Pass stone, a fact which is probably explained by the gradual and slow transgression of the sea over the Culverden area towards the north-west, the limestone, although continuously linked up with the Weka Pass stone, being deposited synchronously with the Mount Brown stone.

(3.) The limestones are followed by sands and gravel beds with bands of conglomerate composed almost entirely of greywacke. These are well developed in the Isolated Hills, where the stratification is much disturbed. They occur with regular dip to the south-east at Mouse Point, near Culverden, accordant with that of the underlying limestones; but they are folded into a well-marked anticline at Hurunui Mound; and they form low hills on the south side of the Hurunui, which extend towards the Waipara River along the eastern side of Mason Flat, and divide that part of the basin from the upper part of the Waikari Valley. These beds overlie the limestones conformably on the western end of the Alexander Range. On following the line of outcrop west past Hawarden and Horsley Downs, the dip becomes very steep to the west till on reaching the Doctor's Range of Trias-Jura rocks the dip is nearly vertical. This part of the basin appears to be formed of beds arranged as a syncline, with the eastern limb much more highly inclined than the western, a feature which appears to be almost invariably exemplified, for the eastern edge of these basins is determined by lines of faulting grading into steep folds. Similar arrangements of the beds occur in the Omihi Valley, in the Lower Waipara, which has its south-eastern margin bounded by a fault, but it is not seen in the Cheviot basin, which lies between the Waiau-Hurunui basin and the sea, being divided from the former by a range of older rocks and from the latter by a similar range, but the limestones pass right over this range without any marked signs of faulting or break. The arrangement of the beds in the Cheviot basin is synclinal, but as the Tertiary strata are followed south-west they exhibit faulting which accounts for the characteristic strip of let-down Tertiaries which occupy the valley of the Greta Creek.

The lithological and faunal evidence indicates clearly that land existed in the neighbourhood of this area at the beginning of the cycle of deposition; that the sea gradually extended over the area, followed by the shallowing of the sea and the deposition of littoral beds. These have been subjected to folding movements in which the underlying Trias-Jura beds are involved, so that the form of the land-surface on which the Tertiaries are laid down is quite different from that which now exists, but there is distinct evidence of the close proximity of land throughout the period of deposition. There is no sign, however, of any erosion of the underlying beds while the later ones were being deposited, judging from the absence of pebbles of limestone in the later deposits, so that it is unlikely that the movements to which the rocks have been subjected had commenced during the latter part of the period of deposition. Owing to erosion of the relatively weaker Tertiary beds, a large area of these rocks has been removed; but it is extremely unlikely that they extended over the whole area. Isolated peaks of Trias-Jura rocks no doubt existed as islands in this sea, but they were by no means as extensive as the present areas of mountains composed of these rocks. The basins have no doubt had an origin in deformational movements either of folding or faulting, both of these movements being closely related to each other.

Hanmer Plains.

This inland basin has generally been regarded as of structural origin, even Hutton admitting this as being extremely probable. That earth-movements have taken place in its vicinity is evidenced by the fault fissures of recent earthquakes, and by the peculiar strip of folded-in limestone which crosses the Waiau River at Marble Point, just below where the river issues from the basin.

CANTERBURY PLAINS.

There is a marked resemblance in general features between the aggraded flood-plain of the Hurunui basin and the Canterbury Plains, which perhaps may be regarded as a large intermontane basin, with the mountain barrier absent on the eastern side. There is some evidence that the plains have been formed by the deposit of gravel on a syncline of Tertiary rocks.

I have noted in the appendix to my paper, " Some Aspects of the Terrace-development in the Valleys of the Canterbury Rivers " (Trans. N.Z. Inst., vol. 40, 1908, p. 40), that there is a probable outcrop of coal-measures beneath the sea of the Canterbury coast, indicated by the frequent appearance in the trawl of the steam-trawler " Nora Niven " of large pieces of lignite or brown coal. These were obtained in depths of between 21 and 43 fathoms on a line following the coast-line and about twenty-five miles distant from it. Beyond the line where these were picked up the sea-bottom rapidly deepens, and it is probable that they have been torn from the edge of a submerged escarpment of Tertiary rocks where the coal will be in position. There is also on Banks Peninsula an outcrop of Trias-Jura rock, similar to that of the Malvern Hills, with overlying rhyolites of identical lithological composition. This, too, is overlaid, at the head of Lyttelton Harbour, at Quail Island, and at Governor's Bay by quartzose sands, whose age cannot be exactly determined owing to the absence of fossils, but it is perfectly possible that they represent similar sands associated with coal-measures on the western side of the plains. The shales with plant-remains occurring near Gebbie's Pass probably date from the same period.

