ART. XXXII.—*The Geology of the Middle Clarence and Ure Valleys, East Marlborough, New Zealand.*

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INTRODUCTION.

THE middle reach of the Clarence River occupies a nearly straight valley, some fifty miles long, trending north-east, between the enclosing ranges of the Seaward Kaikoura or Looker-on Mountains to the south-east and the Kaikoura Mountains to the north-west, which rise to heights of 8,516 ft. and 9,465 ft. respectively. The summits of these ranges are twelve to fourteen miles apart across the valley, so that the area of this part of the valley is some 600 square miles. The north-eastern end of this middle reach of the Clarence is enclosed by an encircling rim of lower mountains, 2,500–4,000 ft. in height, and before reaching this point the river turns abruptly to the south-east and breaks through the north-eastern continuation of the Looker-on Range in a rock-bound gorge nearly 4,000 ft. deep. The Middle Clarence Valley is thus difficult of access, and can be entered only by a number of passes through the surrounding mountains, of which the most used are the Burnt Saddle (2,073 ft.), between Kekerangu and Coverham, crossing the north-eastern rim of the valley; the Mount Clear Saddle (3,000 ft.), between Reserve Station and Quail Flat, and the Palmer Saddle (3,185 ft.), from the Conway River to the Palmer River, the two latter passes lying in the south-western continuation of the Looker-on Range. These saddles are traversed by pack-tracks uniting the above-mentioned places, and there are similar tracks running the whole length of the valley. Other less-used tracks enter from the Awatere Valley, the two chief crossing the Tone Saddle (3,800 ft.) and the Barefells Pass (4,250 ft.). It is possible also to reach the Middle Clarence from Hanmer via Jollie's Pass and down the Clarence.

The surface of the valley is rendered very diversified by the existence of a large number of tributaries from each side, many of which enter the main river by gorges some hundreds of feet in depth. Of these, ten on the north-western side and six on the south-eastern side are large enough to be dignified by the name of river, and there are numerous smaller streams. The pack-track along the valley therefore takes on somewhat of the nature of a huge switchback, often rising a height of 1,000 ft. between two adjacent tributary rivers. The difficulty of access between different parts of the valley is accentuated by the size and strength of the Clarence River, which is not easily forded below the Bluff River.

Being cut off from the prevailing rain-bearing winds by high mountain-ranges the Middle Clarence Valley, like the neighbouring Awatere Valley, has a low rainfall, 20–30 in. per annum, and in consequence rain forest is absent throughout its whole extent. The lower slopes are covered with tussock-grass or manuka thicket, while small areas of beech forest occupy the gorges of many of the tributary streams at heights of about 2,000–5,000 ft. The intermediate rocky slopes and gorges bear, when not too steep, a profusion of flowering-shrubs, but there are large areas of bare rock and of talus slopes (screes and shingle-slips) which are almost destitute of vegetation.

The statement is frequently made that the higher peaks of the Kaikoura and Looker-on Ranges are covered with permanent snow. As a matter of fact, however, the higher peaks, though rising far above the estimated snow-line for this latitude in New Zealand, are frequently free from snow for several months in the year, except for a few days after a snowfall, and in the early autumn only small patches of soft ice persist in the shady hollows near the summit. The freedom from permanent snow must be ascribed partly to the steepness of the slopes and, in the case of the Kaikoura Range, partly also to the low rainfall during the summer. Owing probably to this freedom from snow, alpine plants reach a much greater height on the Kaikoura Range than in other mountains in New Zealand, and Aston (1916) has recorded the presence of a species of *Haastia* at a height of 8,500 ft. on Mount Tapuaenuku.

Owing to its inaccessibility and the broken nature of the country the Middle Clarence Valley has hitherto escaped close settlement, and is divided up into a number of pastoral leaseholds, of which the largest is the Clarence

Run, of 114,300 acres. In early days a large number of small freeholds were alienated, and the maps show road-lines throughout the valley, but it is obvious from an inspection of the ground that both freeholds and road-lines were laid down in the office without regard to topography. At one time homesteads existed at the Bluff River and at Coverham, but they have fallen into decay, and the former was at the time of my visit unoccupied, while the latter is used as a musterers' hut. The only permanent settlement at present existing is that at Quail Flat, which serves as an out-station of the Reserve Station and is continuously inhabited throughout the year. In addition to the above there are a small number of musterers' huts, that at the Dee River lying on the main pack-track through the valley. A traverse from Kekerangu to Reserve Station by pack-horse occupies four to five days, the stops being at Coverham, Dee, Bluff, and Quail Flat (optional).

Although the Middle Clarence Valley differs considerably in form and rainfall from the shouldered and flat-bottomed valleys of Switzerland, such as the Upper Rhone, one cannot help predicting that by the utilization of the tributary rivers for electric power and irrigation it will, like them, one day become the scene of a fairly close settlement. That day, however, lies in the distant future, unless the discovery of mineral resources should hasten it.

Before the actual geological exploration of the valley von Haast (1861) had visited the lower Awatere Valley in 1859 and had gained a near view of the Kaikoura Mountains. From the nature of the boulders in the gravel of the river he inferred that the range consisted of eruptive and volcanic rocks, unlike the Spenser Mountains and the Looker-on Range, which he considered to be composed of sedimentary rocks. He further expressed the opinion that to this volcanic action was due the upheaval of the two latter ranges.

Similarly, in the summer of 1866–67, J. Buchanan gained a view of the Middle Clarence Valley from the summit of the Looker-on Range, and observed the long strip of white limestone forming a series of foothills at the base of the Kaikoura Mountains as far south-east as the Bluff River.

A. McKay was the first geologist to enter and explore the Middle Clarence, which he traversed from Kekerangu to Hanmer in 1884–85, also crossing from Reserve Station to Quail Flat. In 1888–89 he similarly explored the Awatere Valley, and the four long reports (1886–1892) in which he recorded his observations long remained the only source of information as to the geology of these areas. They will be more fully noticed in the sequel, and need not be discussed in detail now.

With the exception of Sir James Hector, who accompanied McKay to Coverham in 1885, the Middle Clarence was not revisited by any geologist until 1912, when Dr. Cotton and myself twice went in from Kekerangu as far as the Dee River. In 1916 I again visited the same ground, and made the ascent of Mount Tapuaenuku from the Dee in company with Messrs. B. C. Aston, A. F. O'Donoghue, and H. Hamilton. Later in the same year I crossed the saddle from Reserve Station to Quail Flat and proceeded down the valley as far as the Bluff River. On three separate occasions also I have visited the middle part of the Ure Valley in company with various companions, including on separate occasions Dr. C. A. Cotton and Mr. H. T. Ferrar.

Following on these visits, Dr. Cotton published in 1913 an account of the physiography of the Middle Clarence Valley, and in 1914 a description and explanation of the mode of origin of the great Marlborough conglomerate as developed in the Dee and Mead Gorges. My own publications on this area comprise some brief observations in the Annual Reports of the Geological Survey for the years 1912 and 1913, a paper on the petrography of the intrusives of Mount Tapuaenuku (1913B), an account of the oil-prospects of the Benmore district (1915), a description of the Amuri limestone and flint-beds as far south-east as the Dee Gorge (1916), and a classification of the Clarentian rocks at Coverham (Woods, 1917).

The fossils collected by Dr. Cotton and myself from the Clarentian beds, as well as the earlier collections made by McKay, have been described in detail by Woods (1917), who has demonstrated the Albian age of the beds below the flint-beds, and has thus added a new interest to the geology of the area.

Although the area covered by my visits is much smaller than that traversed by McKay, whose reports cannot, therefore, be superseded, there are several reasons why a new account of the geology of the area should be presented. Both from a structural and from a stratigraphical point of view the district has become a classical one for New Zealand geology, and a more succinct account is desirable. McKay's descriptions both of structure and of stratigraphy are in the main accurate, but are couched in obsolete terminology as regards the physiography, while the stratigraphy is interpreted in terms of the classification then adopted by the Geological Survey, a classification which has now been universally discarded. In particular, is it vitiated by the false correlation of the Cretaceous rocks below the flint-beds (Clarentian) with those of Amuri Bluff (Piripauan), and this has at times led him to an unbalanced description of the rock sequence, emphasis being placed upon beds which are only locally developed and of relatively small importance. In making these criticisms I do not wish them to detract in any way from the great merit which I consider attaches to McKay's work. His report of 1886, although long neglected by other geologists than Hector, marked a new epoch in New Zealand geology by its recognition of the late Tertiary age of the Kaikoura Mountains, and must always remain a classic.

The area covered in this paper is so great, and the country so broken and difficult of access, that a complete survey would occupy more than one season of continuous work, and many years must elapse at the present rate of progress before the district can be worked out in detail. The observations both by McKay and by Dr. Cotton and myself can be looked upon only as reconnaissance, and, naturally, we have visited somewhat different ground, and devoted greater attention to different parts of the area. There are many new observations, therefore, to be placed on record.

General Account of the Geology and Physiography.

Both from a stratigraphical and a physiographical point of view, the rocks of the area may be divided into three main groups, as shown in the following table. McKay did not explicitly recognize this threefold division, and that part of his classification which relates to the present area is appended in the table. Between his Pliocene and Cretaceo-Tertiary groups he interpolated Miocene and Eocene from neighbouring areas. With the exception of the supposed Pliocene conglomerate, however, he implicitly recognized the unity of the middle group of rocks by describing them together under a special section of his first report (1886).

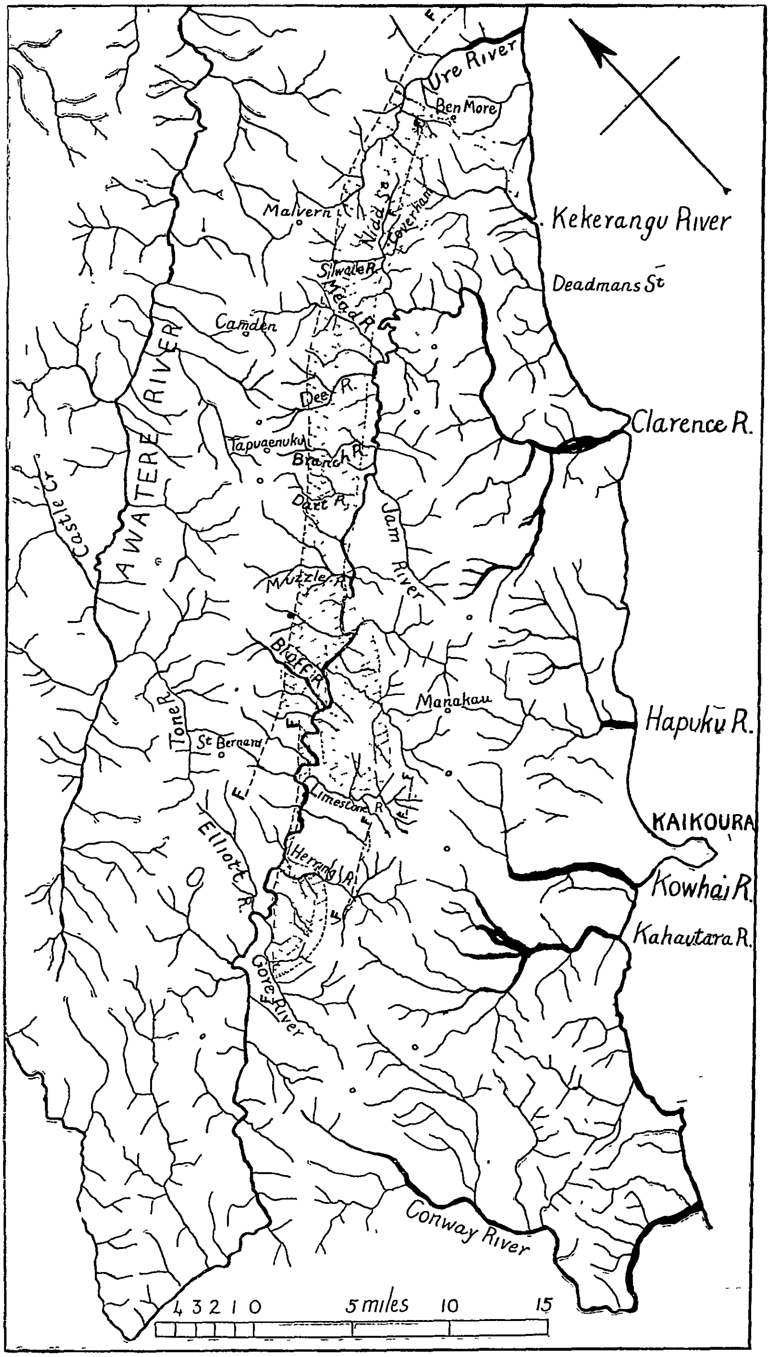


FIG. 1.—Map of eastern Marlborough.

\\\\\\ Amuri limestone and higher Notocene beds; /// Clarentian; pre-Notocene and unsurveyed areas blank; FF, faults. The Notocene rocks of the Awatere Valley and of the coastal area are not shown.

TABLE I.—GENERAL CLASSIFICATION OF THE ROCKS

Stratigraphical.	Physiographical	McKay, 1886 & 1890	Nature of the Rocks.
Notopleistocene	Superficial (unconsolidated)	Recent ..	River alluvium, terrace gravels, river fans, talus, and moraines (?).
Notocene ..	Covering strata (generally weak but with resistant strata of limestone and conglomerate)	Pliocene .. / Cretaceo-Tertiary and Lower Greensand	Mudstones (Awatere beds). Conglomerates (great Marlborough conglomerate). Mudstones (" grey marls "). Limestone (Weka Pass stone). Tuffs and phosphatic greensands (only locally developed). Limestones and flint-beds (Amuri limestone). Mudstones, sandstones, basalts, and conglomerates (Clarentian).
Pre-Notocene	Oldermass (generally strong).	Older Secondary and Palaeozoic	Greywackes, argillites, and jasperoid sediments with syenitic and basic intrusives.

The Notocene rocks in the north-east half of the valley form an elongated strip a few miles in width on the north-western side of the Clarence River. At the Bluff River there are two separated exposures, the south-eastern of which crosses the river and continues for some distance to the south-west, and farther in this direction other isolated exposures occur. The rocks rest with marked unconformity on the pre-Notocene rocks which underlie them on the valley-floor, and of which, with their intrusives, the higher mountains are exclusively composed. The Notocene rocks dip in almost all exposures steeply to the north-west, and on their north-west side end abruptly against fault-lines, with the exception of the south-eastern outlier at the Bluff River. The most persistent of the faults, known as the great Clarence fault, runs along the base of the Kaikoura Mountains a few miles to the north-east of the river, and is described by McKay as a reversed fault. A monoclinal ridge of limestone, cut through by numerous gorges, has been developed by erosion in the tilted Notocene beds a short distance riverwards from the fault, and, rising to heights of about 3,000 ft., forms a prominent series of foothills to the Kaikoura Mountains. The hills closing the north-eastern end of the valley, rising to 4,081 ft. in Benmore, are a continuation of this monoclinal ridge, the line of strike bending gradually from north-east to south-east.

The probable geological history of the area, as interpreted from the stratigraphy, structure, and physiography, is resumed in Table II.

TABLE II.—SUMMARY OF GEOLOGICAL HISTORY OF THE AREA.

Diastrophic Events.	Corresponding Geological Events
Orogenic movements.	Production of mountainous land surface, probably outside the area.
Epoch of relative inactivity (probably Hokonuian).	Rapid erosion with deposition of pre-Notocene rocks.
Post-Hokonui orogenic movements.	Folding of pre-Notocene rocks and production of mountains, with resulting erosion.
Stage of early Notocene sea-advance, with local vulcanism.	Continued erosion of adjacent mountains to peneplanation, with deposition of Clarentian beds, including local lava-flows; invasion of pre-Notocene rocks by dykes and sills.
Local epeirogenic uplift.	Local unconformity between Clarentian and Amuri limestone.
Stage of maximum Notocene sea-advance.	Submergence of land; deposition of Amuri limestone and Weka Pass stone, divided by a period of non-deposition.
Stage of late Notocene sea-retreat.	Renewed uplift and erosion of adjacent peneplains, with deposition of "grey marls."
Local intense differential uplift.	Deposition of fluviatile great Marlborough conglomerate by erosion of uplifted blocks.
Late Notocene sea-advance.	Deposition of Awatere beds.
Slight regional or differential uplift.	Initiation of antecedent or anteconsequent drainage.
Kaikoura orogenic movements.	Elevation of Kaikoura and Looker-on Ranges, with folding and faulting of the Notocene beds; development of consequent drainage; heavy erosion of mountains with development of insequent drainage; mature erosion of valley lowland with slight development of subsequent drainage.
Slight regional uplift.	Rejuvenation.

The area has experienced two epochs of major diastrophism—*i.e.*, two epochs of severe earth-movements of an intensity sufficient to raise mountain-chains—which have left their effects clearly marked in the structure of the rocks, while there is evidence for a still earlier epoch in a neighbouring district. Little is known of the age and the conditions of deposition of the pre-Notocene rocks. They are clearly earlier than Clarentian (middle Cretaceous), certainly Mesozoic in part, and quite possibly wholly Mesozoic. They are composed chiefly of greywackes and argillites in endless alternations, both coarse and fine; marine fossils (*Inoceramus* sp.) have been found only in two places, in what are probably the uppermost beds, while sandstones with obscure plant-remains are reported by McKay in a number of places. The rocks were, therefore, probably deposited in shallow water, and with considerable rapidity, in conditions under which marine benthic life did not flourish. Cotton (1918, pp. 56–57) considers that they might be interpreted as the topset beds of a continental shelf undergoing subsidence, but supplied with a considerable but fluctuating supply of waste. These conditions exist during the first stages of sea-advance following a period of mountain-building, so that we may see in the nature of these sediments the evidence of an earlier epoch of major diastrophism, which has, however, left no other recognizable effects in the area under consideration. Probably the mountains then formed lay outside this area. The rocks stand now for the most part in steep attitudes, often showing in section closely folded synclines and anticlines or contorted bedding, with numerous small faults. Their lines of strike vary rapidly from place to place. The lowest Notocene rocks rest upon them with strongly marked unconformity, the surface of unconformity being a practically plane erosion-surface truncating the pre-Notocene rocks at angles approaching a right angle. It is obvious, therefore, that the pre-Notocene rocks experienced a sharp folding to the degree of mountain-building, and were subject to considerable erosion before the deposition of the lowest preserved Notocene rocks began. The epoch of major diastrophism thus disclosed has been termed by me (1917) the post-Hokonui orogenic movement, from the fact that rocks of Hokonuian age are involved in the present area, and that in other parts of New Zealand the youngest Hokonuian rocks — viz., the Wealden plant-beds of Waikato Heads — are similarly involved. In the Clarence and Awatere districts the lowest Notocene rocks (Clarentian) are of middle Cretaceous age, so that the date of cessation of the post-Hokonui movement in this area must be early Cretaceous at the latest.

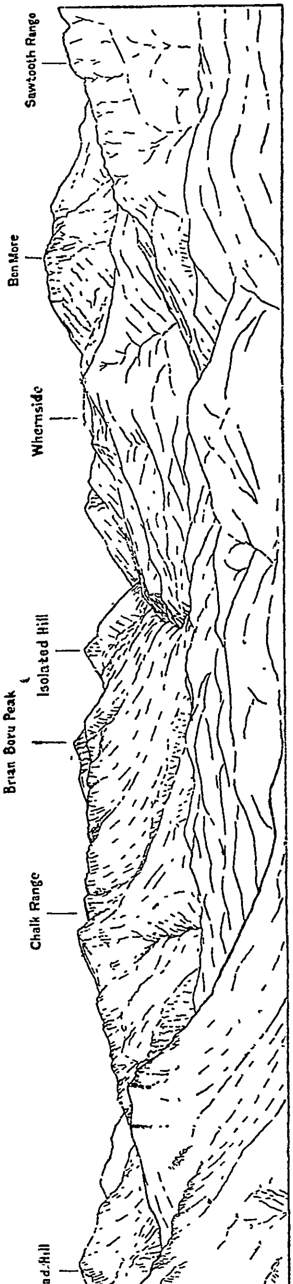


FIG. 2.—Sketch of the north-eastern end of the Middle Clarence Valley (after Cotton).

The evidence for a later major period of diastrophism is afforded by the displacements which the whole Notocene series has experienced subsequent to the cessation of its deposition. A great fault runs along the south-eastern base of the Kaikoura Mountains, along which all the Notocene rocks are deeply involved. For the most part they have experienced a strong tilt, and dip at steep angles to the north-west against the fault, the north-west side of which is occupied by pre-Notocene rocks. From the Swale Valley north-east the Notocene rocks are strongly folded and completely overturned in the upper limb of a recumbent syncline which is truncated by the fault. The production of such structures proves the existence of very considerable earth-pressures after the conclusion of the Notocene deposition, and there are good reasons, as will be shown below, for believing that the Looker-on and Kaikoura Ranges owe their uplift to such orogenic movements of post-Notocene date, which Cotton (1916) has termed the Kaikoura orogenic movements.

Between these two epochs of major diastrophism there ensued a period of relative diastrophic inactivity—the Notocene—during which a great thickness of accordant sediments was laid down. The presence of a thick series of basalts near the base of the Clarentian in the south-west part of the Middle Clarence doubtless points to crustal instability at this period, and there are locally evidences of slight discordance and of disconformity at higher horizons; but such earth-movements as occurred throughout the Notocene, with a single exception outlined below, were epeirogenic and not orogenic in nature, and the general accordance of the whole Notocene is most marked.

The nature and distribution of certain members of the Notocene leads to the belief that these rocks had formerly a much wider extension, and prior to the Kaikoura orogenic movements formed a cover to the pre-Notocene rocks, a cover which has since been removed by denudation where the movements carried it to higher elevations, leaving only a narrow strip in the valley-bottom, where it has been until recently below the effective action of erosive agents—in other words, that the Kaikoura and Looker-on Ranges did not exist as such at the time of the deposition of the rocks in question. If they had so existed, and a long fiord had occupied the site of the Middle Clarence Valley, the deposits of this fiord would have been of the nature of river-delta deposits, mainly conglomerates and sandstones, so long as the mountains existed—*i.e.*, throughout the whole Notocene, since the mountains still exist. Instead we find conglomerates and sandstones only poorly represented in the lower beds, which consist mainly of mudstones, while the middle beds consist of limestones which are in part argillaceous and in part of an indurated chalky and siliceous nature and exceedingly fine-grained. The limestones are succeeded by more or less calcareous mudstones, also fine-grained, and it is not till near the top of the Notocene that coarse detrital matter reappears in the mudstones and in an overlying conglomerate. This in turn is followed by further mudstones. The whole series of sediments, except the conglomerate, has the characters of the deposits of an open continental shelf (*cf.* Cotton, 1918), and not those of delta deposits in a narrow fiord.

