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THE PHYSIOGRAPHY OF THE MIDDLE CLARENCE VALLEY, NEW ZEALAND.

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- A. Introduction. B. Brief description. C. Probability of a regional uplift antedating the Orogenic uplift. D. The great bend of the Clarence. E. Asymmetry in the cross-profile of the valley. F. Earthquake rents. G. Relief-forms developed on the covering strata: (a) The monoclinical ridge of limestone; (b) The dissection of the valley lowland. H. Absence of evidence of glaciation: (a) On the mountains; (b) In the valley.
- Appendix: Note on the solid geology of the Middle Clarence valley: (a) The older-mass; (b) Intrusions in the older-mass; (c) The covering strata; (d) Structure.

A. *Introduction.*

THE long straight valley between the Kaikoura, or inland Kaikoura, and seaward Kaikoura, or Lookers-on ranges, in Marlborough, N.Z., is occupied by the middle reach of the Clarence river, which flows north-east through it, and it is generally known, therefore, as the Middle Clarence valley. Its origin is bound up with that of the enclosing ranges. These are, for the most part, composed of relatively old rocks with a deformed structure, but along the line of the valley younger rocks are involved (Fig. 1); and it is the attitude of these younger rocks, and their relation to the older, that give the clue to the nature of the uplifts which gave birth to the mountains and determined the position of the valley.

The aim of this paper is to give an explanation and description of the detail of the relief, only in the north-eastern portion of the Middle Clarence valley, which the writer has twice visited; once, for a week, in the early part of 1912, and again, for several weeks, in December of the same year. Brilliantly fine weather, allowing excellent opportunities for physiographic work, was experienced on both occasions. The writer

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accompanied Dr. J. Allan Thomson of the New Zealand Geological Survey, the chief object of the expeditions being the collection of fossils, but it was found possible also to investigate the physiography in some detail. It was impracticable, with the resources available, to visit the upper (south-west) end of the valley, but, thanks to the straightness and openness of the valley and the clearness of the atmosphere, it was possible to obtain long-distance views from a number of high points. It is, therefore, with confidence that conclusions as to the history of the Middle Clarence valley as a whole are presented, and these conclusions are further strengthened by the writer's observations made in the neighbouring

FIG. 1.—MAP OF THE MIDDLE CLARENCE VALLEY, MARLBOROUGH, NEW ZEALAND.
THE INSET MAP INDICATES THE LOCALITY.

(Topography from maps by N.Z. Lands and Survey Department.)

Awatere valley, in Eastern Marlborough, and in the Amuri and North Canterbury districts, which lie farther to the south-west.

The writer wishes to acknowledge his indebtedness to Dr. J. Allan Thomson for encouragement and helpful advice, both in the field and in the preparation of this paper.

Since the aim of the paper is to give only an explanatory description of the relief, the account given of the geological structure is limited to the minimum required in explanation of the relief. The use of formation-names is for the same reason avoided. In some cases names in common use are given in footnotes, and an appendix supplies a *résumé* of

what is known of the solid geology. It is hoped in this way to make the description intelligible to readers who are unacquainted with the intricacies of New Zealand stratigraphy and the controversies concerning it.

In order to avoid wearisome periphrases, the writer has been tempted to adopt the terms "oldermass" and "covering strata" from Davis's description of the "morvan." * Although the district cannot be described as a morvan, it may be regarded as a somewhat aberrant morvan in the making.

B. Brief Description.

A general idea of the structure may be obtained from the back portion of the diagram, Fig. 2.† In the diagram, planation of the underlying rock series or "oldermass" is assumed to have been complete before the deposition of the overlaying series or "covering strata." While this assumption

FIG. 2.—DIAGRAM ILLUSTRATING THE TYPE OF STRUCTURE AND SCULPTURE IN THE MIDDLE CLARENCE VALLEY.

may not be fully justified, the uniformity of the covering strata over a large area indicates that the surface was, at least, of relatively low relief.

It will be seen that portions of two anticlinoria are represented with an intermediate synclitorium, one limb, however, being replaced by a reversed fault of enormous throw. The axes of the anticlinoria correspond with the Kaikoura and seaward Kaikoura ranges, and the axis of the synclitorium with the Clarence valley. The immediate result of the deformation was that the synclitorium was occupied by a consequent stream, now known as the middle reach of the Clarence river. From the anticlinoria have been carved the two Kaikoura ranges, which in their present form exhibit essentially the work of normal erosive agencies only.

* W. M. Davis, *Bull. Geol. Soc. Am.*, **23**, p. 118, 1912.

† See, however, Appendix, sec. d, for further remarks on Fig. 2.

They are *one-cycle* mountains, the cycle inaugurated by the orogenic uplift, by which the anticlinoria were uplifted, being still current within the mountains, while a second, much more recent uplift, of a regional character, amounting to a few hundred feet, has caused deepening of the gorges only of the lower reaches of the dissecting streams.

In the cycle introduced by the orogenic uplift the Clarence river became graded. A great portion of the mass of covering strata was eroded off, the weak mudstones forming the lower members * were exposed, and their surface was reduced to low relief; but the outcrop of a resistant stratum of limestone and flint,† occurring in the upper part of the covering strata, formed, and still forms, especially in the north-eastern part of the valley, where it is thickest, a prominent monoclinical ridge along the foot of the Kaikoura range, its dip slope towards the range, and its escarpment facing the valley lowlands. The narrow middle strip in Fig. 2 represents the cross profile of the valley at this stage.

Regional uplift of a few hundred feet next followed, resulting in the rejuvenation of the Clarence and its tributaries, and the dissection of the valley lowland. The Clarence river, graded with respect to the new base-level, is entrenched towards the north-eastern end of the valley, to a depth of 400 or 500 feet. The present form of the mountains and of the valley is shown diagrammatically in the front portion of Fig. 2.

The stages in the history of the valley that have been thus far indicated may be summarized as follows:—

1. Denudation of a deformed oldermass. (Whether nearly complete planation resulted cannot be definitely stated.)
2. Deposition of the covering strata.
3. Orogenic uplift.
4. A cycle of erosion which may be named the "great denudation."
5. Regional uplift of relatively small amount.
6. Renewed denudation, a cycle which is still current, and may be termed the "cycle of rejuvenation."