A most persistent feature of the Tertiary deposits referred to above is the occurence at their base of a fairly fine conglomerate composed usually of pebbles of the underlying Trias-Jura greywackes. At Mount Somers, Rakaia Gorge, Malvern Hills, and in the Trelissick area rolled fragments of rhyolite of a kind which now forms mountains on the eastern front of the Alps from the Selwyn to the Ashburton River is a notable constituent of this conglomerate. The presence of these rolled fragments shows clearly that the existent masses of rhyolite in close proximity to these sedimentaries were a land-surface of considerable extent at the time when the coal-measures of Canterbury were laid down.

On the western slopes of the Alps the basal beds of the coal-measures contain an enormous thickness of coarse conglomerates, approximately 2,000 ft. (*vide* Bulletin No. 13, N.Z. Geol. Survey, p. 51). In this publication Morgan says, " Apparently the highlands supported glaciers, for somewhat outside the subdivision rocks corresponding to the basal conglomerates show glacial characters." He also points out that the land which furnished these boulders lay probably to the north or north-west; that there was then no Grey Valley, no Paparoa Range, and possibly no Southern Alps. As mentioned later, such a land may have formed the sanctuary where the Antarctic and Subantarctic elements in our flora found a refuge, at a time when the site of the present Alps was occupied by land of relatively low elevation.

It is to be noted besides, in places where the conglomerates do not occur, that sandstone beds at the base of the series are coarse in texture, and are indicative of the proximity of land. The presence of coal points to estuarine conditions, and to the existence of a neighbouring land-surface, whether the coal be formed from plants growing *in situ* or from drift material.

The beds succeeding the coal afford evidence of a gradual deepening of the sea, in which sand, greensand, and limestones were progressively laid down; but shore-line conditions must have obtained even then, for the limestone almost invariably thins out or disappears or is replaced by sandy beds as it is followed towards the old land-surface formed of Trias-Jura rocks.

It has also been noted by Hutton that at Stonyhurst a bed of conglomerate formed of subangular pebbles of slate lies between the Amuri limestone and the Weka Pass stone, thus showing that the shore-line was fairly close even at the time that the limestones were deposited in this area (Quart. Journ. Geol. Soc., vol. 41, 1885, p. 271).

It must be admitted, however, that the evidence of the presence of a shore-line is not apparent in all localities where the Tertiary sediments occur, but it is probable that the littoral deposits into which the limestone must gradually pass as it is followed landwards have been removed by denudation. The long strips in which this now occurs have been tilted by earth-movements, and now frequently occupy the floor and north-westerly flanks of the valleys, and the part which abuts against the more resistant Trias-Jura rocks has been necessarily more exposed to erosive agents working along the line of junction of the rocks, especially as the lower members of the overlying series consist of somewhat incoherent sands. There is a distinct suggestion of the former higher extension of these covering beds up the flanks of the mountains in the appearance of the landscape immediately above the present limits of the Tertiary beds, the most striking form being long valleys cut approximately parallel to the line of strike of the Tertiary beds by old subsequent streams operating along the line of junction of the two series, and for a part of their course incising the harder rock underneath. The character of the soil indicates that the limestones and associated beds once had a much farther upward extension than they now have.

A striking illustration of this is found in the valley of the Pareora River, about ten miles from Timaru. Here the Tertiary beds are found passing over the hills of Trias-Jura rock, arching with the rise of the ground and completely capping the tops in some cases, as at Craigmore, without any break in continuity owing to erosion; while farther north the uncovered greywackes project through the Tertiaries. This case is most interesting, as it shows that warping movements have taken place since the Tertiaries were laid down in that locality, and thus renders it probable that similar movements have taken place elsewhere within the Canterbury District, and increases the probability of the wider extension of these beds than exists at present.