The lower and greater part of the limestone may be correlated on lithological and stratigraphical grounds with the Amuri limestone, the upper part of the limestone and the succeeding mudstones with the Weka Pass stone and the "grey marls" respectively of the Waipara district of North Canterbury. These three rocks maintain the same lithological characters and relative positions throughout the whole of North Canterbury and East Marlborough, and it is unthinkable that they can be, in each of the narrow strips in which they occur, only locally deposited rocks, and that they were not laid down under approximately uniform conditions in relatively clear seas over a wide area. They are involved between the mountains not only in the Middle Clarence Valley, but also in the Awatere Valley to the north-west and near the south-eastern base of the Looker-on Range, and it is probable, therefore, that they were formerly continuous over the intervening areas and that the Kaikoura and Looker-on Ranges did not exist as such at the time of their formation, although islands may have existed over their sites. This conclusion has been accepted by Hector, McKay, and Cotton. The great Marlborough conglomerate, however, which occurs near the top of the Notocene deposits of this area, has, on the other hand, all the characters of a narrowly localized deposit, and had not probably at any time a wide lateral extension.

Although the great Marlborough conglomerate is involved equally with all the other Notocene beds in the Kaikoura orogenic movements, the nature of its constituent pebbles and boulders affords proof of considerable differential earth-movements prior to its deposition. It exhibits in the Clarence Valley fairly regular stratification, and appears to be in the main a fluviatile deposit. The majority of the pebbles are derived from the pre-Notocene rocks, and are small and well rounded. In addition, there are larger and often angular boulders, several feet in diameter, of Notocene rocks, including all the beds down to the Clarentian.* It is obvious, therefore, that in the area from which the materials of the conglomerate were derived the Notocene rocks had been elevated above sea-level and exposed to erosion, and, since the underlying Notocene beds are nowhere less than 4,000 ft. thick and reach as much as 12,000 ft., the amount of earth-movement must have been considerable. There is, in the Clarence Valley at least, the further peculiar relation that although the conglomerate contains boulders of rocks exactly similar to the underlying Notocene beds, nevertheless it is perfectly conformable to the underlying "grey marls," and in the Dee and Mead Gorges at least there are transitional beds. This relation is explained by Cotton (1914) by the assumption that faulting took place, not disturbing the horizontality of the beds now underlying the conglomerate, but differentially elevating a neighbouring area to an extent of perhaps 12,000 ft. Since no folding or warping of the Notocene took place, he concludes that the movements must have been block-faulting; with the restriction that the uplifted block alone moved. These movements may perhaps be looked upon as the early stages of the Kaikoura orogenic movements, and must have affected a large part of the Kaikoura Range. Since, however, the conglomerate is involved equally with the other Notocene rocks in the main Kaikoura deformation, it may best be classed as Notocene. This classification is confirmed by the presence above the conglomerate of marine Notocene rocks.

While it is indubitable that the middle part of the Notocene as locally developed—viz., the Amuri limestone, Weka Pass stone, and "grey marls"—formed a cover to the oldermass which has since been removed by erosion from the higher ground, it is not so certain that the Clarentian beds were everywhere also part of the cover. So far as is at present known,

* Near Kekerangu, immediately outside the area, the great Marlborough conglomerate contains large masses of Amuri limestone, some 72 ft. in greatest diameter.

Clarentian beds occur in the South Island only in the Clarence and Awatere Valleys, and in the hill near Charwell Flats, south of the Looker-on Range, where Dr. Cotton and I found "*Modiola*" *kaikourensis* in conglomerates forming the base of the Notocene at that point. Possibly, however, the basal beds of the Notocene in the Puhipuhi Mountains and the Cape Campbell Range are also of the same age. The thickness of the known Clarentian rocks varies rapidly from place to place, suggesting the proximity of land during their deposition. The basal beds from the Herring River to the Bluff River are terrestrial, and the marine rocks, of which the series mainly consists, are throughout terrigenous, consisting of conglomerates, sandstones, and mudstones, with glauconitic rocks but feebly developed. The thickness of the series, 3,000–9,000 ft., exceeds that of the whole Notocene series in localities such as Oamaru, where peneplanation of the oldermass is known to have been complete before sea-advance, and, combined with the lithological characters, affords clear evidence that considerable erosion of not very distant land was going on throughout the whole of the Clarentian. Although the nature of the surface of deposition as seen in unconformable junctions suggests that the relief of the oldermass was not great, the physiographical evidence for peneplanation is not strong, and it is quite possible that during the Clarentian land may have existed on the site of the Kaikoura and Looker-on Ranges, breaking the continuity of the cover laid down on the oldermass. In estimating the minimum extent of the Kaikoura deformations by adding the thickness of the Notocene to the present heights of the mountains, it is therefore wise to omit the thickness of the Clarentian. For the Kaikoura Range, however, it is necessary to take into account the Clarentian volcanics, since the range is seamed with dykes between the present outcrops of these rocks in the Clarence and Awatere Valleys, and at least 1,000 ft. should be allowed on this account.

The total results of the Kaikoura deformations consisted in the formation of two immense tilted blocks, the Kaikoura and Looker-on Ranges, bounded by great fault-scarps on their south-east sides, with an intermediate fault-angle, the Middle Clarence Valley. Hector (1886, pp. xiv, xv) described the nature of the movements as an extremely local but bold anticlinal fold, the crown of the arch of which collapsed with the formation of a deep longitudinal groove, and considered that the thrusting force which produced the reverse fault came from the west. Cotton (1913, p. 227) considered the results of the movements as the production of two anticlinoria, the axes of which correspond with the ranges, with an intermediate synclinorium, one limb, however, being represented by a reversed fault of enormous throw. It appears probable, both from the lack of summit accordance in the north-eastern parts of both ranges and from the strong folding which the Notocene beds have experienced near the Bluff and the Ure Rivers, that the deformation was not simple tilting but was accompanied by folding, and that the initial surface was, at least in places, warped into anticlinoria with an intermediate synclinorium before faulting took place. Since a cover of at least the Clarentian volcanics and the middle Notocene rocks—say, 4,000 ft.—must have once occupied the sites of the Kaikoura Mountains, the total vertical movement must have been at least 13,000 ft.; but if a preliminary folding took place the total displacement along the fault-lines may have been very much less. Cotton (1913) in his diagram represents the great Clarence fault with a throw of 8,000 ft. or 10,000 ft., but states that it is possible that it is considerably more, and that there is no way of arriving at an accurate estimate of its amount (see fig. 3).

The longitudinal profile of the Kaikoura Range, if not actually conclusive of warping, is not inconsistent with such a method of deformation. From Mount St. Bernard north-east to Mount Symons the range has an approximately even crest at a height of a little over 7,000 ft. It then rises abruptly to the Tapuaenuku massif, with several peaks over 8,000 ft., and culminating in Mount Alarm (9,400 ft.) and Tapuaenuku (9,465 ft.). Farther to the north-east a saddle of 5,516 ft. divides this massif from the Camden–Ben Fluick group of peaks, which lie between 6,166 ft. and 6,560 ft. in height. From thence north-east the peaks lessen rapidly in height, the principal being Black Mount (4,835 ft.), Malvern (4,680 ft.), and Blue Mountain (4,080 ft.), and they are separated by relatively deep saddles.

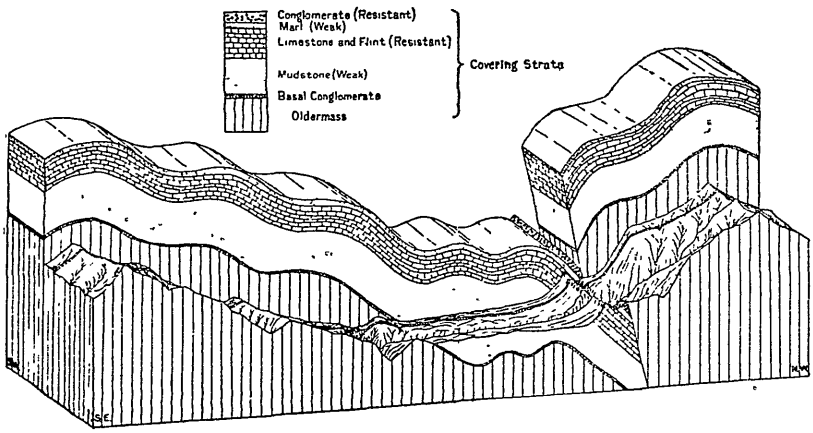


FIG. 3.—Diagram illustrating the type of structure and sculpture in the Middle Clarence Valley (after Cotton).

The range is narrowest between Mount St. Bernard and Mount Symons, and the Tapuaenuku massif is buttressed on the Awatere Valley side by a great spur running from Mount Alarm through Mitre Peak and Mount Gladstone, these three peaks being separated by deep saddles on the spur. Mount Gladstone (7,780 ft.) is three miles north-west of Mount Alarm and is only 1,600 ft. lower, whereas farther south-west the descent from the summit of the range for the same distance is at least 4,000 ft.

The summits of the Tapuaenuku massif are formed of intrusive rocks, which may have enabled them to resist erosion better than other parts of the range; but the summit of Blue Mountain is formed of similar intrusives, and they are probably present throughout the intervening area. The streams draining the lower part of the range to the north-east do not appear in distant views to be more mature than those draining Tapuaenuku, so that it is probable that the original crest sloped fairly steeply from Tapuaenuku to the Blue Mountain. The saddles may be neglected, as they are obviously the result of erosion.

As soon as the earliest Kaikoura deformations raised part of the area above sea-level a drainage-pattern must have been established, which may have been considerably different from the present pattern. There is little reason, however, to suppose that it was markedly different, for the later movements would tend to follow approximately the lines of weakness established during the earlier movements. The drainage-pattern established by the differential uplifts which gave rise to the great Marlborough conglomerate must have been in large part destroyed by the subsequent drowning during the deposition of the marine (Awatere ?) beds which follow the conglomerate. The greater part of the present drainage-pattern appears to be consequent on the later, more intense, deformations. This part includes the Middle Clarence Valley, occupying the tectonic depression between the two mountain blocks, and the numerous large streams entering it on both sides nearly at right angles. The course of the Lower Clarence River in the gorge, however, demands a different explanation.

The Clarence River on leaving the middle valley bends at a right angle, and passes between the north-eastern end of the Looker-on Range and the Sawtooth Range in a rock-bound gorge nearly 4,000 ft. in depth, cut through the pre-Notocene rocks. This bend, as Cotton (1913) has shown, is not an elbow of capture, since there is no gap by which the Clarence could have had its outlet before the hypothetical capture, nor have other eastward-flowing streams made any appreciable progress in breaching the continuous wall of the Looker-on Range. This part of the river-course must therefore be a survival of an older system of drainage, the river cutting down a gorge as the mountains rose.

The Notocene rocks are found at no great distance apart on each side of the range at this point, and it is practically certain that the oldermass was here completely submerged during the later Notocene, so that any pre-existing drainage must have been completely destroyed. The course of the river through the mountains cannot, therefore, be antecedent in the sense of a relict of a pattern existing on an emergent portion of the oldermass during the main Notocene depression. It must be explained, therefore, as an anteconsequent course (*cf.* Cotton, 1917, p. 253)—*i.e.*, a course established during the early stages of the deformation.

The great development of the great Marlborough conglomerate in the area between Kekerangu and the Lower Clarence demands the assumption of local differential movements in this area as well as over the site of the Kaikoura Range, but the mountains then formed may have lain either on the site of the Sawtooth and Looker-on Ranges or seaward of the present coast-line near Kekerangu. The latter is the more probable, since the Sawtooth Range is flanked on the south-eastern side by Clarentian rocks, followed by the Amuri limestone in the Lady Range, which would not be the case if the material of the conglomerate were derived from an uplifted block on this side. The elevation of the Sawtooth Range, then, appears to be due to the anticlinal folding of the later deformations. Prior to these more intense movements one must assume an even or slightly differential uplift after the deposition of the marine beds following the conglomerate, with the formation of a coastal plain sloping to the south-east. On this plain consequent rivers draining south-east became established, and one of these persisted through the later deformations as the lower course of the Clarence River. Probably this anteconsequent drainage removed the greater part of the softer marine beds overlying the conglomerate, so that when the later faulting took place the former were preserved only in the Bluff River and from Deadman's Creek southwards.

The Kaikoura and Looker-on Ranges probably did not escape Notopleistocene glaciation, but its effects have probably been destroyed by the heavy subaerial erosion which followed, since there is no evidence to show that the Middle Clarence Valley was ever occupied by a glacier, while the mountains themselves, so far as explored, now exhibit only the work of normal agents of erosion. It must be remembered, however, that there has been exceedingly little exploration of the higher ground, and that small cirques may exist. In the valley of the Branch River, at a height of about 4,000 ft., I observed from above a peculiar accumulation of debris which seems neither the result of talus slopes nor of stream-action. The upper part of the valley consists of a large depression, circular at the top in plan, filled with a steeply sloping mass of talus in large blocks often many feet in diameter, below which water may be heard trickling. This depression may possibly be a cirque since filled with talus. Farther down the valley, at the point of junction with a large tributary on the right side, there is a large accumulation of shingle running out horizontally from the intervening spur, to which it forms a continuation for some hundred or more yards. The broad top is divided into two parts by a median longitudinal impression. The only explanation of this peculiar accumulation that has suggested itself to me is that it is the commencement of a median moraine formed by the coalescence of two lateral moraines with the intermediate depression not filled. Obviously, however, it is a fairly recent feature, formed after considerable dissection of the range had taken place.

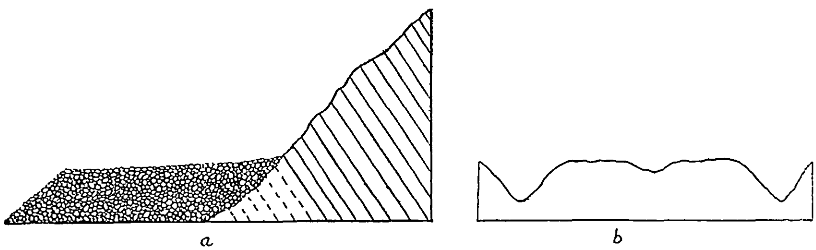


FIG. 4.—Moraine-like accumulation in the Upper Branch—(*a*) in side elevation, (*b*) in front elevation.

The Kaikoura Mountains are asymmetrical owing to the existence of the fault-scarp on the south-eastern side, and have always been so. It is rather on the more gently sloping north-western side, therefore, that snowfields would be likely to accumulate, and the effects of glaciation may be expected to be more intense on that side, which has not been explored. The same holds true for the Looker-on Range. It must be remembered, however, that the north-west side is the more sunny side, and is exposed to the dry north-westerly winds.

Apart from the slight glaciation, the ranges have been greatly dissected by stream erosion, coupled with severe frost-action on the higher ground. Except on actual cliffs, the summits are mantled over with angular blocks of immense size, and Mount St. Bernard, the top of which is dome-shaped, presents the appearance of a gigantic mound of shingle. The upper parts of nearly all the streams consist of huge shingle-slips, and the streams are thus heavily loaded with waste, which nevertheless soon becomes rounded in its transport down-stream. In spite of the immense erosion which is made evident, neither the enclosing ranges nor the Middle Clarence Valley have entirely lost their original asymmetrical character.

The Looker-on Range descends to the valley in spurs of comparatively even and gentle slope, whereas the Kaikoura Range presents much steeper slopes, especially in the lower part, where steep spurs end abruptly near the fault-line. This asymmetry is more marked opposite the Tapuaenuku massif, where a single fault dominates the structure, than in the south-western part of the valley, where there are two or three parallel faults. In the north-eastern part the strip of Notocene rocks lies wholly to the north-west of the river, and is much nearer to the summit of the Kaikoura than to that of the Looker-on Range. Originally the river may have run in the actual fault-angle, and if so it has doubtless been forced to the other side of the valley by the heavy accumulations of talus that must have accompanied the production of the fault-scarp. It is quite possible, however, that the actual angle was not the bottom of the original tectonic depression, and that the present course of the river is approximately the axis of the original synclinorium.

The fault-scarp of the Kaikoura Range along the line of the great Clarence fault is not well preserved north-east of the Dee Stream, where the crowded insequent tributaries of the Limburne, the Mead, and the Swale have dissected the original front scarp. From the Dee south-west for some miles there are steep spurs, passing into veritable facets of some thousands of feet in height, above which appears a prominent bench. It seems probable that this part of the range has undergone a later renewed faulting, for below it the relief forms cut in the Notocene rocks have been, according to McKay's descriptions, completely covered with heavy deposits of gravel. Cotton, who with the writer viewed this part of the valley from a distance, describes it as a stretch of piedmont plain, now dissected, formed by the coalescence of fans of coarse waste.

McKay described and mapped the great Clarence fault as bending obtusely at the Bluff River, and running obliquely to its former course as far as Quail Flat, where it resumed its original direction. It is true that a little to the south-east of the Bluff River the strip of Notocene rocks pinches out, but it appears highly probable that the fault continues on in its original direction for a considerable distance, bounded on each side by pre-Notocene rocks. On the valley side these have not been worn to so low a relief as the Notocene rocks farther north, owing partly to their strength and probably partly to the fact that they form a smaller tilted block facing a parallel fault along the line of the river from Red Hill to past the Herring River, close to which they rise to heights of over 3,500 ft. The line of the great Clarence fault to the south-east of the Bluff River appears, in a distant view, to be marked by a series of well-preserved facets for a number of miles. Doubtless, as between the Dee and the Muzzle, this part of the fault-scarp owes its origin to a later renewed faulting. It may be suggested that the depression in which Lake McRae lies is on the continuation of the great Clarence fault, and that it continues on into the valley of the Dillon River, which is thus, like the Clarence, a tectonic depression.

The greater part of the drainage of the mountain-ranges is, as already mentioned, accomplished by consequent streams which join the Clarence nearly at right angles, together with their insequent tributaries. These streams run approximately south-east and north-west. In the mountains to the west of the Upper Clarence there is a very marked development of streams with north-north-east and south-south-west courses, suggesting a well-developed subsequent drainage. The Elliott River joins the Clarence River with a south-south-west course, immediately opposite the Gore River, which has the same direction, flowing north-north-east. Both these rivers rise in passes through the enclosing ranges, and the line of the two is continued to the south-west by the Conway River, and to the north-east by the Tone River and Castle Creek, tributaries of the Awatere River. This alignment is very marked and can hardly be accidental; but whether it is a case of ordinary subsequent drainage conditioned by the existence of a band of weak rocks, or of an old fault-zone, or is consequent on recent faulting oblique to the general line of the Kaikoura faults cannot be determined on the evidence at present available. It is perhaps significant that this line approximately connects the greatest developments of Clarentian volcanics in the Clarence and Awatere Valleys, suggesting the existence of a pre-Clarentian line of weakness in the same direction.

In the period following the Kaikoura orogenic movements the Clarence River became graded, and the lower slopes of the middle valley, consisting largely of Notocene rocks, were reduced to mature erosion forms. This mature topography has been partially obliterated, south-west of the Dee, by smothering with gravel fans coalescing into a piedmont plain at the base of the Kaikoura Range, and probably due, as explained above, to a renewed uplift along the line of the great Clarence fault. Both the mature erosion forms and these gravel plains have been partially dissected by a revival of erosion caused by a late regional uplift, which elevated the delta of the Clarence River 600 ft. (Cotton, 1914B), and gave rise, after rejuvenation, to well-marked terraces of much less height between Quail Flat and the Bluff River.

In the strip of Notocene rocks involved along the line of the great Clarence fault the hard strata of the Amuri limestone and Weka Pass stone, lying between the softer Clarence mudstones and the "grey marls," stand up as a monoclinal ridge cut through by the numerous gorges of the consequent tributaries of the Clarence River. The south-eastern slopes present precipitous escarpments, passing below into great screes of dazzling white limestone, which cover the outcrops of the highest Clarentian beds and often those of the flint-beds. The north western dip-slopes where not too steep are covered with a rich black soil, and afford the best pastures of the valley. Since the ridge contains no air-gaps, and since the gorges of the streams that cross it often fork within the limestone, Cotton concludes that the drainage must have assumed its present form before denudation had exposed the limestone monocline as a prominent ridge, and that the streams now occupying the gorges may be described as superposed consequents which flowed initially upon great screes from the fault-scarp.

Along the greater part of the great Clarence fault the great Marlborough conglomerate, which is also a resistant band, rests against the pre-Notocene rocks, and does not form a marked feature in the topography; but to the north-east of the Swale Gorge, where it is surrounded on each side by mudstones, it forms a series of hogbacks, the highest of which is known as the Razorback Ridge. This is, nevertheless, much inferior in height to the limestone monoclinal of the Chalk Range near by.

The softer members of the Notocene series, and particularly the mudstones of the Clarentian and of the "grey marls," have been reduced to lower relief with the development of subsequent streams along their lines of strike. In the Clarentian the best-developed subsequents are those of the Nidd, Cover, and Wharf, tributaries of the Swale Stream, which separate low strike ridges, mainly of sandstone. Along the outcrop of the "grey marls" there are a number of short subsequent streams forming a single linear depression, which does not appear ever to have been occupied by a single stream. The grade formerly established in the insequent and subsequent tributaries of the consequents flowing into the

Clarence River has been destroyed by the rejuvenation consequent on the recent epeirogenic uplifts, which has worked back almost to their sources, while a regrading has seldom extended more than a short distance from their mouths.

THE PRE-NOTOCENE ROCKS.

Owing to their monotonous character, and to the general absence of distinctive lithological or fossiliferous strata which might give some indication of their structure and disposition, the study of the pre-Notocene rocks is difficult. I have not attempted it, and must limit myself to such casual observations as I have made. McKay has made a special study of these rocks in certain areas, especially in the mountains between the Wairau and Awatere Valleys, in the Muzzle, and between the Elliott River and the Upper Clarence, and has attempted to establish a sequence in the first and last localities; the lowest beds he describes as grey sandstones and slaty shales with broken plant-remains, and these are followed by a series of red and green rocks which are calcareous near Taylor's Pass, between the Wairau and the Awatere; similar rocks near the Elliott River are again overlain by sandstone.

The directions of strike and dip appear to be very variable, doubtless owing to the folds of a smaller order, and to numerous faults, which tend to obscure the major outlines of structure. On the whole, McKay describes the rocks as striking in a north-easterly direction, with dips to the south-east or north-west. Many of his observations, however, appear to have been made at a distance, and cannot in these cases be accepted as altogether reliable, since joint-control plays a large part in determining the details of outcrop, and greywacke bluffs often trend transversely to the strike. My own observations, resumed in Table III, would tend to show that a strike west of north is prevalent in at least some parts of the area. Cotton (1913, p. 244), arguing from the variability of the strikes and dips, considers it probable that the older axes of folding make an angle with those of the later Kaikoura folding—*i.e.*, that the prevalent strikes are oblique to the trend of the mountains.

TABLE III.—OBSERVED STRIKE AND DIP OF PRE-NOTOCENE ROCKS.

Locality.	Strike	Dip
Spur from upper end of Ure Gorge to Blue Mountain ..	N.E.	Nearly vertical.
Tributary of Wharf Stream from Sawtooth Range, at unconformity with the Clarentian	N. 20° W.	Steep, N.E.
The same stream, half-mile up	N. 50° W.	..
Clarence River, upper end of Quail Flat	N. 20° E.	40°, S.E.
Clarence River, lower end of Quail Flat	N. 30° W.	Nearly vertical.
Herring River, at unconformity with north-western Clarentian outcrop	N. 15° W.	Very steep, S.W.
Herring River, at unconformity with south-eastern Clarentian outcrop	N. 15° W.	50°, S.W.
Pack-track from Quail Flat to Reserve Station, half-mile on Reserve side of saddle	N. 30° W.	Steep, S.W.
The same, a few hundred yards nearer Reserve ..	N. 70° W.	Nearly vertical.
The same, half-mile nearer Reserve	N. 35° W.	Nearly vertical.
The same, 200 yards nearer Reserve	N. 50° W.	56°, S.W.
The same, small saddle two-thirds way down	N. 30° W.	Nearly vertical.