Reasons will be given later for inserting additional episodes of local ‡ and regional § uplift towards and at the end of stage 2 respectively.

The general direction of the numerous tributaries, which reach the Clarence from the mountains on either hand, must, at first, have been consequent upon the form of the surface of the covering strata after the orogenic uplift. In the mountains, where the oldermass has been laid bare by erosion, these streams, if they have persisted in their courses, must now be superposed consequents. To this class the streams draining the highest part of the Kaikoura range (the Tapuaenuku massif) appear to belong, since their courses are approximately at right angles to the elongation of the range, and for other reasons which will be discussed in

* Appendix, sec. c.

† The Amuri limestone. Appendix, sec. c.

‡ Appendix, sec. a.

§ *Infra*, sec. C.

a later paragraph.* In the case, however, of many of the streams from the seaward Kaikoura range, and also, if we may judge from the maps issued by the Lands and Survey Department, of these from the south-western end of the Kaikoura range, the streams are aligned in nearly parallel north-south lines, making an angle of about 45° with the elongation of the ranges and of the Clarence valley. Apparently these lines are determined by some structure of the oldermass, possibly the stratification, but has not been investigated. These streams may be classed provisionally as subsequents.

C. Probability of a Regional Uplift ante-dating the Orogenic Uplift.

The foregoing description has been limited to an area in which the record preserved by relief-forms gives no inkling that before the Orogenic uplift the covering strata had risen above sea-level. The Orogenic uplift was not, however, confined to the Kaikoura mountains. Throughout the whole of Eastern Marlborough, and south-westward into North Canterbury, folding took place which differed from the Orogenic uplift of the Kaikouras only in degree. Moreover, to the north-east and south-west of the Kaikouras, where the uplifts have been of smaller amount, the drainage, instead of following longitudinal courses like that of the Middle Clarence, is transverse, the streams taking a straight course to the sea across both anticlinal arches and synclinal troughs. Streams of this nature are the Waipara,† Hurunui, Waiau, and Conway to the south-west, the Ure and Flaxbourne to the north-east, and the *lower* course of the Clarence itself. The conclusion seems inevitable that, before the folding movement, a simple regional uplift of relatively small amount had taken place, exposing the covering strata as a coastal plain with a gentle slope seaward, down which the above-mentioned rivers took consequent courses to the sea, and that these rivers were able to persist in their courses during the period of deformation by folding. They are thus *antecedent* rivers.

This explanation appears to the writer more satisfactory, than that given by Speight,‡ following out a suggestion of Hutton's,§ that the Waiau, Hurunui, and Waipara are "superimposed," for Speight's explanation is based on the assumption that the oldermass ridges, which the rivers cross, are not anticlinal cores, but formed islands in the Cretaceous and Tertiary sea, a view from which the present writer dissents. Only in the region where the uplift was greatest, *i.e.* in the Kaikoura area, the rivers that formerly crossed the site of the Kaikoura ranges || were diverted by the

* *Infra*, sec. G, a.

† See Speight, R., "The Lower Waipara Gorge," *Trans. N.Z. Inst.*, **44**, pp. 221-233 (1912).

‡ Speight, *Loc. cit.*, p. 225.

§ Hutton, F. W., *Trans. N.Z. Inst.*, **37**, p. 467 (1905).

|| In this connection the effects of the hypothetical local uplift towards the end of Stage 2 (See Appendix, sec. d) would be the same as those of the Orogenic uplift.

rapid rise of the mountain masses, and forced to follow the Clarence depression. Even here, one river, reinforced by the waters of the diverted streams, persisted in its course as the lower Clarence, which crosses the seaward Kaikoura anticlinorium near its north-eastern end in a steep-walled gorge, nearly 4000 feet deep, cut in the rocks of the oldermass.

D. The Great Bend of the Clarence.

It follows from the explanation given in the preceding paragraph that the bend of a right angle, made by the Clarence river as it leaves the broadly opened Middle Clarence valley to enter its lower gorge, owes its existence to the fact that the river there leaves a course consequent on the deformation to follow one antecedent to the deformation. This conclusion, however, might not be reached from inspection of the map. When the

FIG. 3.—THE SAWTOOTH RANGE. VIEW LOOKING SOUTH-EAST FROM THE ESCARPMENT OF THE CHALK RANGE.

writer first entered the Clarence valley he fully expected to find that the great bend of the Clarence was an elbow of capture, and clearly this hypothesis deserved consideration. It was found untenable for two reasons:—

(1) There is no gap by way of which the Clarence could have had its outlet before the hypothetical capture. A search for a possible outlet reveals the fact that the Middle valley, at its north-eastern end, is enclosed by a massive limestone barrier, formed in part by a continuation of the monoclinical ride of the Kaikoura mountain-foot, which swings round to a more easterly direction as the Chalk range (see sect. G, *a*), and farther on by a continuous, much-deformed mass of the same limestone, cut into several peaks and merely notched, at heights of not less than 2000 feet along the divide between the Clarence and Ure basins, by saddles between the heads of young ravines. This high-standing limestone mass not only closes in the valley, but swings completely around the north-eastern end of the seaward Kaikoura anticlinorium, from which, north-eastward of the Clarence gorge, has been carved the Sawtooth range

(Fig. 3). A description of the relief in this rugged limestone area does not come within the scope of this paper, but it has been necessary to mention it in connection with the problem of the lower Clarence gorge. Fig. 4, which is drawn from a field-sketch, with the proportions corrected from a photograph taken from the same point of view, indicates the manner in which the north-east end of the valley is closed.

It is scarcely necessary to add that no traces have been found either of high-level gravels or of terrace remnants that would indicate that the Clarence, at an earlier stage of its history, had its outlet in a north-easterly direction.

(2) No other eastward-flowing stream has made any progress in breaching, by headward erosion, the continuous wall of the seaward Kaikoura range. The only stream, the case of which might be considered an exception to this statement, is the Kahautara, but the Kahautara lies 30 miles to the south-west, and is beyond the highest part of the seaward Kaikoura range, and it is probable that it follows an antecedent course.

The apparently anomalous, roundabout course of the Clarence was pointed out by McKay,* who, however, made no definite suggestion in explanation of it.