After the deposit of the limestones the sea shallowed either by aggradation or by elevation of the bottom, for marls, sands, and coarse rubbly beds with fragments of shells, succeeded by incoherent sandy and marly beds with a littoral fauna, are widespread in Canterbury. It has been pointed out as well that in the Trelissick basin coal-beds occur among the upper members of the series, with marine beds lying on top, showing that the sea advanced over the area once more. It seems, therefore, perfectly clear that the deposits were laid down in the vicinity of a shore-line, but in all probability the land was of slight relief, or that the waters were sheltered from violent currents and waves.

However, in considering the question of the relief of the land as deduced from the character of the deposit, allowance must be made for the situation of the locality of deposition. Even on elevated coast-lines pebble beaches are frequently absent for long stretches, and therefore it is perhaps inadvisable to be dogmatic on this point.

It is found, however, that conglomerates form an increasingly important feature of the beds succeeding the limestones, and towards the end of the Tertiary era they dominate the sedimentaries. This is clearly seen in those places where the Pliocene beds are well developed, such as in the lower Waipara and Teviotdale districts and in the Mount Grey downs. The abundance of coarse gravels indicates the existence of higher land in the vicinity, but the strata containing them appear to be perfectly conformable with the older beds of the Tertiary sequence. This increasing content of Trias-Jura pebbles apparently indicates a rise of the land, but there is no certain evidence of any structural unconformity between these beds and the lower members of the Tertiary sequence. If the rise of the land had occurred this should be forthcoming, certainly as regards shore deposits, although it might be absent in the case of beds laid down in deep water offshore. Some slight variation in the conditions controlling the land-surface, rather than a great modification in the relief, would explain the increasing importance of the coarser materials.

After a careful consideration of the evidence, it seems fairly certain that a land, probably in the form of islands, did persist in the North Canterbury area throughout Tertiary times, although it is quite possible that a deep sea existed on the site of the Kaikouras, and that the deformations which resulted in the formation of those great ridges were less pronounced in the country to their south-west, and probably petered out in the mid-district of Canterbury.

There is another point which may be considered in this connection. Micaceous sandstones are a frequent occurrence in the Tertiary beds of North Canterbury, and the source of this mineral must be looked for elsewhere than in the Trias-Jura rocks to the westward. Although a small amount of this mineral occurs in these rocks as a detrital constituent, it does not seem sufficient to account for the large amount contained in the derived Tertiaries. Although it is a long way to the Chathams from the coast of Canterbury, yet mica and other schists do occur in those islands, and there may have been at one time a closer connection with similar rocks occurring in New Zealand, and the existence of a submerged schist area which might have furnished this material is by no means a remote possibility. If, however, we must look to the granite and schist areas on the west of the main divide to have furnished this material, then the form of the land-surface must have been entirely different from that which now obtains.

The presence of a land connection with the Chatham Islands in Tertiary is absolutely necessary in order to explain the close resemblance of the fauna and flora of these islands to that of New Zealand. Hutton suggested that the land bridge was in existence in Pliocene times, though it broke up soon after, this break being indicated by the fact that some of the Chatham Island species do show a considerable variation from their New Zealand relatives; and, further, there are species occurring in those islands which have not been discovered on the main islands. He therefore considered that the land connection was broken before the Pleistocene period began

This connection he attributed to an elevation of the sea-bottom synchronous with an elevation of New Zealand itself, which he postulated in order to explain the extension of the glaciers. It is reasonable to think that in mid-Tertiary times the Chathams were covered by the sea, from the occurrence of a limestone similar to that of New Zealand with a similar fossil fauna. The form of the land-surface of these islands suggests that subsequently they were base-levelled either by the sea or by subaerial agencies

Again, Cockayne, in his paper on the "Plant Covering of the Chatham Islands" (Trans. N.Z Inst., vol. 34, 1902, p. 316, footnote), says, "The occurrence on Chatham Island of *Coprosma chathamica*, so closely related to *C. petiolata* of the Kermadecs, and of *Rhopalostylis baueri* in both regions, if the identification of the latter be correct, suggests that they travelled along the coast, which would, *in the event of an east and north-east extension* of New Zealand, join the Kermadecs and the Chathams." There is good reason, however, to doubt the occurrence of *R. baueri* in the Chathams. In the same paper (p. 314, footnote) the author notes the occurrence of *Suttonia chathamica* at Stewart Island, a plant formerly believed to be restricted to Chatham Island; but in his report of the botany of Stewart Island the author is very guarded about this occurrence, and considers the possibility of the plant having been introduced by the Maoris, although he thinks this extremely unlikely. If this last contingency is excluded, the Kermadec-Chatham Island coast-line might be prolonged to Stewart Island, following the line of the submarine continental shelf; but it appears somewhat dangerous to base such a conclusion on the evidence from one or two occurrences of plants unless supported by other lines of evidence.

