This species is only known to me from the Isle of Wight, where it occurs all over the island sparingly in the zone of *Holaster planus* and freely in the Chalk between the 'grey marl' and the 'black marl'. It is very near akin to *Biflustra lacrymopora*, D'Orb.¹; but the thick central lamina, the wide and clumsy-looking side walls and narrow area, and the total absence, as far as my experience goes, of oœcia seem full warrant for a specific separation which the very restricted horizontal and vertical range, and the great rarity of *Biflustrine* forms in our Chalk, would tempt one to make on slenderer grounds.

EXPLANATION OF PLATE X.

(All figures × 12 diams.)

FIG.

1. *Membranipora missilis*. Zone of *Marsupites*. Well, Hants.
2. *M. missilis*. Zone of *Marsupites*. Brighton.
3. *M. Fannia*. Zone of *A. quadratus*. Shawford, Hants.
4. *M. Fannia*. Part of the same specimen in a different light.
- 5, 6. *M. cupolata*. Trimmingham.
- 7, 8. *M. vectensis*. Zone of *Holaster planus*. Culver Cliff, Isle of Wight.

(To be continued.)

II.—THE STRUCTURE AND LATER GEOLOGICAL HISTORY OF NEW ZEALAND.

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THE MESOZOIC OROGENIC MOVEMENTS.

AS is well known, the skeleton or oldermass² of New Zealand is largely composed of a mass of deformed sedimentary rocks, the precise ages of the members of which are in doubt but do not affect the problem under consideration. The most profound deformation of this vast sedimentary group took place in late Jurassic or early Cretaceous times during what may be termed the "Mesozoic orogenic period", when probably a great mountain range came into existence.

It was the opinion of Hutton³ that the mountain range which resulted from the Mesozoic folding still survives in the present-day mountains of New Zealand; but this view, though accepted by Suess,⁴ is not specifically maintained by any modern New Zealand geologist. The contrary opinion has, however, rarely been expressed.⁵

¹ Pal. Crét. Franç., v, p. 274, pl. 695, figs. 1-3.

² The writer employs the convenient terms 'oldermass' and 'covering strata' or simply 'cover' in the sense in which similar terms were introduced by W. M. Davis ("Relation of Geography to Geology," Bull. Geol. Soc. Am., vol. xxiii, pp. 93-124, 1912). 'Oldermass' means a mass of rocks, generally of complex structure and of various ages, which have been planed down by erosion and which have been covered, during a later period of submergence, by a series of 'covering strata'.

³ F. W. Hutton, *The Geology of Otago*, Dunedin, 1875, p. 10; see also "On the Geology of the New Zealand Alps", Proc. Roy. Soc. Tas., 1886.

⁴ E. Suess, *The Face of the Earth*, vol. ii, p. 148, Oxford, 1906.

⁵ But see P. G. Morgan, "The Geology of the Mokonui Subdivision, North Westland," N.Z. Geol. Surv., Bull. 6, 1908, p. 43; and also R. Speight, "The Mount Arrowsmith District: Physiography," Trans. N.Z. Inst., vol. xliii, pp. 319-20, 1911; "The Intermontane Basins of Canterbury," *ibid.*, vol. xlvii, pp. 336-53 (p. 353), 1915.

The folds of this system have sometimes been regarded as trending uniformly north-east and south-west parallel with the elongation of the existing ranges in which the rocks occur,¹ and from this it might be inferred that they determine the north-east and south-west trend

FIG. 1.—Locality map of New Zealand.

¹ See, for example, P. Marshall, "New Zealand and Adjacent Islands," *Handbuch der regionalen Geologie*, Bd. vii, Abt. i, p. 58, Heidelberg, 1911; *Geology of New Zealand*, Wellington, 1912, p. 127.

of the land masses of the South Island and the southern part of the North Island, an inference that has apparently been drawn by Gregory, who includes the coasts of Central New Zealand with those of his "primary Pacific type"¹. Such an inference is probably not true for any part of the coast of New Zealand. In the southern part of the North Island—in the vicinity of Wellington, for example—the discordance of the trend of the folds with that of the shore-line is shown clearly by the *en echelon* arrangement of the ridges which may be noted from any high point of view, ridge after ridge and valley after valley of the subsequent features developed by erosion on these strata being obliquely truncated by the western coast. The trend of the ridges, corresponding with the general direction of the strike of the rocks, is only 10° to 15° east of north, while that of the coast is north-east, parallel with the elongation both of the mountainous axis of the island and of the land mass as a whole. Some of the north-east trending coasts of Central New Zealand have recently been described by the writer as resulting from faulting of comparatively modern date.²