The majority of the pre-Notocene rocks show a striking resemblance to the greywacke-argillite series so prominently developed in the Wellington district and in the eastern mountains of Canterbury, but it is perhaps significant that neither McKay nor I have observed the annelid *Torlessia mackayi* Bather, so common in these other areas. The only palaeontological evidence of age found by McKay, besides broken plant-remains, was a fragment of a fern "apparently *Taeniopteris*," from the lowest beds on the west side of the Elliott River. This would tend to prove, if his identification of the specimen and his reading of the sequence are correct, that all the pre-Notocene rocks are of Mesozoic age. They are all, of course, pre-Clarentian—*i.e.*, earlier than the middle Cretaceous. The presence of bands of red and green argillites in the Kaikoura Mountains, however, renders this improbable. During the ascent of Tapuaenuku I observed from above one such band in the hills fronting the fault-line between the Mead and Dee Rivers. The Lands and Survey map of the Tapuaenuku Survey District presumably records a second band of these rocks by the name "Red Hills" given to a spur on the north-west side of the Hodder River. Now, in the similar rocks crossing Taylor's Pass, McKay (1890, p. 116) records the presence of fossiliferous limestones yielding fragments of *Inoceramus* shells. It must be remembered that the Permo-Carboniferous Wairoa limestone also contains fragments of a fibrous shell commonly called *Inoceramus* by McKay, so that it is perfectly possible that the limestone of Taylor's Pass is also Permo-Carboniferous, and that similar rocks occur in the Kaikoura Range.

I have observed in two widely separated localities fragments of fossils which indicate a Mesozoic age for the rocks containing them, but in neither case are the rocks quite typical of the pre-Notocene greywacke-argillite series, and they belong, I believe, to a younger series, though both are most clearly pre-Clarentian. In the lower Dee River, after the basal Clarentian conglomerates are passed, and on the banks of the Clarence River between the Dee and the Limburne, the rocks consist of hard sandstones, not unlike typical greywackes, and much-jointed black mudstones with white bands and large rounded concretions, in which coarse fragments of a fibrous shell like *Inoceramus* are found. Again, in the Herring River, the rocks lying unconformably below the eastern Clarentian outcrop consist of thin and regularly bedded sandstones alternating with shales, none of the rocks being much more indurated than many exposures of the Clarentian. They strike N. 15° W., and dip at 50° to the south-west, whereas the overlying Clarentian rocks strike N. 40° E., and dip at 40° to the north-west, so that the unconformity is exceedingly well marked. From the underlying series I obtained a nearly complete specimen of *Inoceramus*, which I submitted to Mr. H. Woods, of Cambridge, but unfortunately he pronounced it indeterminable as to species. The sandstones also contain plant-impressions. I believe a sufficient collection could be made at this point to determine the age of this series. I discovered its fossiliferous nature only on my way out from the valley and after the pack-horses carrying my luggage had preceded me up the pass, so that it was impossible at that time to spend any length of time collecting.

Sandstones and shales, in general similar to the typical greywackes and argillites, but somewhat less indurated, and containing calcareous concretions, are of wide occurrence in Marlborough. They underlie the Upper Cretaceous beds at Amuri Bluff unconformably, and have been termed by Buchanan (1867) the "marlstones," a name that is certainly inapplicable. Similar rocks were termed by von Haast the "cannon-ball sandstones."

[B. C. Aston, photo.

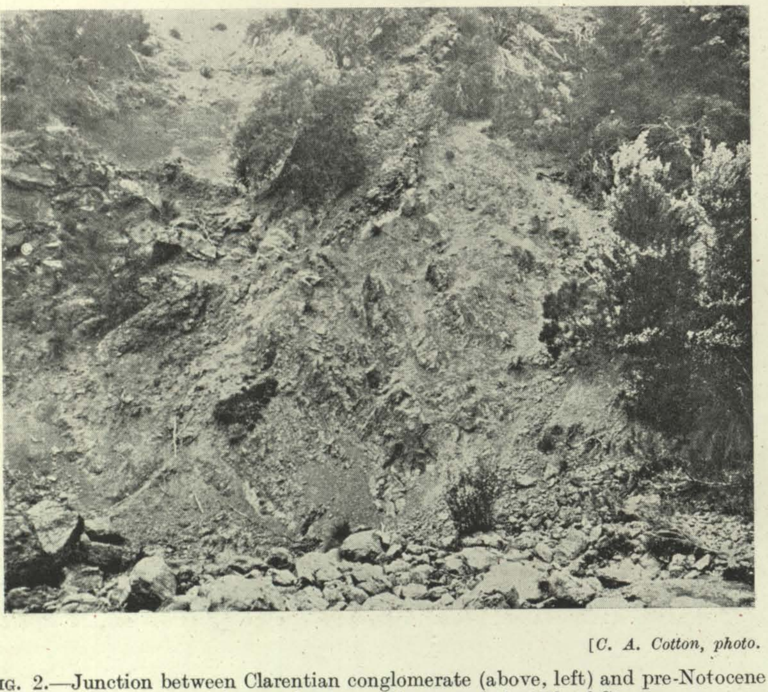
FIG. 1.—The summit of Mount Tapuaenuku, showing the rubble that mantles the higher peaks of the Kaikoura Range.

[B. C. Aston, photo.

FIG. 2.—A cliff of "syenite" on a spur leading from the Dee River to Mount Tapuaenuku, showing numerous intersecting dark dykes.

[C. A. Cotton, photo.

FIG. 1.—View from Coverham, looking westward. The foreground consists of Clarentian rocks, in the middle distance the monoclinal ridge of Amuri limestone is cut by the Mead Gorge, and in the distance Mount Tapuaenuku is seen.



[C. A. Cotton, photo.

FIG. 2.—Junction between Clarentian conglomerate (above, left) and pre-Notocene greywackes (below, right) in a tributary of the Wharf Stream.

I have observed these concretionary rocks in the Awatere Valley between Middlehurst Station Creek and the George River, and around Awapiri. They are present in the lower Woodside Stream, and thence along the road to the Ure River, and for some distance up this valley. In the Clarence Valley they occur not only at the mouth of the Dee, but at Quail Flat and in the Lower Herring River, and the latter occurrence tends to link them up with the *Inoceramus* sandstones farther up the same river. The rocks immediately under the north-western Clarentian outcrop are concretionary sandstones interbedded with thin argillites, and strike N. 15° W., with a dip nearly vertical but steeply to the west.

There is a series of rocks in the Ouse River which perhaps belongs here; it lies below the Clarentian rocks, but the unconformity is not well marked and was overlooked on my first visit, so that I supposed they were all Clarentian. The rock immediately below the Clarentian basal conglomerate is a thick, massive grey sandstone containing shaly partings. Below this for over two miles the rocks consist of hard black shales and hard sandstones with occasional concretions. There are many small contortions and faults, and the dips are very irregular. Two conglomerates of considerable thickness which appear in the series contain greywackes, quartzites, and red jasperoid rocks, besides soft sandstones, crystalline limestone, and porphyries. At the time of examination I considered them, with the overlying rocks, to be Clarentian, and from their great similarity to Clarentian conglomerates elsewhere it is possible that they are of this age and are involved in the pre-Notocene rocks by faulting; but of this I saw no trace. Unfortunately, owing to the amount of water in the stream, I did not examine the relation of the lower conglomerate to the beds farther down the stream.

Intrusive Rocks in the Pre-Notocene.

Intrusive rocks of various kinds have a great development in the pre-Notocene rocks of the Kaikoura Range, and particularly in the Tapuaenuku massif (Plate XXIV, figs. 1 and 2), the upper part of which is composed almost solely of them. Owing to their hard nature they form the majority of the boulders in the Dee and other tributaries of the Clarence, and also in the Hodder and lower Awatere Rivers. In 1913 I described their petrological characters from specimens collected from the Dee gravels, and, although there are doubtless numerous other types besides those collected there, the general character of the series is clearly enough apparent. The more siliceous rocks consist of quartz syenites and quartz diorites. The less siliceous are mostly fine- and coarse-grained doleritic or gabbroid rocks, frequently containing olivine, brown hornblende, and biotite, and rarely quartz. In addition there are hornblende lamprophyres and doleritic rocks with lamprophyric affinities. The list of rock-varieties given by Hector (1886, p. xxxi) does not appear to be the result of microscopical examination, and may be safely neglected; nor can McKay's identifications of the rock-varieties be regarded as more than a general indication as to their nature.

McKay (1890B, p. 130) considered that the rocks were injected into the pre-Notocene at two widely-separated periods, the older rocks, consisting of diorites, syenites, and felsite rocks resembling elvanite, being confined to the pre-Notocene, while the darker-coloured and more basic rocks were intruded subsequently to the deposition of the lower part of the Clarentian. The latter rocks in the Awatere Valley, between the Otterson and Tone

Rivers, he describes as crowded with dark basic dykes, which can be traced into the pre-Notocene of the Kaikoura Range. The evidence of the Clarentian basal conglomerates is to this extent favourable to McKay's division of the rocks: that the only igneous rocks included in them in either the Clarence or the Awatere Valleys are granites, microgranites, and quartz porphyries. Typical granites or quartz porphyries, however, have not yet been found in the Kaikoura or Looker-on Ranges, and I incline to the opinion that the syenites belong to the same period of vulcanicity as the more basic intrusions, and that this period is coincident with the outpourings of Clarentian lavas in the upper parts of the Middle Clarence and Awatere Valleys. There are four reasons for this belief. In the first place, such a differentiation series is common in intrusive rocks, as witness the association of granophyres and quartz dolerites with the Tertiary volcanic rocks of the British Isles. In the second place, intrusions in the greywacke-argillite series of both Islands of New Zealand are rare, whereas in the Kaikoura Range they are abundant, and lie between two prominent developments of Clarentian lavas. In the third place, boulders of the syenites appear to be totally absent from the great Marlborough conglomerate, suggesting that they had not been uncovered by erosion at the time of its formation. Finally, and most conclusively, I observed that the syenites on the spurs leading to Mount Tapuaenuku contained frequent inclusions and schliere of camptonitic facies.

In the ascent of Mount Tapuaenuku I observed occasional dense amygdaloidal dykes in the pre-Notocene rocks of the upper Dee. At about 6,000 ft., on the spur between the Dee and the Branch, the pre-Notocene rocks have a strike a few degrees west of north. The upper part of this spur, right to the summit, is composed of a reddish syenite, intersected by innumerable dark dykes 1 ft. to 2 ft. thick, which have mostly an east–west trend (Plate XXIV, fig. 2). The neighbouring spurs on each side appear to have the same character. On the exterior these dykes are often dense, but in the centre coarsely crystalline. This proves that the syenite had cooled sufficiently to be fissured before the intrusion of the dark dykes, and perhaps even sufficiently to chill the margins of the dykes, although tachylitic selvages were not observed. The dark dykes, however, are intersected and faulted by one another, proving that they were injected at sufficiently distant intervals to permit of consolidation before the next intrusion.

The greatest development of the intrusives is undoubtedly in the Tapuaenuku massif, but they are probably present in smaller number throughout the range. In the upper Muzzle, McKay states that "the sedimentary rocks are more rapidly degraded than the trap-dykes intersecting them, so that the latter, traceable for long distances, form a remarkable feature in a wild and rugged landscape. . . . The brecciated slaty beds and mudstones are broken up and so rapidly removed from the slopes of the range on the east side of the creek that the dykes project various heights above the general surface. They trend for the most part north, between barren slopes of black shingle, while a lesser number of dykes running south-east, and some of them east, enclose areas which, while the barriers stand, are completely walled around. The greater number of the dykes trend north, and pass into or under the cluster of peaks south of Tapuaenuku." (McKay, 1886, pp. 50, 51.)

Judging from the small number of igneous boulders in the Bluff River, McKay considers it clear that comparatively few dykes are present in the mountains drained by it, but he observed "several massive dykes of a serpentinous character" in the lower slopes of the range, near the mouth of the gorge. Between the Dee and the Mead River McKay notes the presence of numerous dykes of grey porphyritic syenite and dark porphyritic hornblende rock intersecting the older rocks of the higher part of the range. From the Mead to Blue Mountain the higher ground is unexplored geologically, but the presence of dykes may be inferred from the boulders present in the gravels of the Swale. The summit of the Blue Mountain and for a considerable distance the spurs descending from it are composed of a dark, coarse-grained dolerite, which weathers to a gritty waste in places covered with a reddish, dry soil. There are lighter-coloured patches within the intrusion, the forms of which were not clear. On the spur running from the upper end of the Ure Gorge to the summit the junction with the pre-Notocene rocks was observed. The latter strike north-east at this point, and dip almost vertically, but a little lower down they are sharply contorted. There appeared to be a contact mineral in the argillites near the junction, but it was too much weathered for microscopical determination. At the observed junction the intrusive rock was light-coloured and finer-grained than elsewhere, and other fine-grained specimens were observed in the screes higher up. I have noted below the occurrence, at a lower level in the Blue Mountain Stream, of fine-grained dark dykes invading the Clarentian. Before the formation of the great Clarence fault these rocks presumably stood at a high level, and may be apophyses of the Blue Mountain intrusive.

So little geological exploration of the pre-Notocene rocks of the Looker-on Range has been made that little can be stated as to the abundance of intrusive rocks. I noted the presence of a moderately coarse doleritic dyke a little on the Reserve side of the saddle on the pack-track between the Reserve and Quail Flat. McKay records the presence of some dykes of grey intrusive rock, judged to be diorite, on the east side of the range, north-east of the Kahutara gorges, and dykes of a darker colour and basaltic character on the western side of the same part of the range. A fair percentage of coarse- and medium-grained doleritic rocks is present in the gravels of the Hapuku River, proving the presence of intrusives in the north-east part of the Looker-on Range. McKay states that he is informed that in the gravels of the George River, entering the Lower Clarence on the south side, there is so great an abundance of dark-coloured crystalline boulders as to make it comparable in this respect with the Dee or the Branch. I observed a boulder of lustre-mottled hornblendic rock in Heaver's Creek, but as this occurred below the outcrop of the great Marlborough conglomerate it is unsafe to make any deductions from it as to the presence of dykes in the headwaters of that stream. The tributaries of the Wharf, draining the other side of the Sawtooth Range, contain no boulders of igneous rocks above the outcrops of the Clarentian conglomerates.

McKay has described a great number of intrusive rocks in the country north-west of the Awatere River, and from his descriptions they seem to resemble those of the Kaikoura Range.

The Notocene Rocks.

So far as Notocene geology is concerned, the east coast of the South Island may be divided into two main diastrophic districts, characterized by the age and nature of the middle limestone member, the dividing-line being the Rakaia River. The southern district has as the middle member of its sequence a relatively shallow-water and mainly bryozoan limestone, the Ototara limestone, which is Ototaran, or Middle Oamaruian, in age. The northern district has as the middle member of its sequence two limestones, often separated by a phosphatic band, the lower (Amuri) limestone being relatively deep-water and chalky, and certainly older than Ototaran. The closing member of the marine sequence in the southern district is Awamoan (Upper Oamaruian), whereas in the greater part of the northern district the closing member is Waitotaran (early Wanganuian). Both districts may be again subdivided according to the age of the earliest marine transgression. The sequence in the southern district commences north of the Kakanui River with Ngaparan (Lower Oamaruian) beds, but south of that river there are two or three localities where it commences with Kaitangatan beds. The sequence in the northern district commences with Cretaceous beds, which south of the Hapuku River are Piripauan (Senonian), but north of that river are Clarentian (Albian).

The reasons for uniting the Notocene rocks of north-eastern Marlborough with those of south-eastern Marlborough and northern Canterbury in a common diastrophic district are especially the presence in each area of the Amuri limestone, Weka Pass stone, and "grey marls"; but there are two other characteristics, besides the age of the basal beds, which distinguish the two subdistricts. In the northern the Amuri limestone attains an enormous development, being measurable in thousands of feet, instead of in hundreds as in the southern, and flint-beds are well developed. Moreover, although where the full sequence is preserved the Waitotaran beds are present in both subdistricts, in the northern one they are separated from the lower marine Notocene beds by a fluviatile deposit, the great Marlborough conglomerate, which appears to have no counterpart in the Waipara area, although it occurs as far south as Greenhills and Amuri Bluff.

There are several separated outcrops of Notocene rocks in the Middle Clarence Valley, due to involvement along parallel fault-lines, and in one case to involvement in a synclinal depression. The fault-lines run in a north-east and south-west direction, and are inclined very steeply. McKay describes them as reversed—*i.e.*, with dips to the north-west—and I have not made any observations which tend to disprove this; but in the majority of sections the fault-line is obscured by slips and talus slopes. The Notocene rocks in all cases lie to the south-east of the fault, and dip at steep angles against it—*i.e.*, to the north-west—the lower beds resting unconformably on pre-Notocene rocks to the south-east. The outcrops thus take the form of strips, narrow in proportion to their length, and trending north-east and south-west.

The principal strip is that along the great Clarence fault, which extends from the Gentle Annie Stream to the Ure Valley. In the middle part of this strip, from the Bluff River to the Mead River, the Notocene rocks form a simple monoclinal series with minor folding in the lower rocks. At each end the rocks are folded into synclinals, that at the north-eastern end being overturned and truncated by the branching of the fault, so that the succession for some distance to the south-east of the fault-line is reversed, and the beds from the limestone upwards are repeated several times.

Along the middle part of the strip, from the Bluff River to the Mead River, the whole Notocene series up to the great Marlborough conglomerate is preserved in such a way that the latter rock everywhere rests against the fault at the surface. As there is no great difference in level at the surface, this shows that the base of the Notocene has not been greatly warped in a direction longitudinal to the fault-line. This is not the case in the other parallel faults.

At the north-eastern end the structure becomes complex. There is a large area of down-faulted Notocene rocks between the Isolated Hill Creek, the upper Nidd, and the eastern side of Whernside. The limestone of Whernside is continuous with that of Benmore by a narrow strip, and presents a steep scarp to the Benmore Stream, where it probably rests conformably on Clarentian rocks. Along its north-western boundary it is probably faulted against the middle or upper Clarentian. The main monoclinal ridge of Amuri limestone passes from the Chalk Range and Brian Boru in a great curve to Benmore, but the outcrop of the Clarentian rocks is divided into two parts by the infaulted limestone of Whernside. The upper Clarentian beds outcrop under the limestone on the same curve, finally feathering out in the upper part of the Isolated Hill Creek. The lower beds cross the upper Wharf into the watershed of the Kekerangu River, where the whole series is presumably again resumed in the Front Ranges.

Discontinuous strips of Notocene rocks are involved along a second fault, which we may call the Quail Flat fault, running from the Gore River to the mouth of the Herring River, thence approximately along the Clarence River past Quail Flat, and ending on the north-west side of Red Hill. Between the Gore River and the Herring River all beds up to the Weka Pass stone are involved at river-level, and in the Herring River the width of the outcrop is extended by well-marked folding for some miles to the south-east of the fault-line, but farther to the north-east only discontinuous strips of the lower Clarentian rocks are preserved. There is evidently along this line strong longitudinal warping of the base of the Notocene, equal to nearly the whole thickness of the series, besides transverse folding.

A third small strip of lower Clarentian rocks only is involved in another parallel fault, which crosses the Herring River several miles above its mouth. This fault has not been traced on either side of the river. McKay (1887, p. 104) mentions the existence of two other "outlying patches" of Clarentian rocks, the one east of Gridiron Hill, the other one and a half miles to two miles east of Limestone Hill, but whether these are involved along the same or still another fault-line or are simple outliers is not known.

The large outcrop of Notocene rocks which extends from Bluff Hill across the Clarence River (below the junction of the Bluff River) to beyond Limestone Hill has not been satisfactorily explored. It is apparently not involved along a fault-line, but seems to constitute an outlier preserved by a synclinal depression west of the great Clarence and Quail Flat faults. The Notocene here attains its greatest elevation, rising to 4,231 ft. in Limestone Hill.*

In the detailed descriptions following it will be convenient to treat separately the Clarentian, the Amuri limestone and Weka Pass stone, the "grey marls," and the great Marlborough conglomerate.

The Clarentian Rocks.

The Clarentian as defined by me in 1917 comprises all those Notocene rocks in the Middle Clarence Valley lying below the flint-beds at the base of the Amuri limestone. In the neighbourhood of Coverham fossils have

* There are at least three mountains in the Clarence Valley to which this name has been given—one in the Upper Swale Valley, one between the Mead and Dee Gorges, and one on the south-east side of the Clarence River, above the junction of the Bluff River. It is the last that is here referred to.

been obtained from almost the bottom to the top of the series, and have been pronounced by Woods (1917) to belong all to one fauna, which he correlates with the Lower Utatur group of India, which is of about the same age as the Upper Gault and Upper Greensand of England—*i.e.*, Albian. Moreover, all other fossils from rocks having the same relative position in both the Middle Clarence and Awatere Valleys are, according to Woods, of similar age, so that the inclusion of all these rocks under one group-name is justified, although the total thickness of the Clarentian at Coverham surpasses the whole of that of the Notocene in places such as the Waipara district, where rocks from Senonian to Pliocene are represented. This is probably due to the fact that the Clarentian deposition followed close on the post-Hokonui orogenic movements, and erosion on a fairly emergent land-mass was still active. Probably also the Coverham area was not far from the mouth of a large river.

The Clarentian rocks, while preserving for the most part the same general character of sandstones and mudstones, vary rapidly from place to place, and there is no single characteristic stratum which can be followed from end to end of the valley. There are, nevertheless, some notable differences in the rocks at the two ends of the valley. The rocks at Coverham are dominantly black mudstones with occasional calcareous concretions, divided into three main groups by sandstones, and resting on conglomerates. In the Herring River, and thence nearly to the Bluff River, the sequence commences with terrestrial coal-measures, followed by several lava-flows, and these are succeeded by a marine series of sulphurous mudstones, sandstones with pebble-beds, loose sands, and glauconitic sandstones.