The presence of a land in Mesozoic times is rendered probable by the persistent appearance of granitoid and other rocks as boulders in strata of Jurassic age, and later, there being no known occurrence *in situ* in close proximity to these deposits which could have furnished these boulders. These deposits occur near Gisborne, in beds which are, according to McKay, of Lower Tertiary or Cretaceous age, but, according to Adams, of Upper Miocene age. They occur in Mesozoic strata near Cape Palliser; at Cheviot; in the valley of the Acheron and Rakaia Rivers; in the Pudding-stone Valley on the north side of the Rangitata; in the Malvern Hills; and in various parts of Otago; and it is probable that they have been shed from a land stretching east which persisted down to Tertiary times. If Adams's determination of the age of the Gisborne deposits is correct, then such a land most probably existed down to the middle of the Cainozoic era, for, as far as is known, the rock pebbles of these beds are not likely to have come from the Trias-Jura ranges to the west.

The origin of the native flora of the country must be considered fully before coming to any conclusion as to the relief of the land. It seems impossible for the Antarctic element to have established itself or to have maintained itself in competition with the Malayan element had the high land been completely removed during any part of the Tertiary era, unless there had been adjacent tracts of elevated country, now completely submerged, to which it might have moved as to a sanctuary; but the difficulty in the way of an invader obtaining a footing seems so great that it appears more likely that an area once peopled has not been subject to great modifications since the colonists obtained a footing. Migrations due to climatic change, or to changes due to the changed elevation of the land, no doubt occur, but very slowly. It seems clear, therefore, that high land must have existed continuously over parts of the South Island, or close to it, since the Antarctic element in the flora appeared, but that the form of the land-surface was entirely different from that existing now. The Southern Alps did not exhibit their present form. Indeed, it seems reasonable that after the first formation as a folded range, at the close of the Jurassic or the beginning of the Cretaceous period, they were reduced to a peneplain—this would take place towards the close of the Cretaceous period—and that on this peneplain the Tertiary beds were laid down; that subsequently they experienced vertical and perhaps differential uplift, with a certain amount of folding and undoubted faulting; and that the Tertiary sediments which now exist as discontinuous remnants in the intermontane basins are survivals of this covering sheet. It is not maintained that they formed a complete veneer over the whole surface, but that elevations that survived the period of erosion projected like islands through the Tertiary sea, and may in some cases have been sufficiently high to form sanctuaries for the Antarctic element in our flora.

ART. XXXVII.—*Recent Changes in the Position of the Terminal Face of the Franz Josef Glacier.*

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

[*Read before the Philosophical Institute of Canterbury, 4th November, 1914.*]

THESE notes as to the position of the terminal face of the Franz Josef Glacier are based on observations supplied to me by Mr. Alec Graham, one of the guides of our alpine region, who resides in the immediate vicinity of the glacier, and to him my sincere thanks are due.

In the year 1909 the officers of the Geological Survey, under the direction of Dr. Bell, made a complete map of the Franz Josef Glacier, and placed pegs in position so that the changes of the face could be regularly and accurately determined. The pegs are numbered in order from the western side of the glacier, and the relative movements of the ice at each since they were put in position are given in the following list, the original situation of each peg being given first for the sake of reference:—

No. 1.—On the steep rock-face on the western side of the front, at approximately 7 ft. above the ice and 3 ft. from it. This peg was placed near the edge of the ice, but was afterwards covered, and now lies buried under the moraine left by the glacier. Since it was put in, the river has cut a huge gap, between the western wall and the ice, for about 24 chains, with a width varying from 2 to 3 chains. The nearest ice across the river is about 180 ft. distant.

No. 2.—On Harper Rock, 29 ft. from the ice-face and about 7 ft. above the river-bank. This peg is now 215 ft. from the face, so that the ice has receded 186 ft.

No. 3.—On Harper Rock, in a ridge about 10 ft. above the lowest part of the ice, but overhung by the cliffs and ice above. In 1912 this was 50 ft. from the ice, and now it is 120 ft.