The Geology and Palaeontology of the Lower Waihao Basin, South Canterbury, New Zealand.

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CONTENTS.

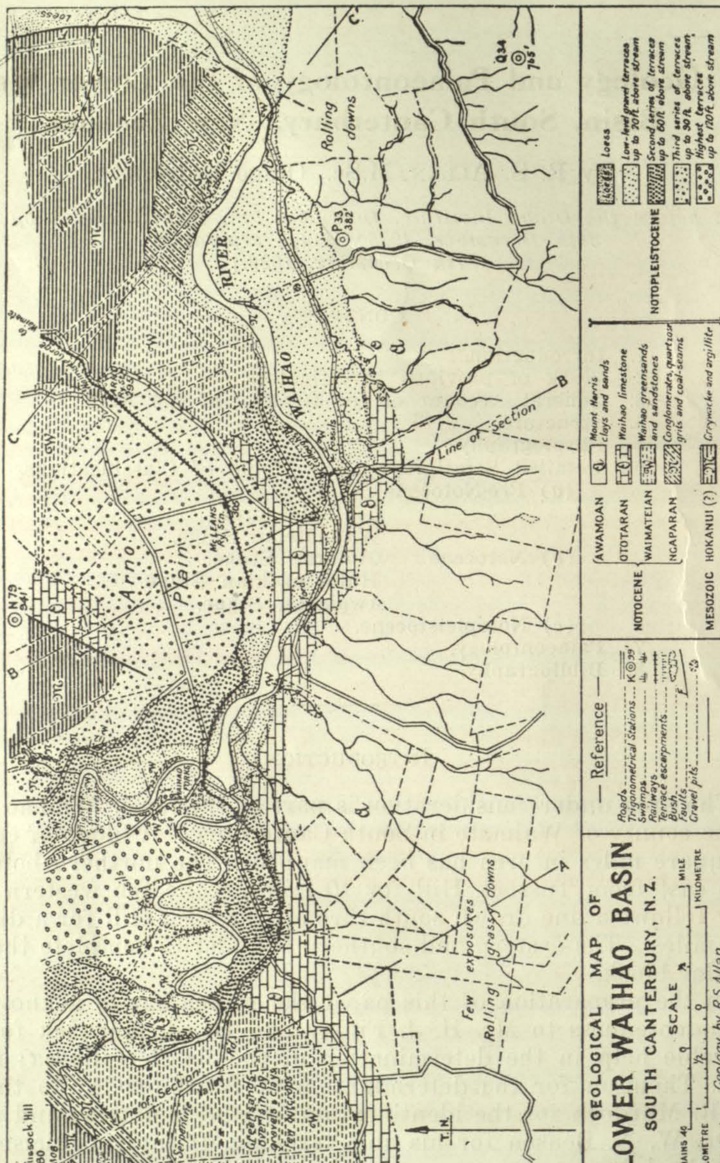
INTRODUCTION.

The area under consideration is part of the lower Waihao basin, in the county of Waimate in South Canterbury. A block of country 30 square miles in area has been mapped. The northern boundary runs east from Tussock Hill for 10 miles, while the western boundary follows a line drawn south through Tussock Hill for a distance of 3 miles. The eastern and southern boundaries complete the rectangular block.

In the preparation of this paper the writer has to acknowledge his indebtedness to Mr. H. J. Finlay and Dr. J. Marwick for considerable help in the determination of the fossil mollusca; to Dr. J. A. Thomson for the determination of Brachiopoda; to the late Mr. R. Murdoch for the identification of land mollusca; and finally to Dr. W. N. Benson for his able teaching, friendly criticism, and helpful advice.

WORK OF PREVIOUS INVESTIGATORS.

The first notice of the geology of the Waihao area is that of von Haast in his *Geology of the Provinces of Canterbury and Westland,* 1879. He recognised two formations, viz., a lower, Oamaru formation of Upper Eocene or Lower Miocene age; and an upper Pareora formation, of Upper Miocene or Lower Pliocene age. The Waipara series, of Cretaceo-tertiary age, Haast considered was not developed in the area. Von Haast seemed to favour the idea that the



Pareora beds (Awamoan) were deposited on and around islands of the Oamaru formation in a later sea; for he says:—

"In many localities, e.g., Waihao River, the calcerous greensands have become greatly denuded before the Pareora beds were deposited above them, or which is more commonly the case, along them, when the former stood as islands in the tertiary sea." (1879, p. 318.)

Lindop, 1885, gave a very brief description of the coal-seams which were being utilised at the time of his visit.

In 1875 von Haast sent to Hutton at the Otago Museum a collection of fossils from four localities, viz., White Rock River, Pareora District; Mount Harris and Point Hill, between the Waihao and Waitaki Rivers; and from certain greensands exposed at Waihao Forks. Hutton referred the whole to his Pareora formation (*Trans. N.Z. Inst.*, vol. 9, p. 593). Von Haast was not satisfied, since his work suggested to him that the fossils from the Waihao greensands came from beds below the limestone. Thus was laid the foundation of a long controversy between the Geological Survey, represented by McKay, on one hand, and Hutton on the other.