Coverham (Plate XXV, fig. 1).—I have suggested the following division of the sequence at Coverham (Woods, 1917, p. 2), but it must be clearly understood that this classification has a strictly local application :—

	Feet.
Sawpit Gully mudstones	3,200
Nidd sandstones and mudstones	550
Cover Creek mudstones	2,000
Wharf Gorge sandstones	450
Wharf mudstones	1,500
Basal conglomerates	250

The conglomerates were examined in a tributary of the Wharf Stream coming from the Sawtooth Range, where they strike at the base N. 40° E., dipping at 45° to the north-west, and near the top strike N. 60° E., with dip 60° to north-west. The underlying pre-Notocene greywackes and argillites strike N. 20° W., with a steep dip to the north-east. The unconformity is well exposed in section (Plate XXV, fig. 2). The conglomerates are, in part, of a peculiar character, not uncommon elsewhere in the Clarentian—viz., that they consist of well-rounded pebbles, a few inches in diameter, of hard rocks such as quartzite, set in a matrix of mudstone. The conglomerate series at this point commences with beds of hard conglomerate alternating with this pebbly mudstone, then some layers of pure mudstone, and then more bands of pebbly mudstone, the whole being about 250 ft. in thickness. The conglomerate consists mainly of well-smoothed ellipsoidal pebbles of hard sandstone and quartzite, up to 8 in. long, but mostly with a major diameter of 3 in. to 4 in., with only a few pebbles of mudstone and soft sandstone near the base. Green and liver-coloured quartzites are relatively rare, but white quartz and bright-red and pink jasperoid quartz are common. Granites and porphyries are only occasionally seen, while dark crystalline rocks appear to be absent. No schist or limestone pebbles were observed. The conglomerates were not followed along their outcrop. They cross the Ouse Stream about a quarter of a mile below the junction of the Wharf as a narrow band of pebbly mudstone only 5–10 ft. thick. As already mentioned, there are two thick bands of conglomerate farther down the Ouse which may possibly be Clarentian.

The Wharf mudstones form both banks of the Wharf Stream between the gorge and the crossing of the pack-track, above which the strike becomes more easterly, and the beds continue into the upper Wharf. The rocks are mainly dark micaceous mudstones without many concretions, and near the junction of the tributary above mentioned yield finely-preserved specimens of *Belemnites superstes* Hector. Near the crossing of the pack-track sandy beds are crowded with the shells of a large depressed *Inoceramus*, and lower down the creek the mudstones contain *Aucellina euglypha* and *Belemnites superstes*. No observations of strike and dip were made, except that in one place on the left side there is a reversal of dip. In the upper Wharf, what are presumably the Wharf beds consist predominatingly of mudstones containing large *Inocerami*, with occasional bands of harder sandstone, forming waterfalls, and thin bands of pebbly mudstone. The beds are thrown into a series of folds, so that a clear section was not observed. The mudstones, however, are very thick. The Wharf beds were again observed in the Ouse, about 200 yards below the junction of the Wharf, in a large cliff on the right-hand side consisting of thin-bedded sandstones and mudstones. The sandstones contain coaly plant-remains, and one block with shell-fragments was obtained, which contained a plicate ostreid shell, part of the dorsal valve of a Terebratellid (the only brachiopod yet obtained from the Clarentian), and a small piece of the test and some minute spines of an echinoid. A concretion picked up at this point contained a gasteropod and a *Dentalium*, and is in the hands of Professor Wilckens, of Jena, for identification.

Still farther down the Ouse, the lowest Wharf beds consist of hard mudstones crowded with a large flat *Inoceramus*, and are the cause of small waterfalls on tributaries coming in on each side (*cf.* Cotton, 1913, fig. 14). No specimens suitable for identification could be extracted, but pieces 9 in. in length were obtained, and the whole shell must be over 1 ft. in length.

McKay's description of the Wharf beds is as follows: "The lowest rocks, as conglomerates, are rather suddenly succeeded by black slaty, marly beds, containing concretions of cone-in-cone limestone, and sandstone bars full of *Inoceramus*, and here and there a belemnite and other fossils characteristic of the Amuri series."

The Wharf Gorge sandstones and mudstones occupy a width of about a quarter of a mile in the Wharf Gorge, which crosses them transversely to the strike, and in the lower part of the Cover Stream. The rocks are dominantly sandstones, in beds 6 ft. thick below and 3 ft. above, and are parted by thin beds of mudstone. The sandstones in the upper part are fissile and slightly micaceous, and contain poorly preserved plant-remains, principally fossil wood, and occasionally the cast of a belemnite. The strike in the lower end of the gorge is E. 10° S., dip 63° to the north. The Wharf Gorge beds extends in an east-north-east direction into the ridge between the Wharf and Cover Streams, but are not there well exposed for study. Where they cross the Ouse the sandstones are not so well developed. They have here a strike of N. 60° E. and dip 45° to the north-west in the lower part, and a strike of N 70° E., and dip 56° to the north-north-west at the junction of the Ouse and Nidd.

McKay describes the Wharf Gorge beds as follows: "The higher beds [*i.e.*, higher than the Wharf beds] are thick bedded sandstones of a grey colour, light-grey or yellow when weathered, parted by thinner beds of black slaty shale."

The Cover Creek mudstones are black micaceous mudstones with numerous small irregular calcareous concretions which are more generally fossiliferous than those of other divisions of the Clarentian. Belemnites and occasionally specimens of *Inoceramus* are also found embedded directly in the mudstones without being surrounded by concretions. There are a few occasional beds of sandstone. The beds below the house at Coverham strike N. 60° E., with dip 55° to the north-west. A little farther up the Cover Creek the strike turns more to the north. The beds cross the lower Nidd and are exposed in the lower Swale, where they have the same characters but are less fossiliferous. The best locality for fossils lies in Cover Creek, about 200 yards above the old sheep-dip. Here were obtained the ammonite *Turrilites circumtaeniatus*, *Belemnites superstes*, *Inoceramus concentricus*, the carapace of a crab, a small compound coral, the skeleton of a fish, numerous fish-scales, and specimens of fossil wood. McKay's description of the Cover Creek and higher beds is as follows: "These beds [the Wharf Gorge sandstones] are followed by softer, more argillaceous or marly strata, until reaching a bed of sandstone, which yields the fossils of the black grit, and thus the sequence of the Amuri series is here somewhat arbitrarily brought to a close. . . . The black grit . . . as a calcareous sandstone contains ammonites, *Inoceramus*, fish-scales, and numerous leaves of a plant common enough in the underlying Buller series. . . . At Coverham, from the horizon of the black grit to the flint-beds underlying the Amuri limestone, there is an enormous development of black micaceous clay-marls, divided into two parts by a band of grey or brown sandstones containing plant-remains. These beds are crowded with calcareous concretions, and, especially in the higher beds, contain *Inoceramus* in great numbers."

Unfortunately the collections preserved by McKay from Coverham were disappointingly small and poor, and the ammonite mentioned above was not amongst them. There is a little uncertainty which is the bed he called the black grit, but it is probably a sandstone in the Cover Creek beds opposite the house, which lies 50–100 ft. below the horizon where *Turrilites circumtaeniatus* was obtained, and which can be traced into the Nidd.

The Nidd sandstones and mudstones cross the Nidd obliquely above the junction of Sawpit Gully with a strike of N. 60° E. and a dip of 55° to the north-north-west, and they cross Sawpit Gully near the bottom. They consist of sandstones with a greenish tinge, 1 ft. to 2 ft. in thickness, separated by 6 ft. to 20 ft. of mudstones. Both sandstones and mudstones contain in abundance a large *Inoceramus*. They are followed, up the Nidd, by sandy mudstones which become flinty above, and contract the valley to a gorge. The mudstones contain a considerable amount of pyrites and exhibit a yellow efflorescence. The flint-beds seem to widen in outcrop to the east in the ridge between the Nidd and the upper Cover, where they form a prominent strike ridge. A little to the south there is a parallel strike ridge, apparently formed by the lower sandstones. The flint-beds do not seem to persist to the west into the Swale, but about a mile and a half above the junction with the Ouse there is a series of banded sandstones and mudstones, striking east-north-east, and dipping 40° to the north-north-west, which probably represents the lower sandstones.

The Sawpit Gully mudstones are clearly exposed in the steep bed of Sawpit Gully (Plate XXVI, fig. 1), and consist predominantly of black mudstones, but occasional thin beds of sandstone are found. There is some folding in the section, but, on the whole, the dip is to the north-north-west, like that of the overlying flints and limestones. Calcareous concretions up to 1 ft. in diameter are common in the upper 400 ft., but below that they are rarer. In the uppermost 15 ft. pyritous nodules are abundant, but they do not persist far downwards. At the actual junction with the flint-beds there is a strong yellow efflorescence. The junction appears to be quite conformable. *Inoceramus concentricus* var. *porrectus* was obtained 20 ft. below the junction and also at about 100 ft. The ammonite *Gaudryceras sayci* was obtained in a large concretion about 300 ft. below the junction.

The Sawpit Gully beds are exposed in the Nidd above the flint gorge, where the valley again opens out in the softer rocks. Near the base there is a band of sandstones and sandy mudstones containing a large species of *Inoceramus*. The higher beds are fine-grained black mudstones with small concretions, in which fragments of crustaceans were observed.

In the Swale, owing to slips and talus slopes, there is not a continuous exposure of the Sawpit Gully beds. Not far from the top there is some sharp folding of the beds, causing local reversals in the direction of the dip (Plate XXVI, fig. 2). From the highest exposure concretions containing numerous specimens of *Aucellina euglypha* and fossil wood and plant-impressions were obtained.

The thicknesses given above for the various divisions of the Clarentian at Coverham were estimated, except in the case of the conglomerates, by measurements from a section drawn to true scale. An average dip of 55° was allowed, but it will be observed that the dip is often steeper and seldom less than that figure. The reversals of dip due to folding are unimportant, but have been allowed for. An almost continuous section of the beds has been observed, and no faults of any consequence were seen. Consequently, unless there is a very strong unconformity between the Clarentian and the Amuri limestone and a repetition of the beds by closely appressed folds, there is no escape from the conclusion that the thickness given is approximately correct. Hector and McKay agree in estimating the total thickness up to the "grey marls" as approximately 12,000 ft. Woods remarks that the thickness, if correctly estimated, is very great in view of the unity of the molluscan fauna.

The beds are marine throughout, and calcareous concretions are abundant, but plant-remains and fossil wood are found in the sandstones and concretions from top to bottom. The black colour also of the mudstones and sandy mudstones is doubtless due to the presence of carbonaceous matter. Glauconite has been observed only in the greenish sandstones of the Nidd beds. The above facts, together with the rapid lateral variation in the sandstones and the presence of the pebbly mudstones in the lower beds, suggest that the whole series was deposited as the topset beds of a continental shelf undergoing rapid depression and near the mouth of a large river, the sands and gravels of which were arrested nearer shore or up the estuary by its drowning.

Hector's subdivision of the beds from Coverham to the Mead Gorge is as follows:—

Contorted sandstones (*Belemnites superstes*); volcanic dykes.
Concretionary marls; large *Inoceramus*.
Sandstone with plants.
Septaria clays, with *Inoceramus*, belemnites, and *Conchothya*.
Black grit with fish-scales, ammonites, *Inoceramus*.
Black marls with sandstone bands.
Plant-sandstones with *Dentalium majus*, *Nerita*, *Natia*, *Inoceramus* (= Amuri sands).
Belemnite sandstone.
Black marls with cone-in-cone limestone bands.
Green sandstones.
Conglomerates and brown sandstones containing plants and coal.

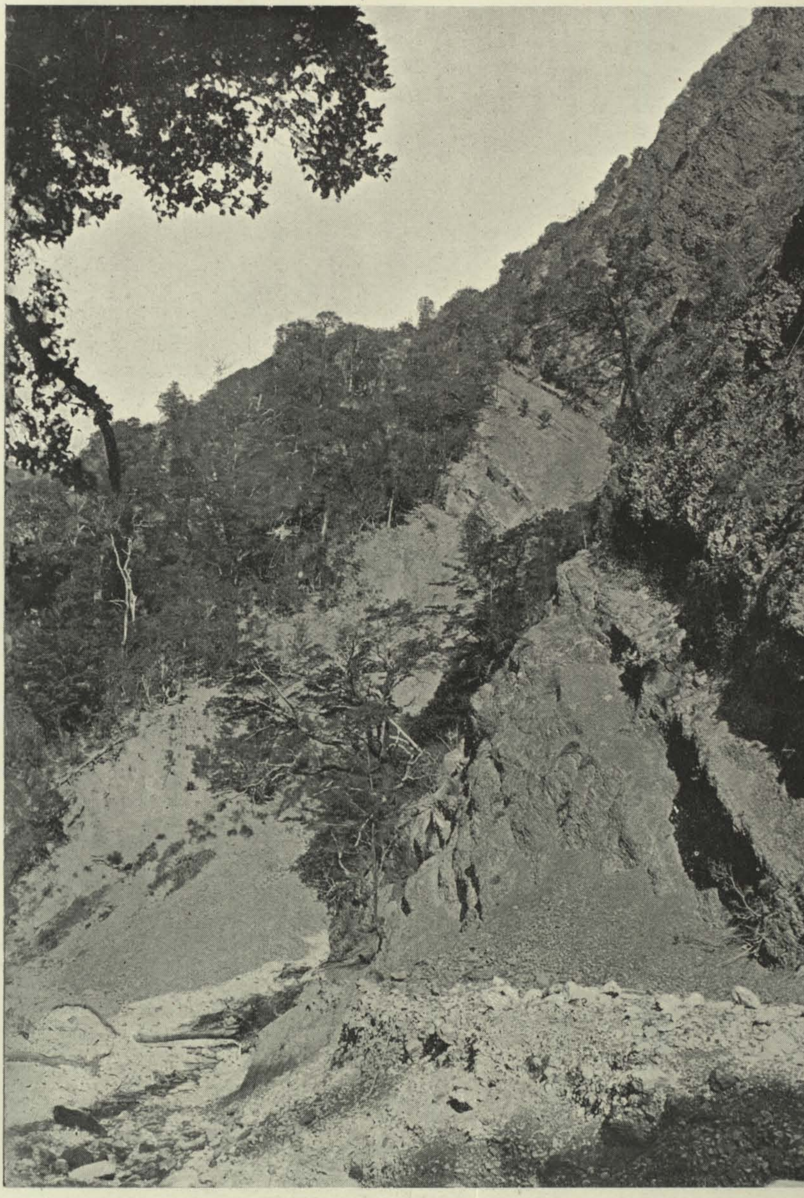
In attempting to establish a similarity with the Piripauan beds at Amuri Bluff, Hector has given in the above succession too much prominence to the sandstone bands and too little to the black mudstones which make up about 90 per cent. of the succession. The green sandstones mentioned were probably observed on the Kekerangu side of the pack-track from that place to Coverham, where such beds occur.

The Clarentian near Coverham is occasionally penetrated by intrusive rocks which consist of very much weathered amygdaloidal basalts. A dyke trending E. 15° S., nearly vertical but with a slight inclination to the north, appears in the north-east bank of the Swale about a mile above its junction with the Nidd. A similar, somewhat thicker dyke, but possibly the same, outcrops a quarter of a mile farther up-stream. McKay describes a dyke in the Wharf as separating the upper and lower beds—*i.e.*, a sill. It is of similar petrological character, and is either a sill or else a dyke truncating the beds very obliquely. These intrusives are similar to one penetrating the Amuri limestone in the Kekerangu River, and are probably to be correlated in age with the volcanic rocks overlying the Amuri limestone in the Ure Valley and in the Herring River.

Isolated Hill Creek, Ure Valley.—From the Chalk Range the Amuri limestone swings round in a great curve to Benmore, and the underlying Clarentian beds follow suit, but owing to the inaccessibility of this heavily forested and deeply gorged country they have been examined only in the Isolated Hill Creek, a tributary of the Ure River which cuts through the limestones and flints in a gorge between Isolated Hill and the spurs of Benmore. At the top of the gorge the strike of the flint-beds and underlying Clarentian is east-north-east, with dip 36° to the north-north-west. About 1,500 ft. of Clarentian beds are exposed, consisting of dark-grey indurated mudstones or sandy mudstones, rapidly disintegrating into small angular fragments on exposure. Concretions of all sizes up to 7 in. diameter occur sparingly thoughout, but are rarely fossiliferous. One large ammonite was obtained in a concretion from the stream-gravels, but was declared by Mr. H. Woods to be indeterminable. The beds terminate downwards against a fault which has brought down the Whernside block of Amuri limestone and flint-beds against the Clarentian.

The junction between the Clarentian beds and the overlying flint-beds appears not only to be perfectly conformable, but to exhibit a passage between the two formations. It is described in detail below.

Upper Ure Valley.—The Notocene rocks in the upper Ure and upper Swale Valleys form a great overturned syncline, truncated by the great

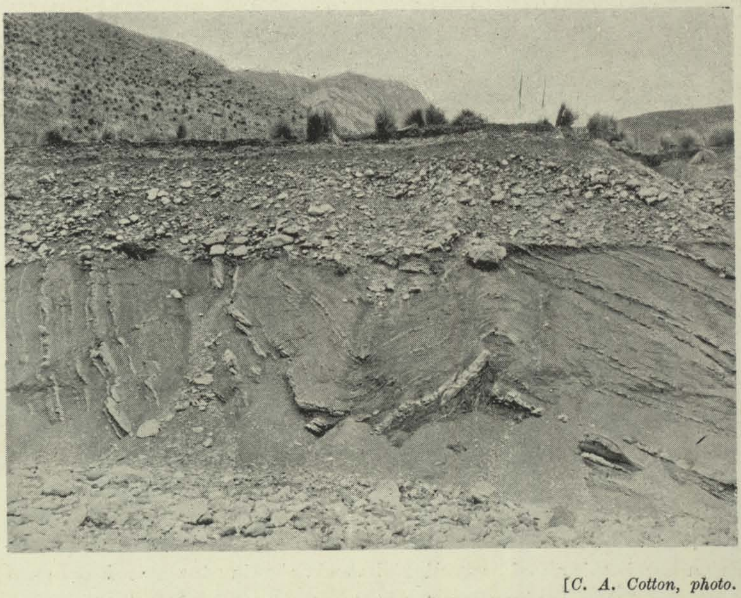


[*B. C. Aston, photo.*

Cliffs on the left bank of Isolated Hill Creek, showing the accordant dip of the Clarentian mudstones (below) and the flint-beds (above).

[C. A. Cotton, photo.

FIG. 1.—The Chalk Range, from the south-south-east, showing Sawpit Gully (in the centre) entering the Nidd Stream (on the left).



[C. A. Cotton, photo.

FIG. 2.—Front of rock terrace in the Swale River valley, showing folding in the Sawpit Gully mudstones.

Clarence fault and its branches. Where on the upper side of the syncline the sequence is reversed, a small thickness of Clarentian beds lies above the flint-beds, between them and the fault-line. These were observed in the large tributary of the Ure River entering it in a south-east direction from Blue Mountain. About 100 ft. of Clarentian beds are here exposed, consisting of micaceous mudstones weathering purple-grey with a yellow efflorescence on joint-planes. They have the same strike as the underlying flint-beds—viz., north-east—with a dip of about 50° to the north-west—*i.e.*, towards the fault-line. A large concretion lying in the creek at this point was observed to be crowded with fibrous fragments of *Inoceramus.* There appears to be perfect conformity with the flint-beds. The actual fault-line is obscured by slips.

In a tributary of the above creek, entering if from the north-east along the fault-line, some decomposed amygdaloidal basic volcanic rocks were seen to the north-west of the flint-beds, and are therefore probably in the Clarentian series.

Middle Ure Valley.—Pebbly mudstones were observed in the Blue Mountain Creek at the apparent top of a series of hard sandstones and thin-bedded mudstones apparently overlying the Amuri limestone or Weka Pass stone, which is here not more than 150 ft. thick, and strikes in a north-easterly direction, dipping north-west. Probably the series is overturned and the succession reversed at this point, as it is higher up the Ure Valley. The conglomerates contain fragments of *Inoceramus* and pebbles of dark limestone (itself containing *Inoceramus*), besides white quartz and red jasper. A fault crosses the creek about two miles up, and above this, in a branch running to the Blue Mountain, the Clarentian rocks appear to be repeated. There is a succession of hard sandstones with occasional shaly beds, both containing occasional plant fossils, and thin pebbly mudstones containing *Inoceramus* fibres. There are many repetitions of the pebbly mudstones in the creek. Many small dark fine-grained dykes were observed intersecting the sandstones.

Lower Ure Valley.—Clarentian rocks are probably well developed in the hills to the north of the lower Ure, where thin bands of Amuri limestone appear, but exposures are not good and the sequence has not been clearly ascertained. Not far above the crossing of the coach-road a syncline of limestone occurs, underlain by sandstones and mudstones containing *Inoceramus.* The limestone crosses the hills obliquely and terminates against the Awatere beds, probably in a fault-line, and the beds farther up the hills to the west are therefore probably Clarentian. They consist mainly of sandstones, but the top of Hungry Hill is composed of volcanic breccia, which may be Clarentian. McKay correlates it with the Flaxbourne breccias, which lie at the base of the Clarentian series in the Ward district

Mead River.—McKay describes the Clarentian rocks exposed in the Mead River as follows: "In the Mead, the conglomerates at the base of the Amuri series are finely exposed. The succeeding beds are grey sandstones and darker shales thrown into a great number of undulations, which are flat and shallow, or more frequently sharply caught up at high angles, and are often crushed and contorted in a most extraordinary manner. Here beds of this character continue without means of distinction upwards into the Waipara formation, and, scarcely altered in character, reach to the under-surface of the great flint-beds that underlie the Amuri limestone."

To this description I have little to add. No recognizable fossils have been obtained from the Clarentian beds in either the Dee or the Mead, and consequently the beds have not been closely studied. The series appears to be considerably thinner than at Coverham, but the thickness is difficult to estimate owing to the contortions near the base. There is also some sharp folding near the top, and the beds run nearly horizontally for some distance. Before reaching the flint-beds, however, they once more assume the dip of these. The actual junction is not exposed.

Limburne Stream.—The series commences with pebbly mudstone, hard sandstone, and a second pebbly mudstone, all striking nearly east and west, and dipping to the north. The succeeding beds are a series of thin-bedded sandstones and mudstones. No fossils were obtained, and the junction with the flint-beds could not be observed.

Dee River.—The Clarentian rocks are not well exposed on the banks of the Dee River, and have yielded no fossils except fragments of *Inoceramus*. The series commences with a pebbly mudstone followed by a hard sandstone. Higher up the beds appear to be mudstones and thin-bedded sandstones with few or no concretions. The total thickness appears to be much less than that at Coverham.

Branch, Dart, and Muzzle Rivers.—For this part of the district we must rely solely on McKay's observations. He states that the lower part of the Clarentian (so-called Amuri series) is essentially the same as in the Mead and the Dee. The upper part in the Dart River, for some distance below the commencement of the limestone, consist of "grey sandstones and soft, crumbling sandy beds of dark colour, with small calcareous concretions containing *Inoceramus*, and small spheroidal concretions of iron-pyrites. . . . In the Muzzle the beds are highly-contorted sandstones and sandy or marly shales containing, near the under-surface of the Amuri limestone, saurian concretions of enormous size, one specimen of which, yet *in situ* on the east bank of the left branch of the river, is about 14 ft. in diameter." The name of "saurian concretion" was given from a mistaken correlation with the saurian beds of the Piripauan.

Bluff River.—There are two outcrops of Notocene rocks in the Clarence Valley near the Bluff River, separated by an anticlinal core of pre-Notocene rocks. The north-western outcrop is similar in its structural relations to those already described from Coverham to the Muzzle River, and is continuous with them. The south-eastern outcrop will be described later.

In the Bluff River the Clarentian rocks are not well exposed, owing to slips on the banks, and I was unable to observe certain beds evidently exposed when McKay examined the section. The lowest beds I observed were about 600 ft. of thick-bedded mudstones and sandstones, with a dip to the south-east—*i.e.*, away from the limestone. Higher up the river there are sandstones on the west bank with a normal dip—viz., 75° to the north-west—the strike being N. 50° E.