E. Asymmetry in the Cross-Profile of the Valley.

The asymmetrical form of the Clarence valley synclorium has determined a pronounced asymmetry in the form of the valley, especially near its north-eastern end. There is a noticeable lack of symmetry in the relief of the valley strip of covering strata, this being made apparent chiefly by the presence of the limestone monoclinial ridge (described in sections B and G, *a*) along the north-western side; and, when the cross-profile of the valley as a whole is considered, a striking contrast is noted between the average slopes, on opposite sides, of the higher parts of the ranges, from which the covering strata have been stripped. The map, Fig. 1, shows that the strip of covering strata in the valley is very much nearer to the crest of the Kaikouras than to that of the seaward Kaikouras.

In a view up the valley, looking south-west from the escarpment of the Chalk range, the asymmetry is very noticeable. Fig. 5 is a panoramic view from this point, drawn from a field sketch, the proportions being corrected from photographs taken from the same point of view. This panorama indicates how the seaward Kaikoura range sends down long spurs to the valley, the average slope of the crests of which is relatively gentle. The ends of the spurs are truncated by precipitous rocky bluffs, but this is the effect of cutting by the Clarence river, and especially of the extra deepening due to the late regional uplift (stage 5 in the history of the relief-development as given in sec. B). In a distant view these precipitous

* A. McKay, 'Geol. Surv. of N.Z., Reports Geol. Expl. during 1888-89,' pp. 88-89 (1890).

FIG. 4.—THE MOUNTAIN WALL ENCLOSING THE MIDDLE CLARENCE VALLEY AT ITS NORTH-EAST END. VIEW LOOKING NORTH-EAST FROM THE CREST OF THE LIMESTONE RIDGE BETWEEN THE DEE AND BRANCH RIVERS.

FIG. 5.—PANORAMA OF THE MIDDLE CLARENCE VALLEY, LOOKING SOUTH-WEST FROM THE ESCARPMENT OF THE CHALK RANGE.

bluffs truncating the spurs are seen to be only a minor feature of the cross-profile, and the ascent from the valley to the crest of the range seems gentle and even. This effect is given, however, only by the crests of sharp-edged spurs separated by young ravines. It is noticeable that, in some cases the spurs, instead of being terminated suddenly at the edge of the Clarence, are continued beyond the river as short island-like ridges, both spur and island-ridges being probably determined in position by more resistant bands in the rocks of the oldermass. The most prominent of the island ridges noted is Gibraltar rock (see Fig. 6) which continues, on the north-west side of the Clarence, the line of the long spur west of the Jam river.

It is on the northern ends of these ridges that should be found preserved, if anywhere, fragments of the fossil erosion surface * upon which the sediments of the covering strata were laid down, and, if neighbouring portions

FIG. 6.—VIEW LOOKING SOUTH-EAST ACROSS THE CLARENCE FROM THE CREST OF THE LIMESTONE RIDGE BETWEEN THE DEE AND BRANCH RIVERS, SHOWING GIBRALTAR ROCK, AND DISSECTED FANS SLOPING AWAY FROM KAIKOURA RANGE.

are in line and parallel to the stratification of the lower beds of the covering strata, it will indicate that the surface was a peneplain. Time was not available for a search for these stripped remnants, but it is suggested that an evenly sloping facet on the north-west side of Gibraltar rock may be of this nature (see Fig. 6).

It will be gathered from the statements in the preceding paragraphs, and also from the map (Fig. 1), that, opposite the highest part of the Kaikoura range, the Clarence river is flowing on the oldermass, some distance beyond the boundary of the covering strata, and no evidence has been noted that would indicate an earlier course along the present outcrop of the covering strata. A possible explanation is that in the stage immediately following the Orogenic uplift, the young consequent stream was forced over to the south-east side of its tectonic valley by the waste

* See W. M. Davis, 'The Colorado Front Range,' *Ann. Assn. Am. Geogr.*, vol. 1, p. 64 (1911).

streams from the Kaikoura range side. The accumulation of waste would be mainly a talus slope of material breaking away from the overhanging fault-scarp as it rose, but this would be reinforced by enormous fans brought down by torrents from the whole of the steep front of the initial Kaikoura range. If this explanation is the correct one, this departure of the Clarence from the present outcrop of the covering strata is a direct result of the asymmetrical form of the valley synclinorium.

The comparatively gentle average slope of the seaward Kaikoura side of the valley, which has been referred to in preceding paragraphs, points to the conclusion that the mean dip of the south-eastern limb of the valley synclinorium was at a fairly low angle. Not only, however, have the covering strata been stripped off, but the rocks of the oldermass have also been denuded to such an extent that the actual form of the limb can be only tentatively restored, as in the left half of the back portion of Fig. 2.

In profile the front of the Kaikoura range forming the opposite (north-west) side of the valley presents a very different appearance (see Fig. 5). In the diagram, Fig. 2, the reversed fault which determines the front of the range is represented with a throw of 8000 or 10,000 feet, but it is possible that it is considerably more, and there is no way of arriving at an accurate estimate of its amount. The abrupt front of the range is connected with the origin by fracture of the initial form, the slope of the whole front from crest to base being steep, and that of the last 3000 or 4000 feet of the descent especially so.

Between the numerous deep ravines are left spurs which end abruptly in the neighbourhood of the fault-line, *i.e.* behind the outlying monoclinial ridge of limestone. Unlike the spurs on the opposite side of the valley, these have not been truncated by the Clarence river. South-westward of the Dee the steep spur ends assume the form of enormous facets (see Fig. 5), and the steep, even slope of these suggests that they preserve, with little modification, portions of the steep face of the range as it appeared immediately after the cessation of the movement on the fault-plane, and of the slumping of the whole mountain face which must have, step by step, accompanied the faulting, since the formation of an overhanging scarp is manifestly impossible.

Above these strong facets appears a prominent bench, the spurs running back with fairly even slope to the crest of the range, and, it may be suggested, indicating roughly the form of the anticlinal arch beyond the fault, as represented in the right half of the back portion of Fig. 2.

The foregoing explanation of the scarp of the Kaikoura range differs from that given by Hector,* who ascribed it to the presence of a network of dykes of igneous rock, which he regarded as absent from the higher part of the range. According to McKay,† however, these intrusions are not confined to the front scarp, but the whole of the higher part of the range,

* Sir James Hector, 'Geol. Surv. of N.Z., Reports for 1885,' p. xvi. (1886).