In the South Island there appears to be by no means a close agreement between the trend of the major features and that of the folds of the oldermass. Scattered observation of the strike made by the writer in the north-east of the island show that it is very variable, but the average trend appears to be the west of north. Observations by McKay in the same district also indicate great variability,³ and both McKay⁴ and Hutton⁵ have noted a more or less definite dome and basin structure. In the main ranges of the Southern Alps the average strike of the rocks was noted by Dobson to be N. 22° E. (*vide* Haast). Haast⁶ and later observers, particularly Morgan⁷ and Speight,⁸ record great variability in that area also. In the study of the major relief features of New Zealand the trend of the Mesozoic folds may be almost entirely disregarded, for these features have been blocked out by much later orogenic movements, and the deformed strata of the oldermass, when affected by the latter movements, have generally behaved like resistant massive rocks.

¹ J. W. Gregory, "The Structural and Petrographic Classification of Coast Types": *Scientia*, vol. xi, pp. 36-63, 1912.

² "Fault Coasts in New Zealand": *Geog. Rev.*, vol. i, pp. 20-47, 1916.

³ A. McKay, "On the Geology of the East Part of Marlborough," *Col. Mus. and Geol. Surv. N.Z., Rep. Geol. Expl.*, 1885, pp. 27-136, 1886; "On the Geology of Marlborough and South-East Nelson," *ibid.*, 1888-9, pp. 85-185, 1890.

⁴ F. W. Hutton, "Report on the Geology of the North-East Portion of the South Island": *Col. Mus. and Geol. Surv. N.Z., Rep. Geol. Expl.*, 1873-4, pp. 27-58, 1877 (p. 32).

⁵ A. McKay, "On the Older Sedimentary Rocks of Ashley and Amuri Counties": *Col. Mus. and Geol. Surv. N.Z., Rep. Geol. Expl.*, 1879-80, pp. 83-107, 1881 (p. 85).

⁶ J. von Haast, *Geology of the Provinces of Canterbury and Westland*, Christchurch, 1879.

⁷ P. G. Morgan, "The Geology of the Mikonui Subdivision, North Westland," *N.Z. Geol. Surv., Bull.* 6, 1908; "A Note on the Structure of the Southern Alps," *Trans. N.Z. Inst.*, vol. xliii, pp. 275-8 (p. 277), 1911.

⁸ R. Speight, "The Mount Arrowsmith District: Physiography": *Trans. N.Z. Inst.*, vol. xliii, pp. 317-42 (p. 319), 1911.

A PERIOD OF EROSION AND DEPOSITION FOLLOWING THE MESOZOIC OROGENIC MOVEMENTS.

Upon the eroded surface of the oldermass lies a series of covering strata, and there can be no doubt that the mountain ranges which resulted from the Mesozoic orogenic movements had been subjected to erosion throughout a long period and reduced to at least moderate relief before the deposition of the oldest (Cretaceous) beds of this cover. It remains uncertain, however, whether at this stage complete peneplanation had been effected over any considerable area. In North Canterbury, indeed, Speight¹ has noted changes of facies in the limestone horizon of the covering strata, and there is certainly overlap in the lower beds, indicating that the eroded surface of the oldermass was there still somewhat hilly when submergence began, and that some hills survived as islands during a portion of the period of deposition of the cover. The available evidence points, however, to practically complete submergence of a large part of the north-eastern district of the South Island in the period of deposition of the Amuri Limestone (perhaps Eocene), and in some parts much earlier. The open-water origin and wide original extension of the Amuri Limestone have been demonstrated by McKay² and Hector.³ Hector's brief statement may be quoted: "All these formations enter into great flexures that have been eroded to form lofty mountains, and the evidence is complete that they at one time spread continuously over a wide area. This view is therefore completely opposed to the suggestion that has been made that the upper calcareous members of the Waipara formation were deposited among islands and in land-locked inlets after the erosion of the present valley systems."⁴

In the Marlborough area there was a long period of uninterrupted deposition extending far into the Tertiary, though to what stage of the Tertiary is not yet satisfactorily established. At this juncture great but quite local uplift occurred in certain areas, probably by block faulting, leading to the deposition in the neighbouring undisturbed areas of that remarkable formation the Great Marlborough Conglomerate.⁵

During the early part of the long period of deposition in Southern Marlborough the neighbouring Marlborough Sounds district to the north and the South-Western Wellington district to the north-east appear to have escaped submergence, for the basal portions of the few small remnants of covering strata, namely, a small area at

¹ R. Speight, "The Intermontane Basins of Canterbury": Trans. N.Z. Inst., vol. xlvii, p. 350, 1915.