McKay describes the succession as he observed it as follows: "The lower beds of the Amuri series are for a short distance obscured along both banks of the river Rocks belonging to the younger series first show on the south-west bank of the river as banded sandstones with shaly beds between. These are overlain by sandstones and conglomerates, some of the conglomerates containing fragments of a large *Inoceramus* and great numbers of a large form of *Trigonia*. . . . Belemnites, usually as fragments, are also found in these conglomerates. The sandstones are almost destitute of fossils. To the north-west, and higher in the section, these beds are followed by dark sandy beds with concretions, the outer part of which consists of cone-in-cone limestone; and these are succeeded by the Amuri limestone."

Gentle Annie Stream.—The Notocene beds continue from the Bluff River into the Gentle Annie Stream, where the Amuri limestone occurs in a syncline. The Clarentian beds below the limestone to the south-east are not well exposed, but the presence of muddy sandstones dipping to the north-west was observed.

Herring (or Seymour) River.—The exposures of Clarentian rocks described from Isolated Hill Creek, Coverham, and the Mead to the Gentle Annie all belong to a continuous strip forming the lower member of the Notocene rocks involved in the great Clarence fault. From Bluff Hill to the Gore River there are other outcrops of Notocene rocks involved along the more north-easterly parallel faults, except for the large outcrop between Bluff Hill and Limestone Hill, which seems to occupy a synclinal depression. Many of these outcrops include only Clarentian rocks, while in others a nearly complete succession of the Notocene is included. The Clarentian rocks in this area commonly commence with terrestrial coal-measures, and volcanic rocks are well developed. The most complete and typical succession is that of the Herring River, which will be considered first, although it disturbs the geographical sequence of the account.

In the lower Herring River the unconformity of the Clarentian and pre-Notocene rocks is well exposed. The latter consist of concretionary ("cannon-ball") sandstones and thin argillite bands, striking N. 15° W., with a very steep dip to the west. The Clarentian rocks strike, at the base, N. 30° E., and dip 44° to the north-west—*i.e.*, down-stream. The Notocene series is folded into a syncline and anticline before reaching the Quail Flat fault-line near the junction with the Clarence River, and the syncline brings the Amuri limestone down to the river-level, thus separating two exposures of the higher part of the Clarentian beds.

The lowest rocks are coal-measures, 50 ft. thick, forming cliffs of a reddish colour. The series commences with a seam of lignite a few feet thick, followed by carbonaceous shales, grits, sands, and ferruginous sandstones, with thin seams of lignite. Some of the sandstones and shales are crowded with plant fossils. Then follows a series of volcanic rocks about 320–340 ft. in thickness. Four well-marked lava-flows can be recognized, but there may be more. The rocks have not been examined microscopically, but appear to be olivine basalts. The lowest lava is not columnar, and is 60–70 ft. thick, and it is succeeded by more coal-measures, varying from 7 ft. to 15 ft. in thickness. The second flow, which is coarsely porphyritic, is columnar for the lower 20 ft.. passing into breccia for the upper 20 ft. The third flow of fine-grained basalt is 15 ft. thick, and is columnar throughout. The fourth flow lies 150 ft. farther up, and is about 50 ft. thick. The outcrops of the interbedded rocks at river-level are covered by basalt screes, but may be exposed on the higher slopes of the valley-sides. The fourth lava is immediately followed by mudstones.

Farther down the stream the section of the succeeding Clarentian beds is far from continuous, as the banks on each side are much slipped, probably owing to the predominance of loose sandy beds. Such rocks as are exposed are mudstones, sandstones, sometimes with pebble-beds, and a thick series of mudstones with yellow efflorescence in beds about 1 ft. thick, alternating with soft sandstones in beds of 18 in. to 2 ft. thick. Higher up in the succession the mudstones become more massive and the sandstone intercalations disappear. Altogether there are probably over 1,000 ft. of strata between the top of the lava and the base of the Amuri limestone. The uppermost 60 ft. consists below of 20 ft. of pale-green sandstone, passing up into bright-green glauconitic sandstone, and finally into hard glauconitic limestone. There is some appearance of unconformity in the overlying Amuri limestone (*cf.* p. 328).

In the north-west wing of the anticline farther down the river the lowest beds seen are about 200 ft. of sulphur mudstones. These are succeeded by about 50 ft. of sulphur sands, of which the upper 15 ft. is glauconitic.

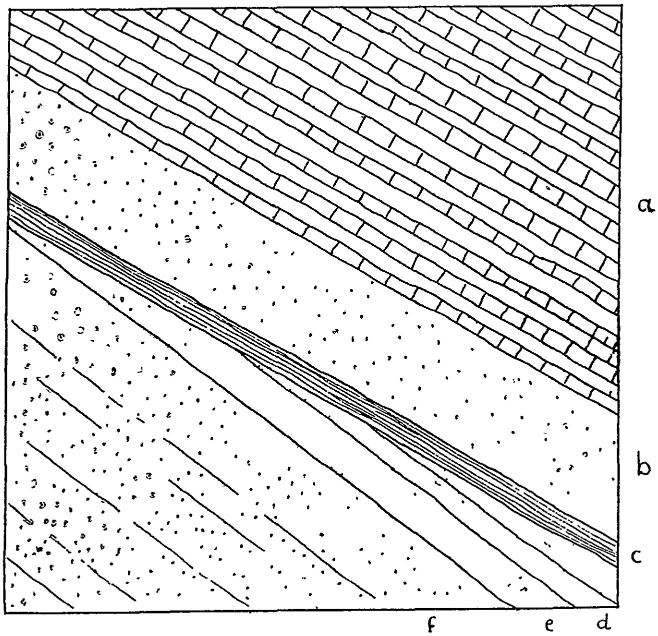


Fig. 5.—Junction of Clarentian and Amuri limestone, north-west wing of anticline, Herring River. *a*, Amuri limestone; *b*, glauconitic sandstone; *c*, mudstone; *d*, brown glauconitic sandstone; *e*, green glauconitic sandstones; *f*, sulphur sands.

The latter bed is apparently truncated at a gentle angle and overlain unconformably by a thin bed of mudstone, which in turn is followed conformably by a glauconitic sandstone, 10 ft. thick, and that by the Amuri limestone. The cliff in which this section is exposed cannot be scaled, and the ground slopes away steeply at the bottom, so that it was difficult to be certain of the unconformity.

McKay recognized only two " great sheets " of volcanic rock, and made a collection of fossils from sandstones and pebble-beds resting on the upper surface of the second sheet. The fossils determined by Woods were *Arca* (*Barbatia*) sp., *Trigonia glyptica*, *T. meridana*, *Modiola kaikourensis*, *Belemnites superstes*. I did not recognize this bed, but a little way down the river from the uppermost lava I picked up in the river-gravel a boulder of conglomerate containing *Trigonia glyptica*.

The upper beds are described by McKay as " soft grey sandstones, and black, sandy, sulphurous, micaceous beds, with cone-in-cone concretions, overlaid by greensands, which, associated with thin beds of volcanic rock (on the north-east bank of the river only), underlie the Amuri limestone." These upper beds of volcanic rock I did not observe.

Quail Flat.—The Quail Flat fault runs from the mouth of the Herring River for some distance along the bed of the Clarence River, then enters the southern bank to pass though Quail Flat, crosses the river again at the southern end, passes through two southerly projections of the north bank, and finally again enters the north bank to run behind Red Hill, where its presence was inferred by McKay. The base of the Notocene rocks must be considerably folded longitudinally along this line, since at Quail Flat and farther north-east only lower Clarentian rocks are involved at approximately the same height as that at which the Weka Pass stone occurs only two miles to the south-west.

The Clarentian rocks are exposed on the southern bank of the Clarence River near the upper and lower ends of Quail Flat, the intervening spaces on the bank being occupied by pre-Notocene rocks. At the upper end of the terrace the pre-Notocene rocks for some hundreds of yards are greywackes and thin-bedded argillites striking N. 30° W. and dipping nearly vertically. Farther up the river conglomerates appear, the line of junction striking N. 65° E., and dipping apparently vertically. The conglomerates consist mainly of rather decomposed, well-rounded basalt pebbles, with a greasy matrix recalling the fossiliferous tuff of Limestone Creek, Awatere Valley. They contain pieces of carbonized fossil wood. Up the river these are succeeded by coal-measures striking north-east, dipping 58° to the north-west, and consisting of thin-bedded mudstones, carbonaceous shales, and sandstones, with elliptical masses of ferruginous sandstone. These rocks strike south-west into a projection of the terrace-bank, and the continuation of the succession is then obscured for about 100 yards. At the end of the projection a volcanic rock appears, and this is followed by a succession of greasy conglomerates and coal-measures similar to the last. It seems probable that the junction between the first-described conglomerate and the pre-Notocene rocks is a fault.

McKay's description of this outcrop is more detailed, and he mentions no break in the succession. The first-mentioned exposure of coal-measures he describes as followed by thick beds of volcanic rock, divided by tufas, conglomerates, and shales, the highest stream of volcanic rock being followed by conglomerates, grits, sandstones, &c. From the beds between the first and second volcanic rocks he obtained leaf-fossils and fresh-water shells, and underneath the higher stream some very fine specimens of dicotyledonous leaves.

At the lower (down-stream) end of Quail Flat the pre-Notocene rocks are concretionary ("cannon-ball") sandstones with thin argillite bands, striking N. 20° E., and dipping 40° to the east-south-east at the lower junction with the Clarentian rocks. The latter series commences with mudstones and lignite seams, striking N. 20° E., and dipping 60° to the west-north-west. The higher beds, exposed up-stream, are sandstones, followed by more lignites. Higher up the succession is obscured by slips, but pre-Notocene rocks appear in cliffs 200 yards farther up the river, so that presumably the fault-line closing the sequence here enters the river-terrace.

This exposure was evidently much clearer at the time of McKay's visit, for he describes a number of beds I did not observe. "At the eastern end of the section the lowest bed is a soft greensandstone, which is followed by grey sandstones, with irregular beds of coaly shale. These latter beds contain elliptic masses and irregular bands of ironstone, which are full of plant-remains. A very large dicotyledonous leaf, with *Dammara* leaves, *Taeniopteris*, &c., occur in the ironstones and in the sandstones and sandy shales which overlie the lower beds. Casts of trees 18 in. to 2 ft. in diameter lie at the foot of the cliff along the river-bank, and these can be seen *in situ* surrounded by a thin layer of bright coal. Hard calcareous sandstones overlie these beds, with which are layers of ironstone, and in these beds dicotyledonous leaves and large specimens of *Taeniopteris* are abundant. About 100 ft. from the lowest beds of the series fine splintery black shales are crowded with long slender leaves having parallel venation; and in these beds and a greensandstone band parting them into an upper and lower division fresh-water shells, as casts of *Cyclas* and one or two species of univalves, are found in great abundance. Fine-grained grey and gritty sandstone follows, with soft sandy beds between, and in these, besides the plants already named, *Polypodium* (?) occurs in fronds of large size and well preserved in the sandstone beds. For the next 150 ft. the beds overlying are soft and hard sandstones alternating, sands and sandy shales, and small nests of coal; and, beyond these, 50 ft. or 60 ft. of dark-green volcanic rock separate this lower part of the section from the higher beds, which are much the same in character" (1886, p. 102).

North Bank, Clarence River, opposite Tytler Stream.—Owing to a bend in the Clarence River the fault strikes across the river below Quail Flat and passes through a projection of the northern bank, on the end of which a small patch of Clarentian coal-measures is preserved. I did not cross the river to observe these, but McKay has given a section of them under the heading of "Clarence Crossing, Quail Flat" (McKay, 1886, p. 101).

McKay describes in general terms a similar outcrop three miles below Quail Flat, presumably also on the north bank of the river.

Red Hill.—According to McKay's description, the Quail Flat fault runs on the north-west side of Red Hill, which is composed of lower Clarentian rocks, while a narrow strip of pre-Notocene rocks occurs to their south-east side, along the banks of the Clarence River The lowest Clarentian rocks he describes as gritty sandstones and pebble-beds without distinct fossils. Next follow sandstones and grey, brown, or dark-coloured shales with plant-remains, not very well preserved, and thin coal-seams, 1 ft. to 18 in. in thickness. From a sandstone under the lowest coal-seam two fresh-water shells were collected. The succeeding beds are grey and soft yellow sandstones, with dark shales and plant-remains, including dicotyledonous leaves, a narrow leaf with parallel venation, and four or five species of fern. These are in turn followed by basaltic rock-tufas and sandstone conglomerates, alternating in an irregular manner, and finally by sandstones and pebble-beds, which in the north-eastern end of Red Hill are calcareous and contain concretions 1 ft. to 15 in. in diameter.

Clarence River below Bluff River.—There is a very considerable development of Notocene rocks from Bluff Hill across the Clarence River to Limestone Hill, which has not been satisfactorily explored either by McKay or myself. As seen from the north-east end of the valley Bluff Hill seems to form a syncline, and this impression is confirmed by the outcrop of lower Clarentian rocks on the north-west side of the Notocene outlier at the mouth of the Bluff River and north-west of Limestone Hill, where in a small creek I observed coal-measures similar to those of the Herring River, overlaid by volcanic rocks. McKay (1886, p. 68) also states that the Buller series—*i.e.*, the coal-measures—underlies the first great sheet of volcanic rocks in Limestone Hill. Unfortunately, neither here nor in the Clarence River was the base of the series observed. If this great outcrop of Notocene rocks terminated to the north-west along a fault-line one would not expect Clarentian rocks except along its south-eastern boundary.

There must be a nearly complete section through this Notocene outcrop where it is crossed by the Clarence River, but as the river here flows in a gorge it cannot be closely followed. McKay describes the section as follows: "The lowest beds are sandstones and conglomerates, containing marine fossils. . . . These fossiliferous sandstones are overlaid by a considerable thickness of volcanic rocks, varying from 50 ft. to 200 ft., and these in turn by sandstones, conglomerates, and shales, followed by a second series of volcanic rocks overlaid by the limestones and grey marls closing the sequence."

The fossils collected by McKay were determined by Woods as follows: *Trigonia glyptica*, "*Modiola*" *kaikourensis*, *Thracia* sp., and *Belemnites superstes*.

The base of the Clarentian is not here exposed, and it is quite possible that coal-measures are present. The lowest rocks I observed were grey sandstones about 26–30 ft. thick, with occasional pebble-beds, striking north, and dipping 25° to the east. These are followed by about 40 ft. of thin-bedded sandstones alternating with mudstones, and then about 300 ft. of massive sandstones with pebble-beds which are sometimes fossiliferous. The pebbles consist of quartzite, greywacke, grey gritty sandstones, jasperoid quartz, and occasionally quartz porphyry. The fossils collected included a belemnite, *Trigonia glyptica*, "*Modiola*" *kaikourensis*, *Thracia* sp., *Aporrhais* sp. and other gasteropods, and *Dentalium* sp. Evidently these are the beds from which McKay collected.

These beds are succeeded by a fine-grained basalt, here 50–60 ft. thick, with large amygdaloidal masses of calcite containing quartz crystals in druse cavities. This is separated from an upper lava or series of lavas by 30–40 ft. of sandstones. The upper lava is scoriaceous at the base, and porphyritic. Its thickness could not be exactly estimated, owing to faults and slips, but appeared to be upwards of 200 ft. It is followed by a bed of mudstone, about 20 ft. in thickness, full of volcanic material, and this again is followed by a third lava, fine-grained and more decomposed and at least 20 ft. thick. The dip of the beds at this point has flattened or appears to have flattened owing to the river flowing along the strike. The next-higher beds appear to be soft sandstones with ironstone concretions, dipping steeply. There appears to be a great thickness of these beds and further lavas before the limestone is reached, but the section was not followed.

On the opposite side of the Clarence River, in the Red Bluff, the section is similar except that the third band of lava was not observed. The top of the second lava is followed by upwards of 40 ft. of mudstones and thin-bedded sandstones.

The Amuri Limestone and Weka Pass Stone.

The rocks in the Middle Clarence Valley termed collectively the Amuri limestone are lithologically similar to the limestone of Amuri Bluff, and occupy a somewhat similar stratigraphical position, but they have a very much greater thickness and probably represent a greater range of time. Geographically they are nearly continuous with the limestone of Kaikoura

Peninsula by way of the Front Range at Kekerangu and the Puhipuhi Mountains, and there can be no doubt that the Amuri limestone of Amuri Bluff correlates with some part, but it is almost certainly only the upper part, of the limestone of the Clarence Valley. It would therefore be more appropriate to name the formation from its greatest development in the Clarence Valley, but the name "Amuri limestone" is too well established to be displaced.

McKay correlated the uppermost part of the limestone formation in the Clarence Valley with the Weka Pass stone, describing the rocks as calcareous sandstones. Although in the north-east part of the valley there appears little justification for any such distinction, in the Herring River beds of greensand with phosphatic nodules and volcanic tuffs separate an upper, light-brown limestone from the lower, white Amuri limestone. Everywhere in North Canterbury and at Amuri Bluff and Kaikoura Peninsula a bed of phosphatic greensand or glauconitic limestone separates the Weka Pass stone from the Amuri limestone (*cf.* Speight and Wild, 1918), and it seems probable that the phosphatic band in the Herring River represents the same horizon and that the upper limestone must correlate with the Weka Pass stone.

The Amuri limestone in the Clarence Valley, excluding the flint-beds, consists mainly of two types of limestone, the one a snow-white, very fine-grained, hard, almost flinty rock, composed almost solely of carbonate of lime and silica; the other an equally fine-grained but somewhat softer, argillaceous limestone, also light-coloured but not so white, and very often with a greenish tinge. The former rock forms thick strata, and also alternates in thin beds, up to 1 ft. thick, with the latter, which is less commonly found in thick beds. The former may for convenience be termed the chalky type, and the latter the marly type.

The base of the limestone formation is in most exposures formed of beds consisting wholly or partly of black flint, but in the upper part of the flint-beds the flints are often light-coloured. Where the beds are partly of flint, the latter form large lenticules and the outer part consists of flinty limestone of the chalky type. In many places, however, the outer part is grey and crystalline, the crystals consisting of dolomite set in a matrix of flint. I have described the peculiar nature of these beds fully in my former paper (1916). Flints also occur sporadically in the upper parts of the limestone, but are not abundant and are not aggregated into definite rows.

Mead Gorge.—The greatest thickness of the Amuri limestone is that of the Mead Gorge, where I estimated it as follows:—

	Thickness in Feet.
Argillaceous limestone (Weka Pass stone)	150
Marly limestone	400
Chalky limestone	280
Marly limestone	420
Chalky limestone	90
Chalky limestone and flint-beds	1,410
	2,750

The dip of the various beds is constantly to the north-west, at angles varying from 45° to 70°, the average angle being between 50° and 55°. The junction with the underlying Clarentian beds is not exposed. The lowest flint-beds seen are of a lenticular character, in layers of 8 in. to 18 in., the beds swelling out around the flint lenticules in such a way that the surface of the bedding-planes is irregular (see Thomson, 1916, pl. ii, iii). The outer layers are composed of crystalline dolomite. Higher up the flint-beds become less lenticular and the exteriors are hard chalky limestone, layers of which also appear between the layers containing flint. Then follows a considerable thickness of hard chalky limestone with flint-beds subordinate, and finally another series consisting dominantly of flint-beds, the top being 1,410 ft. above the lowest observed beds. Above this flint is of relatively rare occurrence, but is by no means absent from the chalky limestones. The marly limestones in part consist of the thin-bedded alternations of chalky and marly limestones above described. No traces of fossils were observed in any of the above beds.

Limburne Gorge.—The Amuri limestone in the left branch of the Limburne consists of flint-beds at the base, then hard chalky limestone, marly limestone with chalky bands, and hard chalky limestone above. The uppermost beds are obscured by slips, and the top band of marly limestone and the Weka Pass stone are probably present, as in the Mead and the Dee.

Dee Gorge.—The flint-beds and the chalky and marly limestones succeed one another in the same order as in the Limburne and the Mead, and the thickness is probably about the same. The uppermost limestone, the Weka Pass stone, is a grey-white argillaceous limestone, without the typical cuboidal jointing of the Amuri limestone. No fossils were observed.

The flint lenticules at the base are present in beds averaging 8 in. thick, but some are as much as 2 ft. thick where the lenticules occur. The crystalline dolomitic rock is not abundant, and is most developed where the flint lenticules are thickest and most irregular. The great majority of the flint lenticules in the lower beds, and all in the upper beds, are not accompanied by crystalline exteriors, but by hard, flinty, chalky limestone. Mr. B. C. Aston has made the following analyses of specimens from this locality:—

Laboratory Number.	Nature of Sample.	SiO_2.	Fe_2O_3 and Al_2O_3.	$CaCO_3$.	$MgCO_3$.	P_2O_5
779A ..	Flinty portion of lenticule ..	92·41	2·95	2·36	2·03	Trace.
779B ..	Near middle, carbonates largely removed by weathering	92·52	3·25	1·86	1·77	Trace.
779C ..	Exterior, also much weathered	81·97	3·70	6·53	7·61	Trace.
780 ..	Dense bluish limestone with minute carbonate crystals	32·73	1·69	60·42	5·26	Trace.
781A ..	Flinty portion of lenticule ..	88·12	3·48	5·07	2·75	Nil.
781B ..	Intermediate portion of lenticule	58·15	4·15	30·98	6·42	Trace.
781C ..	Exterior of lenticule	77·82	3·93	11·49	5·58	Trace.

Chalk Range.—McKay estimates the thickness of the Amuri limestone and Weka Pass stone in the Chalk Range at 2,500 ft., of which the lower 1,000 ft. consists of flint-beds. The middle beds he describes as soft chalk marls, followed by more compact flaggy limestones, which in the highest peak of the range contain beds of a green colour. Above these are beds resembling the Cobden limestone, with large radiating fan-shaped fucoids. The latter is followed by a calcareous sandstone, the Weka Pass stone, and these two uppermost beds contain layers of greensand and quartz sand alternating with the more calcareous strata. It should be observed that McKay described the Weka Pass stone in the Mead and Dee Gorges also as a calcareous sandstone, but it is certainly more argillaceous than arenaceous in these localities.

I observed the base of the flint-beds in Sawpit Gully. The junction with the Clarentian appears to be perfectly conformable, though quite sharp. The lowest flint-beds are dark throughout, and contain no dolomitic exteriors. The uppermost Clarentian beds contain much pyrite in nodules, and show a yellow efflorescence. Microscopic examination of the lowest flint-beds suggest that they are replacing rocks in part clastic.

Isolated Hill Creek.—In the Ure Gorge the sequence of the various beds of the Amuri limestone is difficult to interpret, owing to the complex folding and faulting that has taken place. The flint-beds at the base are, however, well exposed in the Isolated Hill Creek, which has cut a gorge through them (Plates XXVII, XXVIII). They appear to be much thinner than in the Chalk Range, and not much more than 500 ft. in thickness. The junction with the underlying Clarentian rocks is well exposed, and is not only conformable, but appears to show a transition between the two groups of rocks. Near the base black flints in hand-size nodules and lenticules lie in a coarsely crystalline dolomitic matrix, and the flints themselves contain many crystals of dolomite. Followed downwards, the flints contain fewer and fewer crystals, and at the same time become less pure and lighter in colour till they can hardly be distinguished from hardened mudstone, while the matrix also alters gradually into a grey micaceous mudstone. The above transition takes place within 2 ft. of rock. Forty feet below this transition there is a thin layer of impure flints and dolomite, the crystals of dolomite being relatively large. In the intermediate 40 ft. of mudstone there are large concretionary masses, 3 ft. in length and 18 in. across the bedding, consisting of lenticules of black flint in a crystalline dolomitic matrix.