† A. McKay, 'Geol. Surv. of N.Z., Reports for 1888-9,' p. 131 and map (1890).

FIG. 7.—TAPUAENUKU, THE HIGHEST PEAK OF THE KAIKOURA RANGE. NOTE THE ISLAND-LIKE MASS OF LIMESTONE IN THE MIDDLE DISTANCE SEPARATING THE TWIN GORGES OF THE BRANCHES OF THE DEE.

FIG. 8.—VIEW LOOKING UP THE NORTH BRANCH OF THE DEE, IN THE ROCKS OF THE OLDERMASS.

FIG. 14.—FALL NEAR THE MOUTH OF A SMALL TRIBUTARY OF THE OUSE. THIS VIEW ILLUSTRATES THE YOUNG STAGE OF DISSECTION REACHED IN THE "CYCLE OF REJUVENATION."

FIG. 9.—NEAR VIEW OF THE BENCH FORMED BY THE EARTHQUAKE RENT ON THE HIGH SPUR BETWEEN THE DEE AND THE BRANCH. LOOKING SOUTH-WEST.

FIG. 11.—THE ESCARPMENT OF THE CHALK RANGE. VIEW LOOKING NORTH-NORTH-WEST.

including the highest group of peaks culminating in Tapuaenuku, is seamed by them. It is possible that the peaks owe their present height to the resistant character of the intrusive rocks.* It is equally possible, however, that the group of highest peaks marks the point where the anticlinal uplift was greatest, and that the presence of the intrusions does not appreciably affect the relief.

In front of the scarp, south-westward of the Dee, there is a stretch of piedmont plain, now dissected (see Figs. 5 and 6), formed by the coalescence of fans of coarse waste. The writer had not an opportunity of examining the whole of it closely, but it is described by McKay † as completely smothering, at one point, the monoclinical ridge of limestone. The fans were built forward after the reduction of the valley lowland to low relief, and therefore indicate a sudden great increase in the supply of waste from the mountains. This may be explained either by renewed differential uplift of the neighbouring part of the inland Kaikoura range or by some climatic change. If the former explanation is the correct one, and if the renewed uplift took the form of motion along the old fault-plane, it accounts for the good state of preservation of the scarp. Since the piedmont plain has been dissected by the streams revived by the late regional uplift, it may be assumed that active differential uplift is no longer in progress. The writer is unable to say whether this dissection had begun before the regional uplift took place. That disturbance of some kind, though probably not differential uplift, has taken place very recently along the fault-line is indicated by the presence of an earthquake rent which will be more fully described in the next section.

Farther to the north-east (*i.e.* north-eastward from the Dee) the front scarp has been completely dissected by crowded streams (see Figs. 7 and 8). In the north branch of the Dee, for example, the fault is exposed in section on the side of a spur which has been so narrowed that its crest is horizontal for some distance on either side of the fault-line. At this point, then, it is seen that the rocks of the oldermass and the conglomerate,‡ which is the highest member of the covering strata, and is faulted against the oldermass (see Fig. 2), are equally resistant, so that erosion does not reveal the presence of the fault by a break in the crest-line of the spur. Similarly, at no place where these two rocks are in contact has an erosion-formed scarp in either direction been noted.

Towards the north-east end of the valley, owing to the single fault passing into imbricated structure, the hard conglomerate has, in places, softer members of the covering strata on both sides of it, and it is only under these conditions that it stands up locally as a monoclinical ridge, as, for example, behind the Chalk range, and, less prominently, between the

* McKay, *Loc. cit.*, p. 135.

† A. McKay, 'Geol. Surv. of N.Z., Reports for 1885,' p. 128 and section on p. 96, 1886.

‡ The "Post-Miocene Conglomerate" of McKay: see Appendix, sec. c.

Dee and the Limburne. Further reference to these features will be made in section G.

F. Earthquake Rents.

Earthquake rents, or, more correctly, a single more or less continuous rent, mark the course of the Clarence fault along the scarp of the Kaimouras range for many miles south-westward from the gorge of the Dee.* It was examined by the writer on the high spurs between the Dee and the Branch, and could be traced by the eye as far as the Dart. It takes the form of a bench, about 20 feet in width, following an approximately straight line, up and down over the smaller inequalities of the surface, along the facets of the front scarp of the range. Fig. 9, a photograph, shows its profile at the point examined. This is, however, on the edge of

FIG. 10.—VIEW LOOKING SOUTH-WEST ALONG THE LINE OF THE EARTHQUAKE RENT ACROSS THE BRANCH AND TOWARDS THE DART, FROM THE HIGH SPUR BETWEEN THE DEE AND THE BRANCH.

a blunt angular projection of the scarp, and the slope shown is therefore much flatter than the average.

A "rent" of the same nature is present along the north-west side of the Awatere valley (see Fig. 1) throughout the greater part of its length, and it also follows the course of an old fracture. Owing to the abrupt change of slope, these rents, especially where the vegetation is tussocky grass, are visible at a distance of many miles as light-coloured lines along the mountain-side.† It is reported that the rents opened during the

great earthquake of 1855, and perhaps also in 1848,‡ and probably they were in existence before 1848, being then merely re-opened.

So far as the writer has been able to judge from personal observation, the nature of the rents shows that the movement or disturbance that formed them was not a differential movement of the walls of the fault-planes in a vertical direction, for no scarps have been noted in any sense resembling those at Genoa, Nevada, described by Lawson. § Hector's

* A. McKay, 'Reports for 1885,' p. 132.

† For views of the rents in the Awatere valley, see A. McKay, "Reports on Recent Seismic Disturbances within Cheviot County" (November and December, 1911), figs. opposite pp. 10 and 17. Wellington: 1912.

‡ Hector, 'Reports for 1888-89,' p. 41, 1890.

§ A. C. Lawson, 'Bull. Seismolog. Soc. of Am.,' vol. 2, pp. 193-200, 1912.

statement that recent movements have, in the Clarence valley, given rise to an abrupt step at the surface,* is apparently based on a misunderstanding of the description given by McKay.†

It is perhaps less easy, at this late date, to decide whether movement took place in a horizontal direction along the fault-planes as in the California earthquake of 1906,‡ but it must be remembered that horizontal movement produces scarps on the sides of spurs crossed by the fault lines. These face in opposite directions on opposite sides of the spurs,§ and resemble those ascribed to oblique faulting by Martin.|| No direct evidence has been noted either in the Clarence valley or in the Awatere that movement of this nature has taken place.