² A. McKay, "On the Geology of the East Part of Marlborough," Col. Mus. and Geol. Surv. N.Z., Rep. Geol. Expl., 1885, pp. 27-136, 1886; "On the Geology of Marlborough and the Amuri District of Nelson," *ibid.*, 1888-9, pp. 85-185, 1890; "On the Geology of Marlborough and South-East Nelson," *pt. ii, ibid.*, 1890-1, pp. 1-28, 1892 (see pp. 5-7).

³ J. Hector, Col. Mus. and Geol. Surv. N.Z., Progress Report for 1885, 1886; Progress Report for 1888-9, 1890.

⁴ Progress Report for 1885, p. xviii.

⁵ C. A. Cotton, "On the Relations of the Great Marlborough Conglomerate . . .": Journ. Geol., vol. xxii, pp. 346-63, 1914.

Picton¹ and one in the Makara Valley, Wellington,² are regarded as of Tertiary age. The exposures are so poor in each case that the form of the surface on which the beds were deposited cannot be ascertained. We are not under the necessity of believing that the surface must by that time have been reduced to a plain, for it may have been rejuvenated from time to time by uplift, though adjoining areas where deposition was in progress were sinking. It is quite possible that portions of these districts have never been submerged since first uplifted by the Mesozoic movements, though the sculpturing to which they owe their present mountainous character followed much later uplift. Planation may well have happened more than once in the long intervening period. North-eastward of Wellington there is no evidence of submergence having taken place until rather late Tertiary times.³

Farther to the north, in the centre of the North Islands, Speight⁴ notes the presence of a plateau surface truncating the structure of the oldermass in the Kaimanawa Mountains, which he ascribes to marine erosion. The surface presumably passes under and forms the floor of the Tertiary beds (referred to the Miocene) of that district, which occur up to the height of 3,700 feet above sea-level. It appears probable from Speight's description that the covering strata were formerly continuous across the island in the Kaimanawa area, and that the plateau of the higher part of the range has been stripped of its cover by erosion.

In the south-eastern and north-western parts of the South Island the covering strata, with the exception of some of the basal beds, are mainly marine and of such a nature as to indicate that they accumulated in an open sea where the supply of terrigenous sediment was very small. Though the total area over which these rocks now occur is not large, their former extension over a much wider area is proved by the presence of outliers.

From the above considerations and from a general survey of what is known of the Tertiary rocks it is apparent that during the period of their deposition a great part of the site of the present islands of New Zealand was continuously submerged, and that very little of the remainder was left above water.

It is important to note that the members of the covering strata, whether always strictly conformable or otherwise, appear to follow one another without discordance of dip, no satisfactory evidence to the contrary being known. Thus it may be stated that, except quite locally,⁵ the only movements affecting the region after the

¹ A. McKay, *Geol. Surv. N.Z., Rep. Geol. Expl.*, 1890, pp. 153-4.

² A. McKay, "Report on Tertiary Rocks at Makara": *Col. Mus. and Geol. Surv. N.Z., Rep. Geol. Expl.*, 1874-6, p. 54, 1877.

³ J. A. Thomson, "Mineral Prospects of the Maharahara District, Hawke's Bay": *8th Ann. Rep. Geol. Surv., Mines Statement*, 1915, p. 165.

⁴ R. Speight, "Geological History" in L. Cockayne's *Report of a Botanical Survey of the Tongariro National Park*, Department of Land, C. 11, Wellington, 1908, p. 7.

⁵ The hypothetical block movement which has been assumed in order to account for the Great Marlborough Conglomerate has been referred to on an earlier page. In a paper on the "Structure of the Paparoa Range", read before the Geological Section of the Wellington Philosophical Society,

Mesozoic orogenic period until near the end of the Tertiary were epeirogenic. This is contrary to the view of Hutton,¹ who believed that folding movements affected the Cretaceous rocks in early Tertiary times, before the deposition of the remainder of the covering strata.

THE KAIKOURA OROGENIC MOVEMENTS.

The orogenic movements which followed the Tertiary deposition, and to which the present relief is entirely or almost entirely due, must have occurred in or about the Pliocene period. The period of movement may be termed the "Kaikoura orogenic period", since the Kaikoura ranges were the first to be explained by Hector² and McKay³ as owing the whole of their elevation to these late earth-movements. It cannot, however, be definitely stated at present whether the orogenic movements began contemporaneously all over the region. Far too little is known as yet of the ages and correlations of the members of the covering strata to allow us to arrive at a conclusion on this point.