It might be argued that the flint is secondary and has invaded the uppermost beds of the Clarentian, obscuring the true junction. But even if the flint-dolomite is secondary it is replacing calcareous rocks, and the transition in this case is from Clarentian mudstone to limestone by the intermediary of calcareous concretions, and I see no escape from the conclusion that the Amuri limestone is here conformable to the Clarentian.

Upper Ure Valley.—In the upper inverted limb of the overturned syncline behind the Chalk Range the Amuri limestone forms a hogback ridge, cut through on the northern side of the Ure River from Limestone Hill to the White Bluffs by several gorges. From the smaller width and height of this hogback ridge it appears at first sight that the limestone is here considerably thinner than in the Chalk Range, on the lower limb of the synclinal. I observed the basal beds, here lying uppermost, in the large tributary from the Blue Mountain, but could not penetrate down the gorge to observe the upper beds. The beds are here striking in a north-east direction, and dipping at angles of 40° to 60° to the north-west. The sequence will be described as if the beds were not overturned. The Clarentian mudstones are followed perfectly conformably by thin lenticular flint-beds with mudstone intercalations, passing up into greener flints with dolomite crystals, the whole being some hundreds of feet thick. These are followed by hard chalky limestone with reddish-brown blobs of flint, also several hundred feet thick, and these again by limestone with black flint lenticules, beyond which the section could not be followed. The total flint-beds do not seem much inferior in thickness to those of the Chalk

[*B. C. Aston, photo.*

Isolated Hill from Isolated Hill Creek. The light-coloured rocks in the foreground are Clarentian mudstones, the steep cliffs in the middle distance consist of flint-beds, and the higher parts of the mountain are Amuri limestone.

[C. A. Cotton, photo.

FIG. 1.—The ridge between the Dee and the Limburne as seen from the south-west. The monoclinal ridge of Amuri limestone forms Limestone Hill on the right and in the centre the great Marlborough conglomerate outcrops.

[C. A. Cotton, photo.

FIG. 2.—Great Marlborough conglomerate in the Dee Gorge, showing a coarse band in the middle. View looking south-west.

Range, and it is probable that the hogback is formed of these alone, and that the softer marly limestones succeeding do not form a salient in the relief, so that the total thickness of the whole series may be equal to that of the Chalk Range.

Middle Ure Valley.—In the Ure Valley above Waterfall Creek the river runs obliquely across the strike, and the following rocks were observed in ascending order: (1) Hard mudstones, (2) hard sandstones, (3) gap in succession, (4) thick red decomposed volcanic lava, (5) gap in successon, (6) limestones, much folded and puckered, with dip and strike constantly changing, forming the river-banks as far as the Ure Gorge. From some green bands in the lower end of the gorge I collected specimens of *Teredo* tubes indistinguishable from those of *Teredo heaphyi* Zittel.

From the section in the Blue Mountain Stream which enters the Ure along the red volcanic rock, it appears probable that the above succession is reversed. The lava is in this stream followed (apparently) by white mudstones or marls with poor plant fossils, and these by about 150 ft. of limestone, mostly a white or reddish, fine-grained, rather chalky variety, with green bands and much tufaceous material. The limestone is in turn followed by sheared mudstones or muddy sandstones, and may be separated from the latter by a fault. Then follows a further series of similar limestone overlaid by the Clarentian rocks already described, with pebbly mudstone near the apparent top.

If, as I suppose, the succession is here reversed, the volcanic lava follows some part of the Amuri limestone, and quite probably occupies the same position as the tuffs in the Herring River section—*i.e.*, between the Amuri limestone and Weka Pass stone; but some earlier volcanic activity must have occurred to account for the tufaceous bands in the Amuri limestone itself.

Branch, Dart, and Muzzle Rivers.—McKay has not made many observations of the Amuri limestone between the Dee and Bluff Rivers, but states that the flint-beds become much thinner south-west of the Dee, have disappeared altogether in the Dart, and are not found farther to the south-west. I observed these beds, however, in the Bluff River and Gentle Annie Stream, so that it is improbable that they are totally absent in the intervening terrain. McKay states that the Branch Gorge is impassable, but estimates the thickness of the limestones as 1,200 ft. in the Dart Gorge and not much less in the Muzzle, though in the latter it is repeated by faulting. In the Muzzle he states that "there is evidence that the higher beds [*i.e.*, the Cobden limestone and Weka Pass stone] are gradually encroaching on the lower and more characteristic Amuri limestone beds," and mentions finding in the former fragments of a fibrous plicated shell "which probably belong to *Inoceramus*."

Bluff River.—McKay's two descriptions (1886, pp. 78 and 97) of the Amuri limestone and Weka Pass stone in this section do not tally altogether with my observations. The highest bed is, he states, a calcareous sandstone, 15–25 ft. thick, containing various species of *Pecten*, including *P. zitteli*, and overlies soft chalk-marls. The lower beds he describes as "a compact fine-grained rock," and he states that "in its higher beds the harder limestone alternates with soft marly beds, and bands of hard calcareous greensandstone are of frequent occurrence. . . . A little to the south-west the Amuri limestone rests on the saurian beds as a gritty, impure limestone."

The lowest beds I observed were about 40 ft. of much-contorted flint-beds, dipping to the north-west. Above these the section is obscure, but sandy mudstones were observed. It is possible and probable that the upper limit of the flint-beds is a fault and that the sandy mudstones are Clarentian. A little farther up the river, on the western bank, the main exposure of the Amuri limestone series occurs. The lowest beds seen are flint-beds, about 100 ft. in thickness, in beds of from 3 in. to 6 in., with black flints with grey exteriors in the lower part and white flints with hard chalky exteriors in the upper part. The upper beds are separated by muddy, glauconitic partings 2–3 in. thick. From these I obtained two brachiopod specimens, neither specifically determinable, although one was a species of *Terebratulina*. The above beds were overlain by hard chalky limestone with white flints, and from this specimens of *Teredo* were obtained. To this succeeds about 10 ft. of calcareous greensandstone with small pebbles and pyrite concretions. This is overlain by 12 ft. of hard chalky or flinty limestone with muddy, glauconitic partings, and this in turn is followed by another 10 ft. or thereabouts of calcareous greensandstone, greatly contorted. Then succeed upwards of 30 ft. of thin-bedded alterations of chalky and marly limestone. Above this the section was obscured by slips, and the chalk marls and Weka Pass stone mentioned by McKay could not be observed.

Gentle Annie Stream.—The upper outcrop of flint-beds above described in the Bluff River can be traced across country to the Gentle Annie Stream, where they are underlain by Clarentian muddy sandstones. The limestone series forms a regular syncline on the north-east bank of the stream, but an absolutely continuous succession cannot be observed. The flint-beds are followed by a hard rubbly limestone, which is also probably flinty. This appears to be followed by a hard glauconitic limestone about 30 ft. thick, which contains in the middle a layer with rounded masses of white limestone somewhat similar to the chalky limestone but probably concretionary. The next-higher bed observed is hard chalky limestone, and this is succeeded by alternations of marly and chalky limestone forming the core of the syncline.

Bluff Hill and Limestone Hill.—The sequence of beds in the Amuri limestone of Bluff Hill and Limestone Hill has not been made out. The extent and thickness of the outcrops make it probable that the formation is of considerable thickness, perhaps comparable to that in the Mead area. McKay states that calcareous sandstone and indurated fucoidal chalk-greensands abounding in fossil shells form the higher and middle parts of Limestone Hill.

Herring River.—Notocene beds are thrown into a broad syncline and anticline in the Herring River, but the beds above the Amuri limestone are denuded from the axis of the syncline, and are exposed only on the two sides of the anticline in a tributary entering the river on the left side. Time permitted of the detailed examination of only two exposures.

On the south-east side of the syncline the lower beds of the Amuri limestone are seen resting on Clarentian calcareous greensandstones with apparent unconformity which is probably real (fig. 6). The greensandstones dip regularly to the north-west, and are truncated above at a gentle angle by a surface which has also an apparent dip to the north-west. The succeeding limestone consists of marly limestone with numerous thin alternations of chalky limestone, which become closer together in the upper part, the whole as exposed being between 50 ft. and 100 ft. thick. The lowest beds of the limestone follow the truncated surface regularly, but a few feet up the beds are sharply folded in the manner shown in fig. 6. It is, of course, possible that the surface of separation is not a true unconformity, but a fault or thrust-plane; but I observed no sign of crushing or slickensides along the surface.

On the north-west wing of the anticline, in a cliff some distance above the river-bed and about half a mile above the junction with the Clarence River, there is a good exposure of beds from the upper Clarentian to the Weka Pass stone. The apparently unconformable nature of the junction has already been described (p. 320). The Amuri limestone is about 200 ft. thick, the lower 150 ft. consisting of a thin-bedded alternation of argillaceous shaly limestone with harder white bands which are slightly glauconitic,

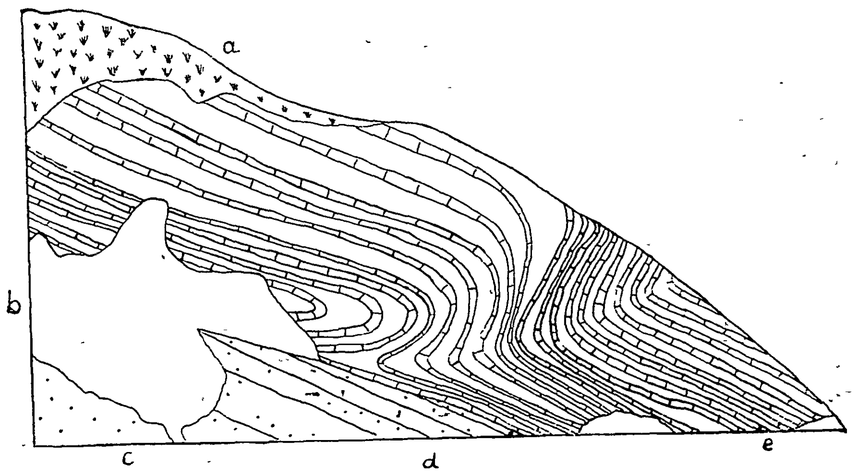


FIG. 6.—Diagram of junction of Amuri limestone and Clarentian greensandstones, south-eastern wing of syncline, Herring River. Only a few of the alternations of chalky and marly limestone can be shown. *a*, tussock; *b*, talus; *c*, sands; *d*, calcareous greensandstone; *e*, Amuri limestone.

while the upper 50 ft. is a glauconitic calcareous mudstone. This is succeeded conformably by 4 ft. of bright-green glauconitic calcareous sandstone with dark phosphatic nodules, and this in turn passes without a break into a dirty brown-green greensand. Both the latter beds contain Oamaruian fossils sparingly.

A few inches of nodular rock follows, very similar to the phosphatic greensandstone separating the Amuri limestone and Weka Pass stone in the Weka Pass. This is in turn succeeded by a thin bed of limestone, 15 in. thick, containing small green fragments which appear to be of volcanic origin. The next bed is a mudstone, about 6 in. thick, with numerous "fucoids," and above this is another bed of limestone, about 6 in. thick, with green fragments. Above this comes about 6 ft. of fine-grained basic tuffs alternating with thin brown calcareous sandstones. The next 10 ft. is occupied by dark tuffs; on these rest another series, about 5 ft. thick, of limestones with green fragments, in beds of about 1 ft. thick, separated by soft shaly material. Finally there is another 4 ft. of dark tuffs, passing up gradually into a massive limestone some hundreds of feet thick. The latter was not examined in detail here. On the opposite side of the river, lower down, it is seen to consist of various types of calcareous sandstone and argillaceous limestone, weathering to light-brown cliffs, and is separated into two parts by a thick band of mudstones very similar to the "grey marls." The strike at the middle of the bend round to the Clarence River is N. 15° E., dip 45° to the west. At the junction with the Clarence the strike is N. 50° E., and the dip 60° to the north-west. The limestone continues down the Clarence River for about 300 yards, and is here an argillaceous limestone with numerous partings, some of which contain dicotyledonous leaf impressions. Marine fossils occur sparingly, and are chiefly Oamaruian mollusca.

Age and Origin of the Amuri Limestone.—The only fossils found in the Amuri limestone of the Middle Clarence Valley are the *Teredo* tubes in chalky limestone from the Bluff River and from the Ure Gorge, and the indeterminable brachiopods found in the glauconitic partings in the flint-beds of the Bluff River. The *Teredo* tubes are indistinguishable from those of the Oamaruian *Teredo heaphyi* Hutton, but it is doubtful whether these deserve specific recognition, and fossils of such a nature are certainly insufficient for purposes of correlation. Probably by renewed collecting determinable brachiopods may be obtained from the Bluff River flint-beds which will suffice to fix the age of these beds. Meanwhile, in the lack of direct palaeontological evidence, the determination of the age of the limestones must remain a matter of inference. A lower limit of age is fixed by the underlying fossiliferous Clarentian mudstones of Sawpit Gully, which contain middle Cretaceous fossils up to within a few feet of their junction with the flint-beds. An upper limit is fixed by the overlying phosphatic greensandstones and Weka Pass stone of the Herring River, both of which contain Oamaruian fossils of at oldest Oligocene age, and, in other areas where these horizons are unfossiliferous, by the still higher "grey marls," which are Oamaruian.

Woods (1917, p. 2) has argued from the facts that the Amuri limestone in North Canterbury and East Marlborough is always overlain by Oamaruian (Miocene) rocks, and is underlain in the former area by Piripauan (Senonian) beds but in the latter area by Clarentian (Albian) beds, that the limestone must be unconformable both to the Piripauan and Clarentian, and that it is probably Eocene.

In 1916, before I had visited the Herring River and Bluff River sections, I discussed the lithology, thickness, distribution, and stratigraphical relations of the Amuri limestone, including the flint-beds, and suggested that it was in large part a chemical deposit. I stated my belief that it was everywhere conformable to the underlying rocks, ranging in age from Piripauan to Oamaruian in North Canterbury, and from Clarentian to Oamaruian in the Middle Clarence area, and that the flint-beds represented a definite horizon absent from the southern area. The discovery by Speight and myself of fossils in an interbedded tuff near the top of the limestone of the Trelissick Basin proved the Lower Oamaruian age of the top of the limestone in this locality. A corollary of the conformity with the underlying beds, by which the conclusion may be tested, is that the underlying rocks of the intermediate district—viz., the Puhipuhi Mountains—where the limestone is intermediate in thickness, must at the top be intermediate in age between Piripauan and Clarentian. Unfortunately, a spell of bad weather prevented my attempted examination of the Puhipuhi Mountains in 1916, and no further opportunity of exploring this area has presented itself. Meanwhile the discovery of the probable unconformity under the limestone in the Herring River area throws new light on the problem.

In 1917 Park suggested that the fossils found by Speight and myself in the Trelissick Basin, and earlier reports by von Haast and himself of Recent brachiopods from the "concretionary greensands" in the Waipara district, proved that the latter were unconformable to the Senonian "saurian beds," and that they, with the overlying Amuri limestone, were Oamaruian. In the same year I showed that the top of the "concretionary greensands" was Senonian, and that if any disconformity exists—for there is no unconformity of the beds—it should be looked for above the "concretionary greensands" in the dark carbonaceous mudstone into which the Amuri limestone passes down. Probably a collection of Foraminifera could be made from this mudstone which might settle its age if a large enough fauna were found. With regard to the supposed *Waldheimia lenticularis* from the "concretionary greensand," unfortunately the specimens do not appear to be preserved, and I have searched this horizon in vain for further specimens. No reliance is to be placed on the identification, for determinations of brachiopod species even by Hutton as late as 1904 were very unreliable, and *Neothyris lenticularis* does not occur fossil below the Wanganuian, and even there it is not at all common. The only *Neothyris* species known to me from the Oamaruian is *Neothyris novara* (von Ihering).

The problem of the age of the Amuri limestone is closely bound up with that of its mode of deposition. In 1916 I pointed out that the hard, chalky type consists predominantly of exceedingly fine-grained calcite, in which matrix isolated but unbroken tests of Foraminifera, chiefly *Globigerina*, occur sporadically, but skeletons of siliceous organisms appear to be absent. That they were formerly present but have disappeared by solution seemed improbable, since there are no spaces of dissolution such as exist in the English Chalk; and although the pressures to which the limestone has almost everywhere been subjected might be considered capable of closing such spaces, this could hardly have happened without the crushing of the delicate tests of *Globigerina*. Although the fact that the flint-beds are thickest where the limestone is thickest would find an easy explanation were the flint the result of a downward migration of silica derived from siliceous organisms in the overlying limestone, the absence of casts of these organisms seemed to prevent the acceptance of such hypothesis, and I put forward the suggestion that the silica of the flint and also the dolomite frequently found with it were chemically precipitated and that the limestone itself was in large part a chemical deposit, but in part composed of foraminiferal tests settling gently into the chemically formed calcareous mud. At the same time I stated, "Much of the above is speculative, but will serve a useful purpose if it calls attention to the peculiar nature of the Amuri limestone, the flint-beds, and the sulphur sands, and provokes an alternative explanation." This hope has been partially realized by the observations published by Marshall (1916, 1917) and by Speight and Wild (1918) on the presence and origin of the flint, but as none of these writers appears to have considered the possibility of chemical precipitation of any of the silica or carbonates of the limestone, and as none of them has discussed the subject from the point of view of the whole problem, it seems desirable to restate it in the light of the evidence now obtainable.

Marshall (1916) agrees with me that by far the greater part of the Amuri limestone over the whole of North Canterbury and Marlborough consists of very fine-grained calcite, while at Weka Pass the chambers of *Globigerina*, which are generally isolated, are fairly numerous. He states that Radiolaria are not infrequent at Amuri Bluff, and mentions sponge-spicules and several examples of a radiolarian at Kaikoura. In the highly siliceous and flinty varieties at Ward and the Ure River no remains of siliceous organisms could be distinguished, but he considered it probable that they had been dissolved. No explanation of the fine-grained calcite base was presented, but he considered the whole rock a pelagic deposit accumulated from the remains of marine organisms.

Marshall in 1917, after the discovery of calcified sponge-spicules in the hydraulic limestone of the Kaipara and Whangarei districts, re-examined specimens from Ward. He considers it probable that diatoms and Radiolaria are present, though much calcified and much destroyed by solution and sees in these the origin of the silica of the flint-beds. His argument may be fairly summed up as follows: By far the greater part of the limestone consists of very fine-grained calcite, but chambers of *Globigerina* which are generally isolated, are fairly numerous. The rock is therefore a *Globigerina* ooze. Radiolaria are not infrequent at Amuri Bluff and Kaikoura, sponge-spicules occur at Amuri Bluff, and it is probable that calcified diatoms and Radiolaria are present at Ward. Therefore the flint in the limestone is probably derived from the skeletons of siliceous organisms. This is rendered the more probable from the occurrence of diatomaceous and radiolarian ooze in limestones of similar age and character in the North of Auckland and at Oamaru. The argument would gain strength by the omission of the diatomaceous earth at Oamaru, which few if any other New Zealand geologists will admit to be of the same age as the Amuri limestone. The facts adduced by Marshall are consistent with the conclusions he derives from them, except that the fine-grained matrix of the limestone is not explained; but they are also consistent with my suggestion of chemical precipitation of carbonates and silica during the formation of the Amuri limestone. All that is necessary to add to my account is the presence of Radiolaria and diatoms in the postulated shower of Foraminifera which helped to form the limestone, the presence of some siliceous sponges, and some secondary migration of the silica.

Speight and Wild (1918) record the presence of flint both above and below the phosphatic layer at Kaikoura and Amuri Bluff, and conclude that its presence cannot be regarded as a criterion of age. Flint *in situ* just below the nodular layer occasionally shows burrows filled with glauconitic material, and so the authors remark that, unless the boring animals were able to penetrate flint itself, the flint must have been precipitated subsequently to the boring of the limestone. I have not claimed that the presence of flint in the Amuri limestone is a criterion of age, pointing out that small flints similar in mode of occurrence to those of the English Chalk are common in the limestone at Amuri Bluff, which I considered as much younger than the lower part of the limestone at Coverham. What I did suggest was that the massive flint-beds occurring at the base of the limestone from the Puhipuhi Mountains northwards occupied a definite stratigraphical horizon, and Speight and Wild's observations throw no light on this point. In suggesting that the silica of the flints was deposited chemically I did not claim that there was no secondary migration of the silica. In case I did not make this clear, I wish now to state that I consider that both the flint of the flint-beds and the sporadic flints occurring at higher horizons are concretionary in their nature, and are the result of the redeposition of silica originally scattered throughout the beds in which the flint occurs. The fact that the evenness of the bedding-planes gives place to rolls around the largest flint lenticules seems to prove this for the flint-beds. The structure of the flint-dolomite exteriors is also more in accord with a secondary than with an original deposition.

Cotton (1918), in examining by the deductive method the kind of deposits to be found in the continental shelf, showed that with advances and retreats of a subsiding shelf corresponding to fluctuations in the ratio of waste-supply to rate of subsidence there may be intercalations of foreset and pelagic beds in the topset beds towards the outer part of the shelf, while farther seaward there will be no intercalations of topset beds but an alternation of pelagic and foreset beds. In this way, he suggests, may perhaps be explained the intercalation of the Amuri limestone between mudstone and marl in Marlborough. Interpreting the chalky limestone as pelagic and the marly limestone as foreset beds passing into pelagic, the frequent alternations of these two kinds of rock in Marlborough receive a satisfactory explanation. Moreover, since both kinds of beds were laid down on the broad continental slopes, and since fluctuations in the supply of waste are regional, it is probable that bands showing such alternations must have a wide geographical range, and can therefore be used in correlation over neighbouring areas. In respect to the pelagic beds Cotton's deductions are unaffected by the method of deposition, whether partly chemical or solely by accumulation of tests of marine organisms.

The following are the reasons for considering that the chalky variety of Amuri limestone is in large part chemically deposited:—

(1.) *Its lithological nature.* As Marshall states, by far the greater part of the rock consists of very fine-grained calcite, with isolated but fairly numerous tests of *Globigerina*. If this fine-grained material is derived also from broken tests of Foraminifera, there must have been great comminution of the tests before consolidation, and it is difficult to imagine any agency which could effect this and yet leave the tests of *Globigerina* in such perfect condition. If, on the other hand, the fine-grained material is the result of solution of tests and recrystallization, it is again difficult to see why the tests of *Globigerina* have escaped the destruction of form the others have suffered. On the other hand, there is no difficulty in imagining the tests settling gently into a fine mud of chemical origin, and preserving their form during the recrystallization that has certainly in some cases taken place.