McKay first published an official account of the area in 1882. It is couched in terms of the Cretaceo-tertiary hypothesis of Hector, which unfortunately led him into a false interpretation of the Waihao sequence. His correlations with the beds of North Canterbury cannot be upheld. He gives the following succession for this area:—

Age.	Formation.
Recent to Pliocene	Alluvial and glacier deposits.
Lower Miocene	Gravels and sands, with lignite beds. Pareora clays.
Cretaceo-Tertiary	Ototara limestone. Chalk-marls (=Amuri Limestone) Marly greensands. Island sandstone. Coal Beds.
Carboniferous Upper Devonian	Matai Series Te Anau Series } (Mapped together).

McKay considered the Mt. Harris beds to rest with marked unconformity on his Cretaceo-tertiary beds since the Upper Eocene beds of Hector are said to be absent from the district.

All the beds below the Mt. Harris beds are referred to the Cretaceo-tertiary. The Waihao limestone is correlated with the Ototara stone and with that of Maerewhenua. The lower part of the limestone was correlated with the "chalk-marls" and was considered the equivalent of the Amuri limestone. The "Marly greensands" ere shown to be inferior to the limestone and to contain well-preserved fossils.

Apart from his belief in an unconformity above the limestone, McKay gives a sequence which has been accepted by all other geologists who have visited the area except Hutton; and which, were it not couched in the confusing terminology of the Cretaceo-tertiary hypothesis, would still be a very satisfactory description. Hutton, however, was not satisfied. From his examination of von Haast's fossils he believed that the Waihao greensands belonged to his Pareora formation, i.e., the greensands were younger than the limestone which he placed in his Oamaru formation, therefore he visited the area in 1885 "to clear up the difficulty." (1887, p. 430.) The point to be settled was this—"Do these greensands underlie the Marl of the Oamaru system. (i.e., underlie the Waihao limestone) or do they lie unconformably against the eroded edges of that System?" (1877, p. 431.)

He proved to his own satisfaction that the palaeontological evidence was in favour of the latter supposition. "The stratigraphical evidence is not so satisfactory, for no clear sections exist . . . in no case are they (the greensands) seen to pass below the marl or to lie upon it; consequently the palaeontological evidence must be taken as proving the superior position of the greensands." (1887, p. 432.) Hutton gives a surprising section to illustrate his views but remarks, "it is of course to some extent hypothetical, as no positive stratigraphical evidence is available." (1887, p. 433.)

In September, 1886, McKay, after a further visit to Waihao replied to Hutton's stratigraphical evidence thus:—"It is so much at variance with the conclusions of all other observers, and in itself a statement so positive, that it requires to be supported by proofs equally decisive and incontrovertible; and if true, the conclusion is unavoidable that at least four geologists (Dr. von Haast, Park, Lindop, and myself) have imagined they saw that which cannot be seen. Ours, however, is testimony of a positive character; Professor Hutton's is simply that he did not see." (1887, p. 101.)

McKay then stripped the problem of its local significance and made it apply to the whole question of the succession of the younger beds of New Zealand, holding that Hutton was in error, not only with regard to these Waihao beds but also with those of a more or less similar nature at Kakahu and Hampden which he had placed in his Pareora System. McKay showed quite conclusively that the greensands do pass under the limestone and gave several convincing sections to prove his point. He then attacked Hutton's palaeontological evidence; but as Hutton later remarks, "Mr. McKay . . . although an excellent collector, has not yet shown any great acquaintance with Palaeontology." (1888, p. 266.) It would serve no purpose to follow up the palaeontological dispute.

In October 1886 McKay published a further paper in answer to Hutton's criticism. For the most part, it is a resumé of the previous report. He summed up the position as follows:—"Beyond all question, the greensands underlie the Waihao limestone: and as explanations of the contrary view, islands and fiords without number, crush, faults, contortions and, in short, all that might render the geology of a district complicated and obscure, are invoked in vain." (1887, p. 439.)

In 1888, Hutton answered McKay's criticism of his palaeontological evidence, but little of use evolves.

Professor Park, 1905, gave the following sequence of beds exposed on the banks of the Waihao River. (1905, p. 527.)

Waitaki Stone	1. Calcareous sandstone.
Mount Brown Beds.	2. Greensands. 3. Bluish-green sandy clays and sandstones with hard calcareous layers.
Waihao Beds	4. Bluish-green sandstones. 5. Grey Sandstones. 6. Quartzose grits, shales, fire-clays and brown coal.