The 1855 earthquake, in the central portion of New Zealand, was the result of regional, vertical movement, or tilting,¶ affecting a large area,** and it seems probable that, since there is no evidence of movement, either on the Clarence or the Awatere fault, in the sense of the old thrusts, there was no movement at all of the walls relatively to each other, the general disturbance merely causing the old fault-fissures to gape at the surface as open trenches, which, when filled with *débris*, would present the appearance of the rents as they now are. There is no reason to believe that the earthquakes of 1848 and 1855 were caused, either wholly or in part, by earth movements along these lines.

G. Relief-forms developed on the Covering Strata.

Relief-forms developed on the covering strata are best discussed under two heads: (a) the monoclinical ridge of limestone; and (b) the dissection of the valley lowland.

(a) *The Monoclinical Ridge of Limestone.*—Mention has already been made of this monoclinical ridge which follows the base-line of the Kaikoura range, and then, as the Chalk range swings around more to the east, forming the northern rampart of the valley. It is seen in Figs. 4, 5, 11, and 13, and in the diagram (Fig. 2) its relation to the structure of the covering strata is indicated. The ridge forms a striking feature in almost any view of the north-eastern part of the valley, and it is by the scenery of the limestone gorges by which several streams break through it that earlier observers have been more impressed. McKay, for example, describes the gorges of the Swale, Mead, and Dee as "impressing the explorer

* Sir James Hector, 'Reports for 1885,' p. 15 (1886).

† A. McKay, *ibid.*, pp. 131-2.

‡ A. C. Lawson and others, 'The California Earthquake of 1906,' Carnegie Inst. Publication.

§ R. S. Tarr and L. Martin, 'U.S.G.S. Prof. Paper 69,' p. 39 (1912).

|| L. Martin, 'Econ. Geol.,' vol. 2, p. 79 (1907); also Tarr and Martin, *Loc. cit.*, p. 40 and Fig. 1.

¶ C. Lyell, 'Principles of Geology,' 10th ed., vol. 2, p. 82 (1868).

** See map of "Earthquake Origins in New Zealand," by G. Hogben, in Marshall's 'Geography of New Zealand,' p. 219.

with the massive solidity and giant proportions of the great cliffs rising from the deepest part of the gorge," and continues, "Yet high above in the sky these terminate in clear-cut pyramidal peaks, gables, and roofs, massive below, light and airy above. Architectural in aspect, these vertical walls and steep slopes, bearing just a due proportion of flowering plants and gorgeous shrubs, may be seen and admired, but are not easily described; and when a peep of sky dropping west from the zenith is seen, filled by the glistening snows and jagged summits of Tapuaenuka, art may strive in vain to copy the beauty, the grandeur, and the majesty of the picture." *

The Chalk range portion (Figs. 4 and 11) is about 5 miles in length, and presents a very even crest-line, with a height of about 3200 feet. There is a precipitous escarpment facing south-south-east, which is in most places unscaleable for the last 1000 feet, and below that is a scree of limestone and flint fragments, the lower part clothed with soil and vegetation, which almost everywhere conceals the soft beds beneath the limestone and flint (see Fig. 11).

The Chalk range ends to the east-north-east, at the point where the simple monocline of the limestone in the valley gives place to the completely crumpled and fractured mass that closes the end of the Middle Clarence valley. This mass is cut by deep ravines into several peaks, which are seen in Fig. 4.

The continuous ridge of the Chalk range is separated from the north-eastern end of the Kaikoura range by the broad upper valley of the Ure river, which in this part of its course is longitudinal and subsequent, or, possibly, consequent, upon the deformation, and is in strong contrast with the lower antecedent portion, which crosses the disorderly uplifted limestone mass by an almost impassable gorge.† Access to the upper Ure valley is possible by two routes; one of these crosses the escarpment of the Chalk range from the Clarence valley, and the other crosses the Kaikoura range from the Awatere valley. The openness of the valley is in part due to the branching of the fault‡ giving rise to imbricated structure, thus causing repetition of the highest members of the covering strata. Owing to the same cause, the upper conglomerate stands out as ridges in the depression.

Farther to the south-west, where the limestone monocline closely follows the base of the highest part of the Kaikoura range, there is, behind it, only a linear series of subsequent depressions, all of which have never been occupied by a single stream.

The continuity of this part of the ridge is broken by the gorges of streams, which may be regarded, as indicated in section B, as consequent

* A. McKay, 'Reports for 1885,' pp. 30-31 (1886).

† It is said that once a party of surveyors made their way through the gorge with great difficulty, resorting at some places to swimming.

‡ McKay, 'Reports for 1885,' pp. 93 and 118 (1886).

upon the initial form of the uplifted mass, having flowed initially, across the site of the ridge, upon great screes from the fault scarp.

Before the late regional uplift the series of subsequent depressions referred to above was eroded behind the limestone outcrop, causing the latter to stand out as a ridge with its dip-slope facing the mountains, but the amount of drainage tapped by the subsequent streams was small, and, consequently, in the later Cycle of Rejuvenation scarcely a beginning has been made in the reduction of the subsequent valleys to the new local base levels.

There are no air gaps in the limestone ridge. The drainage pattern must, therefore, have assumed approximately its present form before denudation had exposed the limestone monocline as a prominent ridge.

FIG. 12.—DIAGRAM ILLUSTRATING THE FORMATION OF TWIN GAPS BY THE SUPERPOSITION OF THE FORKS OF A STREAM ON A MONOCLINE OF RESISTANT ROCK.

Four of the superposed consequent streams cross the higher outstanding part of the ridge in deep gorges, namely, from north-east to south-west, the Swale, the Mead, the Limburne, and the Dee. In the last three a striking result of superposition is seen in the "splitting" of the gorges, for the Dee and the Limburne are each formed by the junction of two, and the Mead of three, branches immediately upon the limestone outcrop, with the result that twin and triple gorges have been cut. Three-sided pyramidal hills of limestone remain between the gaps, each having two sides formed by gorge walls, and the third by the dip-slope of the limestone. The formation of twin gorges by the superposition of the forks of a stream upon a monoclinical ridge is represented diagrammatically in Fig. 12. In the actual examples the pyramidal hills are lower than neighbouring portions of the ridge, owing to the fact that the stream junctions lie a little within the escarpment (see Fig. 13, a view of the gorges of the Mead).