(2.) *Its chemical nature.* Specimens of chalky limestone from districts where the flint-beds occur and others from districts where flints are rare show alike a considerable silica-content. The mean of ten analyses I have collated gives 10·25 per cent. of silica. As the rock contains exceedingly little terrigenous sediment, this silica must be mainly ascribed to siliceous organisms if chemical deposition is ruled out; but neither the remaining skeletons nor the probable casts of such skeletons are present in sufficient amount to account for such a large percentage of silica. The position becomes worse if we add in the silica of the flint-beds, supposing this to be derived by solution and migration of silica from the overlying limestone and not from redeposition *in situ* of the silica of radiolarian or diatomaceous oozes.

The presence of dolomite in the flint-beds is difficult to explain if the limestone is a deposit accumulated in deep, cold water solely from skeletons of marine organisms. The total amount is not very great, and perhaps not more than might be expected if it represents a downward migration and accumulation at the base of all the magnesium carbonate originally present in the whole mass of limestone, but it creates a considerable difficulty if the flint-beds are considered as siliceous oozes of organic origin reprecipitated *in situ*.

(3.) *Its lack of fossils.* Although the *Globigerina* oozes of the present oceans do not afford a suitable bottom for some forms of benthic life—*e.g.*, brachiopods—yet they are by no means devoid of other forms. Moreover, the European Chalk, which presumably represents a pelagic deposit laid down in not very deep water on the continental slopes, is not conspicuously poor in fossils but can be zoned by means of them. The Amuri limestone, on the other hand, is practically without any fossils of benthic organisms from bottom to top, and this can hardly be due to their destruction after consolidation, since the tests of *Globigerina* and also sharks' teeth have endured. This means, then, that benthic life was practically absent during its accumulation. The presence of bands of alternations of marly and chalky limestone proves that the limestone is not an abyssal deposit, but was laid down on the slopes of the continental shelf. The absence of benthic life is in accord with a hypothesis of the precipitation of a calcareous mud by the presence of solutions in the bottom waters inimical to animal-life. It is not necessary to postulate the presence of sulphur bacteria to produce such solutions, for it has recently been shown that albuminous bacteria can produce similar effects.

There is reason to believe that the formation of the flint took place soon after deposition, and before the beds were folded and jointed. The flints are themselves much jointed, and, moreover, in the overturned syncline between the upper Ure and Coverham the flint-beds overlie the limestone in the reversed upper limb and underlie it in the lower limb. Supposing the flint-beds to result from a downward migration of silica, it is very doubtful whether silica-bearing or other solutions could have passed freely through the marly limestones before these were jointed. It is noteworthy that the flint-beds are always associated with massive chalky limestones, and where these fail, as in the Herring River, there are no flint-beds. If, then, the alternations of chalky and marly limestone imposed an obstacle to the downward migration of silica, the flint-beds in the Mead section must result from the redeposition of the silica of only the lower 1,500 ft. of limestone, of which they compose the greater part. The amount of silica in these lower beds is so great that it could not be explained, apart from the chemical theory, without concluding that these beds were originally in large part radiolarian or diatomaceous oozes. Why such oozes should be so completely altered as to retain no evidence of a former organic origin is a problem which must be answered by the opponents of the chemical theory.

The above reasons seem to me to establish a *prima facie* case for the chemical precipitation of calcium carbonate during the deposition of the Amuri limestone. If this took place it is not difficult to believe that there was deposition also of magnesium carbonate or of dolomite in a similar manner. The chemical deposition of silica presents a greater difficulty to the imagination, and I do not consider that the evidence for this is so strong, although, as I have shown above, there are also difficulties in accepting any other explanation.

In seeking to infer the age of the Amuri limestone, the question arises whether it is a continuously-formed deposit or whether there may be within it disconformities or planes corresponding to periods of non-deposition. The junction between the limestone and the phosphatic greensand at the base of the Weka Pass stone in North Canterbury and South Marlborough appears to represent such a plane, since, although there is perfect parallelism of dip and strike of the two rocks in all exposures, the surface of the Amuri limestone is perforated by borings filled with glauconitic material and the loosened fragments of limestone lying at the base of the greensand are phosphatized.

Barrell (1918) has shown that in epicontinental beds, such as form the greater part of the geological record in North America, disconformities must be much commoner than was formerly supposed. These beds, however, were deposited in shallow epicontinental seas not often more than a hundred fathoms in depth. His conclusions cannot be made to apply to rocks such as compose the bulk of the Notocene in New Zealand, which have been deposited on a continental shelf fringing a deep ocean, and, for the greater part, on the outer slope of this shelf. Here, as Cotton (1918) has shown, when foreset beds fail through insufficiency of waste to compensate subsidence, or for other reasons, the deposition of pelagic beds immediately commences. It is difficult to imagine conditions which can bring about a disconformity between pelagic and foreset beds, such as exists at the above-mentioned junction. If the pelagic beds are in large part a chemical deposit, however, it is not difficult to imagine a change of conditions which would put a stop to chemical deposition, and the formation of purely organic ooze might be so slow as to allow time for the boring of the last-formed bed and the phosphatization of its upper surface before the deposition of the foreset greensand began.

The absence of other phosphatic layers in the Amuri limestone makes it probable that other similar disconformities do not exist, and the enormously greater thickness of the formation in the Mead area than of that at Amuri Bluff and farther south proves without any doubt that in the former area it must have taken much longer to accumulate. If, however, the limestone is in large part a chemical deposit, and if chemical deposition was more active in forming the lower part than the upper part, the time taken to form the greater thickness may not have been much more than twice that taken for the lesser thickness, although the ratio of the thicknesses is as four to one. The fact that in both areas the limestone is covered by the phosphatic greensands and the Weka Pass stone makes it probable that the top of the limestone is of the same age in both areas. Consequently the base of the limestone must be much older in the Mead area than it is at Amuri Bluff.

To believe with Woods (1917) that the Amuri limestone of the Mead–Coverham area is disconformable to the Clarentian and that it is Eocene places a much greater strain on the imagination than to believe that it is conformable and ranges in age from the top of the Clarentian to the base of the Oamaruian. It would mean that the Clarentian beds were emergent without tilting all through the Cenomanian, Turonian, Senonian, and Danian, and yet suffered no subaerial erosion such as would truncate their structures or dissect their surface, and that in the succeeding Eocene transgression so rapid was depression that there was no marine erosion or deposition of clastic beds, but instead the immediate formation of pelagic beds. It implies also that a similar succession of events happened at Amuri Bluff, except that emergence lasted only throughout the Danian and lower Eocene; but the depression, which was large and sudden, must have been much later than that in the Clarence area, since the limestone there is four times as thick. On the other hand, it is only to be expected that the deposition of pelagic beds was continuous on the outer slopes of the continental shelf which must have been formed immediately after the post-Hokonui deformations, and the differential movement of the Kaikoura deformations were certainly large enough to elevate even bottom-set beds above sea-level and certainly extended over a great part of the area covered by the Notocene continental shelf. There is thus no *a priori* reason why conformable pelagic and foreset beds extending from Clarentian to Oamaruian should not be found. The perfect conformity of the limestone to the Clarentian in the area where it is thickest—viz., from the Dee Gorge to Benmore—and the presence of apparent passage beds in the Isolated Hill Creek is most easily explicable on the theory of actual conformity.

The unconformity in the Herring River does not militate against the above conclusion. The limestone is here very thin, and consists of alternations of chalky and marly limestone which must be correlated with the similar band in the Bluff River and the upper of the two similar bands in the Mead Gorge. Two hypotheses in explanation are possible. The Clarentian beds may have been emergent during the period when the lower part of the limestone in the Mead Gorge was formed, or the upper part of the beds in the Herring River described as Clarentian may be foreset beds younger than the youngest Clarentian beds of the Coverham section. They consist of sulphur sands and mudstones similar to those of the Piripauan, and are followed by greensands as in the Piripauan. This resemblance may be more than accidental. The only Albian fossils found at this end of the valley come from beds near the base of the series.

The absence of flint-beds in the Herring River, however, and their presence in small amount under a small thickness of limestone in the Bluff River, makes it unsafe to predict that the beds immediately beneath the flint-beds of the Hapuku Mountains are Turonian. They may be also Clarentian and separated from the overlying limestone by an unconformity. In the Kekerangu area the limestone appears to be thin and separated by fairly thick mudstone bands, and again in the hills to the north of the lower Ure the limestone is quite thin. Obviously there is still a great deal to be learned about its thickness, nature, and relationships in East Marlborough, and any final conclusions about its age are premature.

The " Grey Marls."

The term " grey marls " was first applied by McKay to beds of more or less calcareous mudstone following the Weka Pass stone in the Weka Pass. Similar beds at Amuri Bluff had previously been termed the *Turritella* beds by von Haast, and the *Leda* marls by Cox, who correlated them with the so-called *Leda* marls of Whangape Lake, Waikato. The term " grey marls " was accepted by Hector and applied to beds of similar position and age throughout North Canterbury and Marlborough, and also, owing to a false correlation by McKay, to mudstones underlying the Ototaran limestones of Oamaru and South Canterbury. The " grey marls " were considered by Hector and McKay the closing member of the Cretaceo-Tertiary formation, the succeeding Mount Brown beds in the Weka Pass district being termed " Upper Eocene." So far as Marlborough is concerned, the Cretaceo-Tertiary formation of Hector and McKay had this justification: that the conformable Notocene sequence so far as known closed with the " grey marls," the great Marlborough conglomerate being considered unconformable, while the Awatere beds represented a younger Tertiary transgression. Outside the diastrophic district of North Canterbury and East Marlborough, in the South Island at least, no correlative beds of similar nature and position are known, and I suggested in 1916 that the term "grey marls" if confined to mudstones following the Weka Pass stone in this district remains a useful geological term, but that its usefulness is destroyed if it is used indiscriminately for Tertiary mudstones of any age or position.

The "grey marls" are generally fine-grained or sandy mudstones with little calcareous matter except as actual fossils, although concretions are sometimes found. They form cliffs of a grey colour, in opposition to the bluer and generally more calcareous Wanganuian papas of the North Island and of the Awatere series, and frequently exhibit the peculiar conchoidal weathering of indurated but massive mudstones, and seldom show shaly partings. Very frequently the beds become more sandy and may be described as muddy sandstones. Bedding-planes are in general obscure. Fossils are present in almost all exposures, but are often scanty and frequently crumbling. The larger fossils are chiefly molluscs and corals, while Foraminifera are in places plentiful. Echinoids are occasionally present, but brachiopods are almost absent.

In the Middle Clarence area I have studied these beds only in the Mead, Limburne, and Dee Gorges, and must rely on McKay's descriptions for other parts of the area.

Mead Gorge.—McKay describes the beds as "about 400 ft. of greenish-grey sandy marls, which contain concretions and a few fossils, not sufficiently well preserved to be of value in determining the age of the beds. Casts of *Dentalium* and *Solenella* were obtained, and fragments of a nacreous shell are abundant in some part of the softer beds."

The Mead Gorge flares out in crossing the "grey marls" and forms a sort of basin-shaped excavation, the sides of which are in great part slipped. A continuous section is exposed only at the top of the cliffs on the south side, but the cliffs are here practically unscalable. The junction with the Weka Pass stone is well exposed on the north side, the latter rock striking N. 18° E. and dipping 55° to the east. It is an argillaceous limestone, somewhat shaly, and passes up quite gradually into hard, somewhat fissile mudstones, of which only about 30 ft. are here exposed. On the south side the lower part of the "grey marls" is covered by slipped material, except near the top of the cliff. The upper part on this side appears to be quite conformable to the overlying great Marlborough conglomerate, but shows no well-defined bedding. There are a number of small greywacke pebbles in the uppermost part of the "grey marls," seeming to establish a passage to the conglomerate.

Fossils are present in the upper part of the "grey marls," both isolated and in concretionary blocks. It appears possible, however, that these blocks are not concretions *in situ* but are derived, for they are frequently angular in outline and exhibit the broken-off ends of shells on their exteriors. The blocks are small at a horizon 10 ft. from the top, but are as much as 18 in. in diameter at 100 ft. from the top. There are in addition many ellipsoidal and rope-like masses which appear to be concretions *in situ*.

From a horizon 130 ft. from the top I collected *Cardium patulum* Hutt. (?). A horizon 100 ft. below the top yielded *Voluta arabica* Mart., *Dentalium mantelli* Zitt., and *Paphia curta* Hutt. At 30 ft. I collected

Turritella murrayana Tate, *Polinices gibbosus* (Hutt.), *Siphonalia conoidea* Zitt. (?), *Miomelon corrugata* (Hutt.), *Ancilla hebera* Hutt., *Malletia australis* (Q. & G.), *Chione meridionalis* (Sow.) (?), and *Paphia curta* Hutt.; at 25 ft., *Turritella murrayana* Tate, *Ancilla hebera* (Hutt.), *Glycymeris globosa* (Hutt.), *Zenatia acinaces* (Q. & G.), *Dosinia magna* Hutt., and *Paphia curta* Hutt.; at 20 ft., *Clio* (*Styiola*) *rangiana* (Tate), *Turritella murrayana* Tate, *Ancilla hebera* (Hutt.), and *Limopsis aurita* (Brocchi). Other isolated fossils found in the slips included *Struthiolaria cincta* Hutt., *Ancilla pseudaustralis* (Tate), and *Limopsis aurita* Brocchi. One of the supposedly derived boulders yielded *Calyptraea maculata* (Q. & G.), *Ancilla hebera* (Hutt.), *Anomia walteri* Hector (?), *Glycymeris globosa* (Hutt.), *Mactra scalpellum* Reeve, and *Paphia curta* Hutt. Another similar boulder obtained from a slip contained *Turritella murrayana* Tate, *Calyptraea maculata* (Q. & G.), *Dentalium mantelli* Zitt., *Anomia walteri* Hector (?), *Glycymeris globosa* (Hutt.), *Mactra scalpellum* Reeve, and *Paphia curta* Hutt. All the above determinations and those that follow from the Dee Gorge were made by the late Mr. H. Suter.

Limburne Gorge.—The gorge of the left branch of the Limburne is narrow, and where it opens out on the "grey marls" is much slipped, so that no exposures *in situ* can be observed. The rocks present in the slips are mudstones of the usual type.

Dee Gorge.—In the north branch of the Dee the lowest beds of the "grey marl" series are separated from the Weka Pass stone by a fault of low angle. They consist of hard sandstones forming yellow cliffs, and are succeeded above by mudstones of the usual type. From the lower part of these, in cliffs on the south side, I obtained *Turritella murrayana* Tate. In the upper part of the mudstones, about 20 ft. below the top, there are thin bands of mudstone alternating with thin bands of sandstone containing plant-remains. There are also occasional small pebbles of greywacke in the mudstones and some thin beds of fine conglomerate. The junction with the overlying conglomerate is not seen at this point. From these upper mudstones I collected *Acmaea* or *Patella* n. sp., *Turritella murrayana* Tate, *Struthiolaria tuberculata* Hutt., *Polinices gibbosus* (Hutt.), *Siphonalia subnodosa* (Hutt.), *Dentalium mantelli* Zitt., *Glycymeris globosa* (Hutt.), and *Cytherea chariessa* Sut.

A little farther up the stream the junction with the conglomerate may be observed over a distance of about 12 ft. It is perfectly sharp at this point, and there is no bedding observable in the uppermost "grey marls," which are mudstones.

In the south branch of the Dee the hard sandstones at the base of the "grey marls" have the same dip and strike as underlying Weka Pass stone, but the actual junction is not seen. In a subsequent stream entering this branch from the south-west along the strike of the "grey marls" the latter series appears to be about 300 ft. thick. The lower beds on the south-east side are hard sandstones, while the upper beds on the opposite side are softer mudstones, in which, however, no shell-beds were observed. The junction with the overlying conglomerate is exposed, and appears to be a gradual passage, lenses of fine conglomerate appearing in the upper few feet of the mudstones.

In a second small subsequent tributary entering the south branch farther up on the same side there are a few lenses of sandstone near the top of the "grey marls," but no shell-beds. A crinoid stem was collected about half-way up this creek. The uppermost mudstones contain pebbles of greywacke, and there is a good deal of mudstone in the bottom of the conglomerate.

McKay does not describe the "grey marls" in the Dee River, but his section represents the junction with the overlying conglomerate as unconformable, the erosion surface on the "grey marls" being gently undulating.

Upper Swale and Ure Rivers.—McKay describes the "grey marls" on the western side of the Chalk Range as blue or greenish-grey unfossiliferous marly beds, about 300 ft. thick, resting conformably on the Weka Pass stone. They are repeated by folding or faulting farther to the westward.

Farther to the north-east the "grey marls" apparently disappear through the pitching of the inverted syncline to the south-west, Amuri limestone being continuous across the Ure River from Brian Boru and Isolated Hill to the White Bluffs. In the middle Ure, below the gorge, I have already described the beds which underlie the Amuri limestone, but which, owing to the probable inversion of the strata, may represent the Weka Pass stone and "grey marls."

Dart River.—McKay describes the "grey marls" as about 500 ft. thick and resting conformably on the limestone. Fossils occur as nests in and sparingly distributed through the grey or greenish marly clays, including *Galeodea senex* Hutt., *Ancilla* sp., and *Pecten* aff. *zitteli* Hutt. Fine-grained concretions similar to those in the Mead Gorge are found, but do not yield fossils.

Muzzle River.—Here again the "grey marls," according to McKay, are about 500 ft. thick. Resting on the Amuri limestone is a band of tufaceous calcareous greensand with *Waldheimia* sp. and *Cristellaria haasti.* Higher beds consist of dark-grey or greenish sandy clay, parted by thin beds of calcareous sandstone, some of which are richly fossiliferous and yielded *Cristellaria haasti, Pecten zitteli, Venus* ? sp., a small, strongly-ribbed *Pecten,* small univalves, *Rhynchonella* sp., and Echinoid fragments.

Bluff River.—McKay does not describe the nature or thickness of the "grey marls" in this section, but mentions the occurrence of *Pecten zitteli* and *Galeodea senex,* with casts of *Malletia, Leda,* corals, &c.

Herring River.—McKay does not describe the "grey marls" in this area, but his section shows their presence between the Weka Pass stone and the great Marlborough conglomerate, and they are enumerated as "grey marls containing *Dentalium, Natica,* Foraminifera." In describing the conglomerate, he mentions that at the top of a high cliff on the left of the junction of the Herring River with the Clarence River the Weka Pass stone is in contact with the older rocks (pre-Notocene) along the fault-line, and this I also observed. At lower levels McKay describes an agglomerate resting on the "grey marls," and consisting of blocks of Amuri limestone, Weka Pass stone, saurian concretions, and blocks and concretions of middle Tertiary rock without any evidence of stratification. He seemed uncertain of their dip, but estimated the thickness at 200 ft., and considered them involved in the fault-angle. It is difficult to see how, if the Weka Pass stone, which is dipping towards the fault, rests against it at the top of the cliff, younger beds can be present against the fault at lower levels. McKay did not recognize the layer of mudstone, similar to the "grey marls," which separates the Weka Pass stone in this area into an upper and lower band, and I believe he has taken an exposure of this rock for the "grey marls" and has mistaken a talus deposit for the great Marlborough conglomerate. In this case the "grey marls" are absent in this section. A closer study of the upper beds of this area is desirable.

Age and Formation of the "Grey Marls."—Owing to the great range of the majority of Oamuruian Mollusca, the list of fossils so far collected from the "grey marls" is insufficient in itself to prove whether the beds are Lower, Middle, or Upper Oamaruian. If, however, a correlation with the "grey marls" of the Weka Pass district is admitted, it is necessary to consider them Middle Oamaruian or Ototaran, since in that locality they are followed by the Mount Brown beds, the uppermost limestone band of which is Awamoan, and the middle or main band Hutchinsonian on the evidence of the rich brachiopod fauna. It is, indeed, possible that part of the Mount Brown beds is Ototaran, so that the "grey marls" can hardly be younger than that stage.

According to diastrophic considerations, the presence of thick beds of mudstone following limestone in such a series as the Notocene is evidence of a gradual sea-retreat, causing renewed denudation of the thick soil-mantles accumulated on the peneplained land which formed the coasts of the middle Notocene seas. If this sea-retreat is in the main due to movements of the hydrosphere, then the correlation of the "grey marls" throughout North Canterbury and Marlborough appears well based. The uniform lithological characters of the upper part of the Amuri limestone, the phosphatic greensand, the Weka Pass stone, and the "grey marls" throughout these areas supports the belief that the changes of the deposits are mainly due to movements of the hydrosphere. The chief difficulty lies in the conception of gradual emergence in the district north of the Rakaia River at the very time (Ototaran) when there was greatest submergence south of that river. Perhaps the true explanation is that the whole of the Ototaran is comprised within the Mount Brown beds. which were formed in a period of renewed depression. This would involve the consideration of the "grey marls" as Waiarekan, but there would still be the difficulty of the gradual emergence in the northern district at the time of a marine transgression in the southern area, so that there seems no escape from an hypothesis of warping in minor diastrophic districts, to some extent masking the effects of movements of the hydrosphere.

The Great Marlborough Conglomerate and Awatere Beds.

The conglomerate which closes the Notocene series in the greater part of the Middle Clarence Valley (Plate XXIX, fig. 1), in common with similar conglomerates in other parts of Marlborough, was termed by McKay the "great post-Miocene conglomerate," from the belief that certain Tertiary sandstones which occur as boulders within it were of Miocene age. The Miocene of Hector and McKay's classification comprised the beds now classed as Awamoan and Waitotaran, the latter stage being later than Miocene, so that the name used for the conglomerate is unsuitable. Although McKay considered that the conglomerate contained boulders of sandstones of the Awatere series, which ranges from Awamoan to Waitotaran, there is reason to believe that in the Clarence Valley there are no boulders of rocks younger than Oamaruian in the conglomerate, which itself appears to be an Oamaruian rock. It is preferable, therefore, to use a local name for the rocks, and I suggested in 1913 the alteration of McKay's name to "great Marlborough conglomerate." Under the latter name Cotton in 1911 described fully the nature of the conglomerate and discussed its relationship to the underlying formations in the Mead and Dee Gorges, and for these localities I have little to add to his account, which is freely quoted below.

McKay's conception of the conglomerate as post-Miocene necessarily involved a considerable unconformity between it and the "grey marls," which he classed as Cretaceo-Tertiary. Perhaps in consequence of this he did not examine the junctions between the two rocks very carefully. In all his sections the conglomerate is shown as resting unconformably on the "grey marls," generally with very slight truncation of the beds of the latter, but in the Mead Gorge the truncation shown is very marked. Hector's section shows the conglomerate overlapping the "grey marls" on to the Weka Pass stone, but this is in marked disagreement with his plan. Dr. Cotton and I examined carefully all the exposed junctions in the Mead and Dee Gorges and could find no evidence of unconformity. If there is any, it is more probably between the upper and lower parts of the rocks above described as "grey marls," for a violent unconformity may escape recognition in mudstone cliffs. The upper "grey marls" are certainly Oamaruian, so that even were an unconformity present below them the conglomerate would still be much older than McKay supposed.