The immediate cause of the disturbance may have been compression, for, in Central New Zealand at least, compression in a north-west and south-east direction accompanied the movements. In Marlborough the uplifted and depressed areas are elongated with a north-easterly trend, and major faults, some of which are certainly reverse faults, trend in the same direction, as do also folds in the previously horizontal covering strata. Perhaps owing to the rigidity of the oldermass, the strata of which had previously been folded on other lines and would strongly resist the new folding, the region was broken up into a number of 'blocks' bounded on one or more sides by faults, folding being generally subordinate to faulting except in the higher members of the covering strata, where the resistance of the rigid floor had least effect.

In recent years, wherever detailed geological work has been done, evidence has accumulated of the importance of the part played by young faults in the structure of New Zealand, as may be found by reference to the accounts of the structure of parts of Westland, Nelson, Otago, and Auckland by Bell, Morgan, Park, Henderson, and others in the bulletins of the Geological Survey, and to a paper by Henderson⁴ in which much information regarding faults in Western Nelson is brought together.

While in a few cases the recognition of these faults rests on the evidence of fault-scarps or fault-line scarps, the majority of the faults described are such as bring the covering strata against the older rocks. Many other faults less easily detected by purely geological August 18, 1915, Dr. J. Henderson stated that in Western Nelson a succession of similar movements had taken place. In these cases, however, during and after the movement, accumulation of sediment went on in the immediate vicinity on an undisturbed sea-floor.

¹ *Geology of Otago*, Dunedin, 1875, p. 76.

² Progress Report, Rep. Geol. Expl., 1889-9, p. liv, 1890.

³ "On the Geology of Marlborough and South-East Nelson," pt. ii: Rep. Geol. Expl., 1890-1, p. 7, 1892.

⁴ J. Henderson, "On the Genesis of the Surface Forms and Present Drainage-systems of West Nelson": Trans. N.Z. Inst., vol. xliii, pp. 306-15, 1911.

methods also occur. The long straight fault-lines shown on the map by McKay¹ and the later maps by Park,² connecting up known portions of faults, must of necessity be highly hypothetical, and they probably fall far short of representing the facts; but it is true, nevertheless, that to McKay belongs the credit of being the first to recognize the importance of faults in determining the physical features and geological boundaries.

McKay's views are strongly opposed to those of Hutton, who conceived only of regional (epeirogenic) movements of uplift and subsidence in later geological times.³ Hutton recognized no young faults and no orogenic movements later than those at the close of the Jurassic except "a certain amount of folding" restricted to certain localities, which, he believed, took place "at the commencement of the Tertiary".⁴

"Not only," he wrote, "was the last touch given at this time [commencement of the Tertiary] to the geological structure of the [Southern] Alps, but the chief valleys were also marked out at this period.

"For example, we find our oldest tertiary rocks occupying the valley of the Waitaki . . . and the Maruwhenua . . . In the valley of the Shag they extend up nearly to its source. . . ."

To the explanation of the geological history of New Zealand thus expressed in 1875 Hutton afterwards closely adhered, as will be gathered from the following statements as to supposed changes in river courses, which are based on the assumption that the present relief has survived from very ancient times. This represents Hutton's opinion in 1899: "The Shag River at one time drained the Maniototo Plains until the gorge of the Upper Taieri was cut. In early Cretaceous times the Hurunui and Waiau-ua united and entered the sea at Kaikoura. At a later time they turned down the Weka Pass, and it was not until the Pliocene period that each cut its own valley to the sea. The Upper Manawatu flowed into the Wairarapa, and in the older Pliocene a river ran from the Manawatu gorge to Napier. The courses of all these rivers were changed by the deposition of marine rocks in the valleys, which blocked them; and this, on the subsequent rise of the land, caused the rivers to overflow to one or the other side, according to the position of the lowest opening."⁶

The depressions, such as the Shag Valley and that extending from the Waiau to Kaikoura, regarded by Hutton as eroded valleys and assigned by him in the foregoing passage to ancient courses of various rivers, are more satisfactorily explained as tectonic features which came into existence in the Kaikoura period.

¹ N.Z. Rep. Geol. Expl., 1892, p. 1.

² J. Park, *Geology of New Zealand*, Christchurch, 1910, pp. 263, 265.

³ *Geology of Otago*, Dunedin, 1875, pp. 77-85 and pl. ii.

⁴ Loc. cit., p. 76.

⁵ Loc. cit., p. 77; cf. also "Sketch of the Geology of New Zealand", Quart. Journ. Geol. Soc., vol. xli, p. 196, 1885.

⁶ "The Geological History of New Zealand": Trans. N.Z. Inst., vol. xxxii, p. 180, 1900.

(To be concluded in our next Number.)