The main arguments for regarding the south-eastward flowing streams from the highest part of the Kaikoura range as superposed consequents are contained in the foregoing paragraphs, and may be here summarized as follows :—

1. Since erosive processes have failed to excavate a continuous subsequent valley, behind the limestone ridge, along the outcrop of the weak stratum overlying the limestone, and since there are no air gaps in the

FIG. 13.—GORGES OF THE BRANCHES OF THE MEAD, ENCLOSING BETWEEN THEM AN ISOLATED PYRAMIDAL PORTION OF THE LIMESTONE MONOCLINE. THE BRANCH ON THE LEFT BIFURCATES AGAIN BEFORE THE OUTCROP OF THE LIMESTONE IS PASSED. VIEW LOOKING WEST.

limestone ridge, it may be concluded that present drainage lines were determined before the limestone monocline was exposed as a prominent ridge.

2. The writer has failed to find any explanation of the twin gorges through the limestone ridge except that outlined above, which is founded on the hypothesis of superposition.

(b) *Dissection of the Valley Lowland.*—It has been stated in section B

that in the cycle of the "Great Denudation" (which is still current in the mountains), the weak rocks forming the lower members of the covering strata, as developed in the north-east portion of the valley, had been worn down to faint relief, as represented in the middle strip of the diagram, Fig. 2. Owing, however, to late regional uplift, the valley lowland thus produced has been dissected by rejuvenation of the streams which cross it. These are mainly of two kinds, viz. (1) the superposed consequents from the Kaikoura range, and (2) insequent tributaries of these and of the Clarence, while there is a marked tendency, especially in the extreme north-east end of the valley, towards the development of (3) subsequents separated by concretionary and sandy bands in the prevailing mudstones.

The streams of the first class, which carry always a considerable volume of water, are graded up to, and in some cases through, the limestone gorges. Where they cross the mudstones their revived gorges are sub-mature, being opened to a fair width. The smaller, insequent streams, which carry little water and are intermittent in flow, have reached a much less advanced stage in the "Cycle of Rejuvenation," and their courses are broken by numerous waterfalls, which, as a rule, are placed one above another like a flight of steps, and which are still quite near the stream mouths. As mentioned above, the streams of the third type, subsequents, are best developed in the amphitheatre-like, north-east end of the valley, where they are represented by the several south-west flowing streams that unite to form the Ouse river. These streams, while always carrying a flow of water from the surrounding semicircle of mountains, are not yet graded. In Fig. 11 the gorges of two of these revived streams (the Cover and the Nidd) are seen, incised in the mature surface which was developed on the weak mudstones in the earlier cycle. Some flood-plain remnants, now forming high terraces, testify to the maturity of the streams before rejuvenation.

H. *Absence of Evidence of Glaciation.*

(a) *On the Mountains.*—The mountains of the Kaikoura and seaward Kaikoura ranges support no glaciers at the present day. Accumulation of snow takes place on steep screes of broken rock ("shingle slips"), with which, as elsewhere in the south island of New Zealand, the higher slopes are mantled, as a result of the activity of frost action and diurnal temperature changes, favoured by the shattered nature of the rocks forming the summits. Owing to the steepness of the screes, however, the snow accumulation reaches no great thickness, and, after a few warm days, disappears almost entirely.

Since small glaciers are present on the higher slopes of the isolated volcanic mountain, Ruapehu, which is about equal in height to Tapuaenuku, and is three degrees nearer the equator, their absence from the Kaikoura range must be ascribed solely to the steepness of the slopes resulting from the activity of normal agencies.

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It may be noted that Hector * remarks, "There is a total absence of the results of glacier action usually found in such regions."

It is just possible, however, that some of the summit forms (see Fig. 7) were moulded in part by small valley-head glaciers during the Pleistocene glacial advance when the snow-line must have been much lower than it now is; but if that is the case, traces of glacial erosion have, almost everywhere, been removed by normal agencies, the excessive activity of which, owing to the steepness of the gradients, will perhaps be made apparent by the following quotation from McKay †: "The mountains on either side of the valley [of the Muzzle] rise 2000 feet to 2500 feet higher, and are above heights ranging from 4500 feet to 5000 feet, absolutely devoid of vegetation. Rock avalanches are as frequent here as their icy brethren are in the Alps of Canterbury, and the valley was not passed up and down without some danger from flying fragments and rolling rock-masses."

Glaciation of restricted amount might have increased the supply of waste so as to bring about the formation of the strip of piedmont plain, at the base of the Kaikoura range, referred to in section E. The occurrence of glaciated stones in the fluvatile deposit has not, however, been reported, although McKay probably searched for them, since he says that the deposit "at first sight" appears to be morainic.‡

The preservation of glacial markings on the boulders of the fan material, if these boulders have a glacial origin, is to be expected by analogy with similar deposits described by Trowbridge § in Owen's valley, California.

(b) *In the Valley*.—A much more intense glaciation of this part of New Zealand has been claimed by Park,|| who describes the whole of the south island of New Zealand as covered by an ice-cap,¶ sometimes regarded as an extension of the South Polar ice-sheet **; he mentions also a "Clarence glacier." ††

It will be gathered, however, from the description already given, and no less clearly from Fig. 5, that the cross profile of the valley does not suggest that it has been moulded by ice. Nor is there an outlet through which a great ice stream could have made its way (as it is assumed that it

* Sir James Hector, 'Reports for 1885,' p. xiii. (1886).

† A. McKay, 'Reports for 1885,' p. 50 (1886).

‡ *Ibid.*, p. 128 (1886).

§ A. C. Trowbridge, 'Terrestrial Deposits of Owen's Valley, California,' *Journ. of Geol.*, vol. 19, pp. 706-747 (1911).

|| J. Park, 'Geology of New Zealand,' p. 183 (1910). For a more conservative account of N.Z. Glaciation, see P. Marshall, *Trans. N.Z. Inst.*, vol. 42, pp. 334-348 (1910).

¶ 'Geology of New Zealand,' pp. 183, 249.