Cotton (1914) has discussed the question of the unconformity of the conglomerate fully, and has shown how a false impression of unconformity in the Mead Gorge may be received. In the first place, owing to the widening-out of the gorge where it crosses the outcrop of the weak "grey marls," the junction has an apparent dip which the eye is tempted to compare with the true dip of the Weka Pass stone as seen below on dip slopes. In the second place, the surface of the junction, originally plane, is now broken by a number of small faults, giving it an undulating form in section. Cotton records the strike of the junction plane as N. 25° E., and the dip as 47° to the west-north-west. My observation of the strike of the Weka Pass stone was N. 18° E., and the dip 55° to the west-north-west. The slight differences between these figures are less than occur within similar thicknesses of the Amuri limestone lower down in the section.

A further argument in favour of conformity is the presence of greywacke pebbles and of plant-bearing sandstones in the upper "grey marls" of the Mead section, and of conglomerate lenses in a similar position in the Dee section. Hector has described similar plant-bearing sandstones at the base of the conglomerate in Shades (? Deadman's) Creek and in Heaver's Creek. In the latter locality I was unable to separate these from the upper "grey marls." In the Mead section their intercalation with Oamaruian mudstones is certain.

In almost all exposures McKay records the presence of crystalline rocks belonging to the intrusive dykes which seam the pre-Notocene rocks in the Tapuaenuku massif. A careful examination of all the exposures in the Mead, Dee, and various exposures near Kekerangu convinced Dr. Cotton and myself that these rocks are practically absent, or at least rare. In almost all exposures there are small boulders of doleritic and porphyritic igneous rocks which bear a closer resemblance to the Clarentian volcanic lavas of the Clarence and Awatere Valleys than to the intrusives, and syenites such as compose the bulk of the upper part of the Tapuaenuku massif appear to be quite absent. McKay considered that the crystalline material in the gravels of the Swale and Ure Rivers was derived from the conglomerate; but in the latter river this is certainly not the case, the bulk of the material coming from the dark, coarse-grained dolerite of the Blue Mountain, of the existence of which McKay was not aware.

Mead Gorge.—As already mentioned, the upper part of the "grey marls" contains pebbles of greywacke, and concretionary masses with fossils which may possibly be derived boulders. Cotton describes the basal layer of the conglomerate as a bed 2 in. thick of conglomerate formed of small rounded pebbles of greywacke. "Next follows 2 ft. 6 in. of bedded sandstone, covered by 1 ft. of mudstone, and that again is followed by many feet of fairly coarse conglomerate interbedded with sandstone and mudstone bands 1 ft. to 3 ft. in thickness, and with bands of very coarse conglomerate." The boulders in the conglomerate bands are of varied sizes, about one-third being over 6 in. in diameter, and blocks of to 2 ft. in diameter being common. Still larger blocks occur, but are rare. Small pebbles of greywacke are very abundant throughout, and are smooth and well-rounded. "There is in addition a large proportion of fine, sandy material filling the interstices, and the conglomerate is cemented into a very hard rock." The rocks represented are—pre-Notocene greywacke and jasperoid pebbles, forming the bulk of the finer material; sandstone blocks of all sizes, probably mostly Clarentian; small boulders of basalts resembling those of the Clarentian of Herring River and Mouat's Lookout in the Awatere Valley; Amuri limestone, not very abundant, in blocks up to 6 in. in diameter, but rarely larger; water-worn blocks of fine Tertiary sandstone, crowded with shells, and resembling in appearance and fossil-content the supposedly derived boulders in the underlying "grey marls."

Dee Gorge (Plate XXIX, fig. 2).—The lower part of the conglomerate is very well bedded by thin sandstone bands. The material is generally similar to that in the Mead, and the presence of Clarentian rocks is proved by the presence of blocks of sandstone containing fragments of *Inoceramus*. A very large block of flint-beds was observed near the base on the north side, but in general the size of the boulders, as in the Mead, is smaller than in the exposures of the Kekerangu area. For further details Cotton's description should be consulted.

Upper Swale and Ure Rivers.—There are several separated outcrops of the conglomerate in the upper Swale Valley, presumably owing to its repetition of folds or faults, but their relations are unknown except in the case of the most easterly, which McKay examined and found resting on the "grey marls." Mr. A. Tomlinson, of Awapiri, Awatere Valley, informs me that these conglomerates are reddish in colour and form three sharp ridges known as the Razorbacks. In the upper Ure, as seen from the summit of the Chalk Range, there is a main outcrop of conglomerate running from behind the Whaleback across the river and terminating opposite Whitewash Creek. This outcrop evidently occupies the core of the overturned syncline. Two smaller outcrops are seen on the watershed between the Ure and the Swale, dipping towards Limestone Hill, which is formed by the Amuri limestone of the upper limb of the syncline

Dart River.—McKay describes the conglomerate as resting on the "grey marls." The series is 500 ft. thick, and dips 50° to 60° to the north-west. The lower beds are coarser than the middle and upper parts. In the middle beds there are gritty sandstones with broken shells and black shales with abundant plant-remains forming coaly streaks. The upper part, which is well stratified near the top, is mainly formed of moderate-sized pebbles, with beds of black shale.

Muzzle River.—McKay describes the beds as of about the same thickness as in the Dart and the Dee. In the west branch they are standing vertical and rest against the fault. In the eastern branch they form a syncline resting on the "grey marls," and the junction along the fault is obscured. Fossiliferous blocks of Tertiary rocks and concretions and fossiliferous blocks from the Clarentian are abundant in both sections.

Bluff River.—McKay describes the conglomerate as much thicker than elsewhere to the north-east, and as very coarse in its lower part, containing blocks of Amuri limestone 10–35 ft. in diameter, together with boulders of Clarentian rocks and fossiliferous Tertiary concretions mingled with well-rounded pebbles of sandstone and volcanic rocks. The higher beds of the conglomerate are much finer than the middle and lower parts, and alternate with beds of sandstone, forming a passage to an overlying series of sandy clays with ribs of hard sandstone which are difficult to distinguish from the "grey marls."

Seymour River.—As has already been stated in describing the "grey marls," it appears improbable that the great Marlborough conglomerate is present in this section, and more likely that the agglomerate described by McKay really represents an old talus deposit. The only doubt is caused by his reference to the presence of "blocks and concretions of middle Tertiary rock."

Deadman's Creek.—Although this section lies outside the area here described, the relationships of the great Marlborough conglomerate are of great importance in any discussion of its origin. Deadman's Creek lies immediately south of Deadman's Hill on the coast south of Kekerangu. Hector and McKay have referred to it as Shades Creek, but the true Shades Creek is still farther to the south.

The sequence commences with Amuri limestone or Weka Pass stone, here argillaceous and with many layers of mudstone. This dips north-west —*i.e.*, up-stream—and is succeeded by "grey·marls." Above this comes a strong band of the great Marlborough conglomerate, some hundreds of feet thick. Unfortunately the junction with the "grey marls" is obscure, but the lower 15 ft. of the conglomerate consists of fine sandstones. The succeeding 60 ft. of the conglomerate is fairly coarse, although blocks larger than 3 ft. in diameter are rare. The majority of the boulders are well rounded, and they consist preponderatingly of pre-Notocene greywackes and jasperoids and Clarentian sandstones. Volcanic rocks similar to the Clarentian lavas are commoner than usual. Boulders of Amuri limestone are moderately abundant, and flints are occasionally seen. Boulders of fossiliferous Tertiary sandstone are not very common, and are generally of small size and uniform in character.

The gorge of the creek in the conglomerate is impassable, and the creek-bed below is described by McKay as "choked with huge fossiliferous blocks from 3 ft. to 15 ft. in diameter, from which a collection of Awatere fossils of such variety and excellence could be made that the like could not be obtained from any one locality where the beds occur *in situ.*" Hector agrees with McKay in believing that these blocks are derived from the conglomerate. As a matter of fact, no blocks of such size were observed in the conglomerate, and those in the creek-bed are undoubtedly derived from a series of shell-beds *in situ* apparently resting on the conglomerate. To these I have given the name of the Deadman's Creek beds. They consist of sandstones crowded with shells along certain layers, some bands containing predominantly *Polinices*, others *Turritella*, and others *Glycymeris*. About 100 ft. of these beds are exposed in the cliffs, and another 100 ft. along the creek-bottom, where they contain pebbles, the majority of which are of greywacke and quartz, but one pebble of basalt was observed, and some blocks of fossils, apparently derived. The junction of these beds with the underlying conglomerate was not clearly made out. The dip of the two rocks is the same—about 60° up-stream—and in the cliffs they appeared to be conformable, but in the bottom of the creek the junction appeared to be faulted.

From these Deadman's Creek beds I collected fossils, which were determined by the late Mr. H. Suter as follows: *Turritella murrayana* Tate, *T. concava* Hutt., *Struthiolaria tuberculata* Hutt., *Polinices gibbosus* (Hutt.), *Siphonalia subnodosa* (Hutt.), *Voluta arabica* Mart., *V. depressa* (Suter), *Glycymeris globosa* (Hutt.), *Dosinia greyi* Zitt., and *Protocardia sera* Hutt. This is certainly an Oamaruian assemblage, and very similar to that of the sandy shell-beds of the White Rock River (Awamoan).

The cliffs farther up the stream are slipped for some distance, and there is a gap in the observable succession corresponding to about 100 ft. of rock with the same dip. Then another band of the great Marlborough conglomerate appears, about 600 ft. thick, dipping about 60° to the north-west (up-stream). This is similar in character to the first-mentioned band, and passes up gradually into a very regularly bedded series of thin sandstones and fine conglomerates with occasional layers of mudstone, passing in turn up to massive mudstones in the Ericaburn. Above this the dip becomes reversed, and the mudstones can be again traced downwards into sandstones and thin conglomerates. Beyond this there is a break in the observable succession, and massive mudstones with large calcareous concretions and a few friable fossils form large cliffs in the Ericaburn about half a mile above its junction with Deadman's Creek, and present a great resemblance to the Awatere mudstones in the upper part of Starborough Creek (Awatere Valley). The thickness of the beds above the conglomerate up to the point of reversal of dip was estimated at about 700 ft.

It is exceedingly unlikely that there are two bands of great Marlborough conglomerate separated by 300 ft. of marine sandstones, and it is almost certain that a fault intervenes between the two outcrops. The boulders of fossiliferous Tertiary sandstones in the conglomerate are so similar to those formed by the present creek from the Deadman's Creek beds that it seems exceedingly likely that it is to these latter beds that we must look for the source of the boulders of the conglomerate in this locality. In this case a fault must be interposed just above the lower conglomerate, and the Deadman's Creek beds must be regarded as a facies of the "grey marls."

Origin and Age of the Great Marlborough Conglomerate.—Both Hector and McKay regarded the great Marlborough conglomerate as fluviatile in origin. "This singular conglomerate probably originated through erosion by a great river-system which has since disappeared, and the subsequent dislocation of the land-surface that it had covered with its alluvial detritus in the form of shingle river-beds and great fan-shaped accumulations spread out into the plains" (Hector, 1886, p. xxxvi). McKay (1892, pp. 4–5) described the rocks as having usually the character of glacier morainic matter and more or less well-rounded river-gravels. "On the whole it is a drift formation, and the evidence is conclusive that the drift of the material was from south to north, or from the south-west to the north-east." The evidence for this drift he found in the nature of the fossiliferous Tertiary sandstones which were not found *in situ* in the area occupied by the conglomerates but closely resembled rocks developed in the Mason River and Lottery Creek, far to the south-west, and also in the presence in the coastal area near Kekerangu of boulders of the Tapuaenuku intrusives. We have already seen that this assumption is unnecessary, since the Deadman's Creek beds to the north-east consist of fossiliferous

Tertiary sandstones, and there are probably other beds of a similar nature as yet undiscovered in other parts of the area embraced by the outcrop of the conglomerate. There are also a small number of blocks of Tertiary sandstone in the upper part of the " grey marls " in the Mead and Dee Gorges.

Park (1910), who examined only the exposures of the Kekerangu River and Deadman's Hill, concluded that the conglomerate was a glacial moraine of Pleistocene (early Notopleistocene) age. This hypothesis involves the formation of the great Clarence and other faults in the late Notopleistocene, and is quite untenable. In any case, the evidence for the fluviatile origin of the lower beds of the series is overwhelming.

Cotton (1914) agrees with Hector and McKay that the conglomerate as developed in the Middle Clarence Valley is of fluviatile origin, but considers it not necessarily the work of a single river. The line of outcrop thirty miles in length indicates that it was there deposited as a piedmont alluvial plain and not as isolated fans. The evidences of fluviatile origin are chiefly the rough sorting of the material into coarser and finer bands, and the presence of fine regular sandstone bands, often lenticular, coupled with an absence of distinct false bedding or an arrangement of foreset beds that would indicate beach or delta conditions of subaqueous deposition. The character of the conglomerate presents striking analogies with the terrestrial deposits in Owen's Valley, California, and satisfies most of the criteria drawn from the study of alluvial and fan deposits.

As has already been stated in the general account of the geology and physiography, Cotton accounts for the peculiar features of the conglomerate —viz., that it lies conformably on the " grey marls " but contains materials of all the underlying Notocene beds—by assuming that a neighbouring area was differentially elevated to the extent of perhaps as much as 12,000 ft. without seriously disturbing the horizontal altitude of that portion of the Notocene series which, a little later, had the conglomerate deposited upon it. Since folding and warping seem to be out of the question, as the surface of the " grey marls " is not appreciably tilted, he concluded that the differential movement must have been block-faulting, with the restriction that the uplifted block alone moved. The presence of small normal faults dislocating the conglomerate and " grey marls " is held to be significant in this connection, since block-faulting usually takes place along normal faults, and for a long period after the main faulting the formation of small normal faults continues, dislocating the fan deposits resulting from the erosion of the earlier fault-scarp. Cotton, it should be noted, confined his explanation solely to the conglomerate as developed in the Mead and Dee Gorges. Whether it is equally applicable to all other exposures of the conglomerate cannot be decided without a much more intensive study of these exposures than has yet been made, but its frequent if not invariable association with the " grey marls " is significant.

In all the exposures in the Clarence Valley, and in the majority elsewhere, the conglomerate rests on a surface of the " grey marls." The chief exceptions, as described by McKay, are at Greenhills (south of the Looker-on Range), in the Kekerangu River, and in the hills between Ward and Lake Grassmere. At Greenhills McKay's section (1886, p. 81) shows it resting, apparently conformably, on the Amuri limestone, but he states that " somewhat obscurely conglomerates are seen on the east side of the saddle mentioned, and it is at the same time quite apparent that the limestone could not terminate in the manner it does without being suddenly cut off by a fault somewhat in the manner shown in the following sketch" (the section above referred to). It is quite possible, therefore, that here also the "grey marls" are present. In the Kekerangu River McKay and Hector represent the conglomerate as resting with marked unconformity on a surface of pre-Notocene rocks, but McKay remarks that "from the absence of Amuri limestone and Awatere rocks the evidence that these [conglomerates] are identical with those in Heaver's Creek is not quite conclusive." I observed three bands of conglomerates in going down the Kekerangu Gorge. The first two resemble the pebbly mudstone of the Clarentian, the third and thicker band resembled more the great Marlborough conglomerate, but appeared to be faulted down among the pre-Notocene rocks. The relations of the outcrop near Lake Grassmere are not at all well known. In searching for it in 1912 I ascertained that part of the area mapped by McKay as great Marlborough conglomerate is in reality occupied by the basal Clarentian (?) conglomerates of the Notocene series forming the hills to the eastward from The Rocks to beyond Ward, so that the great Marlborough conglomerate may in this locality form a narrow strip interposed between the Awatere beds and the Clarentian (?) rocks. It appears probable that it is here involved along the fault-line which separates the Awatere and Cretaceous rocks between Ward and The Rocks. In all the other known outcrops of the great Marlborough conglomerate on the coast near Kekerangu, in Heaver's Creek, and in Deadman's Hill and Deadman's Creek it is resting on the "grey marls," as it does in the Clarence Valley. This is very significant, because the "grey marls" form a very weak stratum and are now almost everywhere deeply eroded compared to the neighbouring Amuri limestone and pre-Notocene rocks. If the great Marlborough conglomerate were so much younger than the "grey marls," as McKay supposed, and the latter were emergent during a considerable part of the Tertiary, one would expect to find the conglomerate at least as frequently on the Weka Pass stone or Amuri limestone as on the "grey marls." I am disposed, therefore, to accept the conformity of the conglomerate with the "grey marls" not only in the Clarence Valley but in the coastal area near Kekerangu. This involves the ascription to it of an age similar to that of the Mount Brown beds in North Canterbury, which follow the "grey marls" conformably —*i.e.*, Upper Oamaruian.

The relationship of the great Marlborough conglomerate to the Awatere series thus becomes of interest. The upper Awatere beds near Seddon are Waitotaran, but the lower beds in Tachall's Creek, near Ward, contain Oamaruian molluscs, and are probably at least as old as Awamoan. The junction of these lower beds with the Clarentian of the hills north of the Ure River could not be observed, and, as no conglomerates were seen, it is possibly faulted. In the Awatere River, near the Jordan accommodation-house, the basal Awatere beds consist of conglomerates and sandstones, and rest with marked unconformity on the pre-Notocene rocks, while all the pebbles in the conglomerates are of pre-Notocene rocks. In the lower beds in the Medway River Mr. L. J. Wild collected species of *Cucullaea*, so that these too appear to be Upper Oamaruian. The Awatere beds appear to be repeated with exactly similar relationships in the blue cliffs forming the north-west corner of Palliser Bay. There is a thin basal conglomerate resting unconformably on an unweathered surface of greywackes and argillites. The succeeding mudstones contain an Oamaruian fauna, while the higher mudstones near the Ruamahanga River contain a Waitotaran fauna. Obviously, then, in the north-eastern part of the South Island and the south-eastern part of the North Island a marine transgression commenced in the Upper Oamaruian and continued into the Waitotaran. It appears to have covered areas of pre-Notocene rocks not submerged in the earlier Notocene transgressions, since no boulders of these rocks are found in its basal conglomerates so far as examined, and this could hardly be the case if a cover of Notocene from Clarentian to Oamaruian had been stripped off the pre-Notocene. The Awatere series is absent from the upper part of the Awatere Valley, and probably never covered this area, since in the lower valley the beds are involved along the Awatere fault and it would be reasonable to expect to find them similarly involved in the upper valley if they were ever present there. It appears, therefore, as if differential earth-movements were at least a partial cause of the Awatere transgression. We have, then, an emergence of the Clarence and Kekerangu areas during the formation of the great Marlborough conglomerate, and a transgression of the sea over the Awatere area, and both these events took place in the Upper Oamaruian. It appears that they followed one another in the order named, and that the Awatere transgression affected the Clarence and Kekerangu areas.

In Deadman's Creek the upper outcrop of conglomerate is followed by a well-bedded marine series of sandstones and fine-grained conglomerates passing up into mudstones. The geology of the area between the upper part of Deadman's Creek and Clarence Mouth is unknown, but from the accounts given me by settlers it seems that there is a considerable extent of blue mudstone, or "papa," containing fossils at Parakawa. The marine rocks following the conglomerate can hardly be other than the representatives of the Awatere transgression, which may have a considerable development in this district. From McKay's descriptions it is evident that similar rocks are present following the conglomerate in the Bluff River. He states that these beds are so like the "grey marls" in appearance that it is hard to distinguish them. As at Deadman's Creek, they are separated from the coarser layers of the conglomerate by beds of sandstone and fine conglomerate. Obviously the evidence of fossils is necessary to confirm this correlation of the marine beds above the conglomerate with the Awatere beds.

The existence of these overlying marine beds proves that the Clarence and Kekerangu areas, in which a fluviatile deposit was forming, gradually became submerged. The presence of a fairly thick series of sandy mudstones at the Bluff River suggests that the submergence was considerable—at least over 600 ft.—since the beds are apparently foreset, and that the continental shelf of which they formed a part had an abundant supply of fine waste. Cotton estimated the differential movement necessary for the formation of the conglomerate as perhaps as much as 12,000 ft. (the maximum thickness of the Notocene up to the top of the "grey marls"), but, as the average thickness of the Clarentian is only about 3,000 ft., a differential elevation of 6,000 ft. would be sufficient to account for the features of the conglomerate. If the elevated area were also tilted, as is conceivable, an elevation of half this amount might suffice. In the formation of 400–600 ft. of conglomerate the relief of this elevated area, especially near the fault-scarp, would be considerably reduced, and by a subsequent drowning of, say, 1,000 ft. the relief would be further reduced. The nature of the beds of the marine series following the conglomerate is not inconsistent with Cotton's explanation of its origin. Although it is not necessary to conclude that the conglomerate was everywhere submerged and covered with the marine beds, it appears quite probable that this was so. The physiographical evidence is consistent with the supposition that a regional or very slightly differential elevation preceded the main Kaikoura deformation, and from the coastal plain thus formed the overlying soft mudstones and sandstones might be largely stripped by subaerial erosion before the involvement of the Notocene along the great Clarence and other faults. In any case, it could only be by a favourable sequence of events that such beds, if involved, could be preserved during the subsequent erosion that has occurred. If they had been so involved and subsequently eroded, there would be at first a fault-line scarp formed, and the steep scarps south-westward from the Dee may be, in part, of this nature.

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After the above paper was written I had an opportunity of spending two days at the Awapiri out-station in the upper valley of the Swale. The structure of the Notocene rocks in this area proved much too complex to unravel in the time available, but the following points were ascertained. At the upper end of the Swale limestone gorge the upper part of the Amuri limestone rests against the great Clarence fault without the interposition of the "grey marls" and great Marlborough conglomerate. Farther to the north-east an alternation of Amuri limestone and conglomerate occurs, doubtless due to faulting, so that the limestone is repeated at least three times. From a stratigraphical point of view the most interesting fact ascertained was the presence of a mudstone resembling the "grey marls" and containing rare Oamaruian fossils, which apparently lies between the limestone and the conglomerate. This mudstone is in places crowded with small and large rounded boulders of Amuri limestone. This observation points to the probability of an unconformity between the "grey marls" and the lower beds. I hope to have an opportunity of revisiting this area in the near future and furnishing a connected account of its structure and stratigraphy.

ART. XXXIII.—*Descriptions of New Zealand Lepidoptera.*

By E. MEYRICK, B.A., F.R.S.

Communicated by G. V. Hudson, F.E.S.

[*Read before the New Zealand Institute, at Christchurch, 4th–8th February, 1919; received by Editor, 12th February, 1919; issued separately, 28th July, 1919.*]

THESE notes are based as usual on material kindly sent by Messrs. Hudson and Philpott, and include ten new species. The discovery of an example of the Diplosaridae shows that the possibilities of surprise are not yet exhausted.

CARADRINIDAE.

Aletia falsidica Meyr.

A ♂ (36 mm.), received from Mount Earnslaw (Hudson), has antennae shortly bipectinated (*a* 1, *b* 1½), towards apex simple: this character establishes the distinction from *griseipennis*, which has antennae of ♂ simple.

HYDRIOMENIDAE.

Chloroclystis semochlora n. sp.

♂♀. 26–28 mm. Head, thorax, and abdomen green, patagia tipped with grey hairs beyond a black bar. Palpi 2, green, tip whitish. Antennal ciliations fasciculated (3½). Forewings broad-triangular, termen hardly waved, rounded, rather oblique; green; basal, second, and third fasciae deeper olive-green, especially third, somewhat curved, waved, slightly marked with black on edges, third preceded and followed by slight whitish