** *N.Z. Geol. Surv. Bull.*, No. 7 (n.s.), p. 43 (1909); *Trans. N.Z. Inst.*, vol. 42, p. 606 (1910).

†† 'Geology of New Zealand,' p. 204. (This reference is clearly not the glaciation of the Upper Clarence referred to in *Trans. N.Z. Inst.*, vol. 42, p. 598 (1910).)

did *). Further, no *roches moutonnées* have been found, nor stripped and glaciated rock surfaces, such as are found in formerly glaciated valleys in New Zealand as well as elsewhere. Lastly, no glacial deposits have been found on the floor or sides of the valley, the only superficial deposits, which, as McKay † says, “at first sight appear to be morainic in origin,” proving to be of fluvatile origin as noted in section E.

Park has described under the heading “Marlborough Moraines” ‡ the conglomerate which is the highest member of the covering strata.§ Whether this conglomerate had or had not a glacial origin, its presence can have no bearing on the glaciation of the existing valley, or the explanation of any existing land-forms, for, since it is involved, equally with the other members of the covering strata, in the movements of the orogenic uplift, its formation must antedate those movements.

APPENDIX.

Note on the Solid Geology of the Middle Clarence Valley.

The reports by McKay || are almost the only source of information on the geology of this portion of New Zealand. The following brief account is based mainly on the information contained in these reports, supplemented in a few instances by the writer's own observations.

In sections A and B of this paper use has been made of the terms “oldermass” and “covering strata.” The exact sense in which these terms are used will be made clear by the following tabular comparison with the formations distinguished and mapped by McKay in the Clarence valley:—

THIS PAPER.	Age.	McKay.¶	Formation.
	Pliocene.		Great Post-Miocene Con- glomerate.
Covering strata . . .	{ Cretaceo-Tertiary and Cre- taceous.	{	Cretaceo-Tertiary [or Waipara **] and Lower Greensand.
Oldermass	Carboniferous.		Maitai.

It must be noted, however, that, while the above is the classification on McKay's map, it is qualified in the text †† by the statement that the “Maitai series of the Table of Formations and on the map accompanying must be understood to include such older secondary strata as have not been satisfactorily determined as such.”

* ‘Geology of New Zealand,’ p. 204.

† *Loc. cit.*

‡ ‘Geology of New Zealand,’ p. 204.

§ “Post-Miocene” conglomerate of McKay. See Appendix.

|| A. McKay, ‘On the Geology of East Part of Marlborough,’ Geol. Surv. of N.Z., Reports of Geol. Expl. during 1885, pp. 27–136 and map, 1886; ‘On the Geology of Marlborough,’ *ibid.*, during 1888–89, pp. 85–185 and map, 1890, and during 1890–91, pp. 1–28 (1892). (See also ‘Progress Reports,’ by Sir James Hector in same volumes.)

¶ *Loc. cit.*, 1890, map, p. 96.

** *Loc. cit.*, 1886, pp. 43–44.

†† *Loc. cit.*, 1890, p. 116.

a. *The Oldermass.*

Rocks similar to those of the oldermass of the Kaikoura ranges, occurring in various parts of New Zealand, are commonly correlated, on purely lithological grounds, or on account of the occasional presence of the annelid *Torlessin mackayi*, Bather, with the Maitai series at Nelson,* which was regarded by Hector's Geological Survey as Carboniferous, by Park † in 1904 as Jurassic, and in 1910 as Carboniferous, and by Bell, Clarke, and Marshall ‡ as Trias-Jurassic.

Park, however, separates a great area of rocks, including those of the Kaikouras, from the Maitai, and includes them in his Hokobui system § (Permo-Jurassic). McKay, in his first report (1886), described the rocks of the Kaikouras as Old Secondary and Palæozoic. Hector, however, in the Progress Report in the same volume, assigned them to the Maitai Series of Carboniferous Age, and McKay, in 1890, followed Hector, stating at the same time that he believed them to be in part of secondary age, but had insufficient evidence to make a definite subdivision. ||

Within the area described the rocks of the oldermass appear to be all clastics, some coarse and some fine, the latter often black owing to the presence of carbonaceous matter. On the south-east side of the Clarence valley they are, at least in places, thin bedded, and, in places, much contorted; ¶ while on the north-west side, where they are separated from the younger strata by the reversed fault, they are thick-bedded and much crushed, so that stratification is scarcely recognizable. The presence in the Kaikoura range of a bed of the red-jasperoid rock, common in similar rocks throughout New Zealand, is shown by the abundance of boulders of it brought down by the streams.

The rocks of the oldermass had been folded and denuded before the deposition of the covering strata, but the direction of the axes of the older folds is unknown. The few recorded observations** go to show that strikes and dips are variable, and it is, therefore, probable that the older axes make an angle with those of the later folding, which has affected the covering strata also, and is termed in this paper the "Orogenic Uplift." Describing adjacent areas, both Hutton †† and McKay ‡‡ have remarked upon the dome and basin structure.

b. *Intrusions in the Oldermass.*

The higher part of the Kaikoura range is described by McKay §§ as intersected by a network of dykes, and igneous rocks are brought down by the streams in great quantities.

c. *The Covering Strata.*

The beds grouped under the name "covering strata" lie with marked unconformity upon the denuded surface of the previously folded oldermass. Their

* See, e.g., P. Marshall, 'New Zealand,' *Handbuch der regionalen Geologie*, vol. 7, 1, pp. 15-21, and map, p. 10, 1911; and 'Geology of New Zealand,' p. 179, Wellington, 1912.

† J. Park, *Trans. N.Z. Inst.*, vol. 36, p. 431, 1904; 'Geology of New Zealand,' p. 52, Christchurch, 1910.

‡ *N.Z. Geol. Surv. Bull.*, No. 12 (N.S.), p. 22, 1911.

§ 'Geology of New Zealand,' map. || McKay, *Loc. cit.*, 1890, p. 116.

¶ McKay, *Loc. cit.*, 1886, p. 59.

** McKay, *Loc. cit.*, 1886, pp. 46, 47, 53-55, 59, 60; and 1890, p. 122.

†† F. W. Hutton, 'Reports Geol. Expl. during 1873-74,' p. 32, 1877.

‡‡ A. McKay, 'Reports Geol. Expl. during 1879-80,' p. 85, 1881.

§§ *Loc. cit.*, 1886, p. 47; 1890, p. 131. (See also J. Allan Thomson, 'Intrusions of the Tapuaenuku Range,' *Trans. N.Z. Inst.*, vol. 45, 1913.)

limits as mapped by McKay (1890) are shown by a dotted line in Fig. 1. In the north-eastern part of the valley the series begins with conglomerate, upon which lies a thickness of several thousand feet of strata with marine Cretaceous fossils. These beds are chiefly mudstones with occasional intercalations of fine sandstone, while, towards the south-west end of the strip of covering strata, the Cretaceous beds are represented by sandstones and shales with plant fossils,* covered by a thick volcanic series. Since the writer has not visited that part of the valley, a description of the relief developed on that facies of the Cretaceous beds have necessarily been omitted.

Next follows, apparently with complete conformity, a stratum of unfossiliferous, hard, fine-grained, "lithographic" limestone (the Amuri limestone), the thickness of which, at one point, is estimated by McKay † at 2050 feet. Of this thickness nearly 1000 feet at the base has been replaced by flint.

The limestone in its upper part becomes more and more argillaceous, and passes up by a gradual transition into the Grey Marl with a thickness of a few hundred feet. The Grey Marl is the upper member of the Cretaceous-Tertiary system of Hector's Geological Survey, and no more definite statement of its stratigraphical position can at present be made. It is probable, however, that the work of the present Geological Survey will, in the near future, result in its correlation with some Tertiary horizon. The total thickness of the covering strata, up to this horizon, is estimated by McKay, ‡ in the north-east part of the valley, as 12,000 feet. A revised estimate by Dr. J. Allan Thomson is expected to appear shortly.

The Grey Marl is followed by a coarse conglomerate § series, which is the highest member of the covering strata present, its upward limit being the reversed fault that brings it against the oldermass of the Kaikoura range. This is the "Post-Miocene Conglomerate" of McKay, who regards it as unconformable || upon the Grey Marl with a discordance of dip. ¶ In the gorge of the Mead, however, and, in fact, in all the sections examined by the writer, the dip of the conglomerate was found to be the same as that of the indulating series. The strike also is strictly parallel, not only with that of the Amuri limestone, but also, for a long distance, with the fault. This is strikingly brought out by McKay's map,** which indicates that, for a distance of 27 miles, one wall of the fault is formed by the conglomerate, a formation that is, throughout the whole distance, highly inclined, and nowhere more than a few hundred feet in thickness.

It is thus certain that, *within the area in which the covering strata are preserved*, the conglomerate was laid down upon a horizontal surface of the Grey Marl, and has participated in all the movements, whether of tilting or of folding, to which the lower members of the covering strata have been subjected. Since, however, the conglomerate contains an abundance of material derived from lower members of the covering strata, a like conclusion cannot be reached for the whole area originally occupied by those beds.

* A. McKay, *Loc. cit.*, 1886, p. 102.

† A. McKay, *Loc. cit.*, 1886, p. 93.

‡ *Ibid.*, p. 94.

§ Perhaps more correctly "Fanglomerate." (See A. C. Lawson, *Bull. Geol. Soc. Am.* 23, abstr., p. 72, 1912.)

|| A. McKay, *Loc. cit.*, 1886, p. 95.

¶ *Ibid.*, section on p. 94; see also Hector, *Loc. cit.*, 1886, pp. xxxiv., xxxv.

** *Ibid.*, 1890, p. 96

d. Structure.

The structure of the oldermass is so obscure that no attempt has been made to indicate even its main outlines in Fig. 2, except in so far as it has been affected by the Orogenic uplift, which has folded the covering strata also. A generalized account of the structure of the covering strata has already been given in section B. The assumption that the surface on which the covering strata were deposited was one of very low relief was made for convenience in constructing Fig. 2, and is perhaps not warranted by facts of observation. Nothing, however, has been observed which would indicate that the assumption is false.

The folds in the back of Fig. 2 have been restored up to the horizon of the Grey Marl. The restoration was not made up to the surface of the "Post-Miocene Conglomerate," because the nature of the conglomerate leads to the belief that it never extended over the whole of the area represented. The same objection does not apply to the Grey Marl and underlying beds, the wide original extension of which has been satisfactorily shown by McKay * and Hector.†

The conception of the uplifts as anticlinal agrees with the observed facts and with the explanation of the structure given by Hector,‡ and the section across the valley (in Fig. 2), while necessarily diagrammatic, will be found to agree in general with the sections along the Dee and Mead rivers given by McKay.§ The great reversed fault is that described by McKay as the Middle Clarence Fault || or Great Clarence Fault.¶

The restoration of the seaward Kaikoura anticlinorium in the left portion of the diagram is probably a fairly accurate representation of facts, but no account is taken of a possible thinning of the covering strata in that direction.

The restoration of the Kaikoura anticlinorium north-westward of the fault plane in the right portion of the diagram is offered with less confidence, for it is certain that a *pre-conglomerate* uplift of some kind, possibly of the nature of block faulting, must have affected an area *outside that in which the covering strata are preserved* in order to provide the material for the conglomerate, and it is probable that the movement affected at least a considerable portion of the rocks occupying the site of the Kaikoura range. This is the episode of local uplift towards the end of stage 2 referred to in section B. The nature of the movement being unknown, it was decided to ignore it in constructing the diagram. This portion of Fig. 2, however, while admittedly not representing all the facts, should prove helpful in explaining the post-conglomerate movements.

INŌ CHŪKEI AND THE FIRST SURVEY OF JAPAN.**

By E. B. KNOBEL.

It will not be uninteresting to record something of a remarkable man who alone undertook a survey more extensive in area than that of the whole British Isles, and who accomplished it so well, and, for his period, so

* A. McKay, *Loc. cit.* 1892, pp. 5-7.

† Sir James Hector, *Loc. cit.*, 1890, pp. xxxvi., xxxvii.

‡ *Ibid.*, 1886, pp. xiv., xv., and 1890, pp. xxxviii., liv.

§ *Ibid.*, 1886, pp. 94, 95.

|| *Ibid.*, 1886, p. 130.

¶ *Ibid.*, 1892, p. 14.

** Substance of a discourse delivered to the Royal Astronomical Society.