He said (1905, p. 527) "the succession is almost identical with that seen in the Waitaki Valley." He disagreed with Hutton, and agreed with McKay that beds 3 are beneath the Waihao limestone. He showed that the greensands and bluish-green sandy clays are in all exposures inferior to the limestone; and the beds "follow the contours of the escarpments in such a way as to everywhere preserve the same relative position with respect to the Waitaki Stone. ... Captain Hutton attempts to explain this by suggesting that his Oamaru series of Oligocene age was deposited, elevated, sculptured into narrow valleys and channels, and again submerged so as to permit the accumulation of his Pareora beds on the newly eroded channels." (1905, p. 528.) Professor Park concludes, "The stratigraphy is not obscure nor the sections involved; and I fully concur with McKay's interpretation, which is, moreover, borne out by the sections at Black Point, Wharekuri, and Kakahu." (1905, p. 528.) Of the beds considered to be above the limestone by the writer Professor Park remarks "The Mount Harris beds in this neighbourhood contain a fauna which is the same as that of the Waihao clayey greensands, and, (they) nowhere overlie the Waitaki Stone. ... The Stratigraphy is not very clear, but the palaeontological evidence clearly correlates these beds with the Waihao Forks, Black Point, and Hampden Beds, which are acknowledged by the Survey to underlie the Waitaki Stone." (1905, p. 529.)

In 1910, p. 120 *et seq.* Professor Park again made a similar statement. This conclusion is one which does not accord with the writer's observations and one which is later (1918) corrected by Professor Park himself.

Dr. Thomson, 1914, reported on the coal prospects of the Waihao area. He gives the first detailed map of the area. This map has been the foundation of that prepared by the writer. A concise account of the topography and physiography is given and it is pointed out that the lower course of the Waihao is relatively new and is an excellent illustration of stream piracy. A general account of the geology follows; the Tertiary rocks are subdivided into four groups as follows:—

1. Mt. Harris beds;
2. Limestones;
3. Greensands; and
4. Coal Measures.

The coal-beds are then discussed, and a table of 13 analyses is given (see below). Dr. Thomson sums up in these words: "It follows, therefore, from the poor quality of the coal, its hydrous nature, and the difficulties of mining, that the Waihao area is never likely to become an important coalfield, although a small amount of coal may be mined around the outcrop for household use in Waimate and the surrounding district." (1914, p. 162.)

Dr. Marshall, 1915, publishes lists of fossils collected by Dr. Uttley from the Waihao District. Fossils were collected both from the Waihao greensands and from the Awamoan beds at Mt. Harris and Elephant Hill. No stratigraphical break was observed in the sequence. The age of all the beds is stated to be probably Miocene.

Dr. Thomson, 1915, draws attention to the fact that the fauna of the Mount Harris beds is apparently similar to that of the Waihao greensands. This resemblance seems to the writer to be more apparent than real, and it will be shown that the two faunas are distinct.

Dr. Thomson follows McKay's sequence, for he states "That position has not been challenged since 1888, and after a few days' study in the field is, to my mind, self-evident." (1915, p. 123.) He also shows that the Cretaceo-Tertiary theory of Hector and McKay is untenable. "All the beds in the Oamaru and South Canterbury districts classified by Hector and McKay as Cretaceo-Tertiary, and notably the Waihao greensands, contain only Tertiary fossils." (1915, p. 123.)

Dr. Thomson, 1916, disagrees with the correlation of the Waihao greensands with the Awamoa beds and of the Waihao limestone with the Hutchinsonian. His evidence "suggests strongly that the Waihao limestone is the correlative of the Ototara limestone, and the Waihao greensands the correlatives of the Enfield-Windsor beds." (1916, p. 32.)

In 1918, Professor Park corrects his error of 1905. He says (p. 110) "At Waihao in South Canterbury, the Waihao stone, a calcareous glauconitic sandstone, is underlaid by greensands and followed conformably, as shown by McKay and Thomson, by the Awamoan Mount Harris beds." The Waihao stone is placed in the Hutchinsonian. Professor Park says "The view that the Waihao stone is the time equivalent of the Oamaru stone (=Ototaran) would imply the absence of the whole of the Hutchinsonian in South Canterbury. Such a hiatus would mean an unconformity between the Waihao stone and the Mount Harris beds, of which, however, there is no evidence." (1918, p. 110.)

Professor Park's table of correlations of Oamaru, Waitaki and Waihao Cainozoic strata is appended.

	Oamaru District	*Lower Waitaki Valley*	*Waihao District*
Awamoan	Blue clays and shelly sands.	Sandy beds.	Blue clays and sands, calcareous.
Upper Hutchinsonian	Glauconitic s. stone. (Devil's Bridge, Landon Creek)	Calcareous glauconitic sandstone (Waitaki stone).	Glauconitic sandstone. (Waihao Stone)
Lower Hutchinsonian	Greensands.	Greensands.	Greensands.
Ototaran	Coralline (Oamaru) limestone.	Bluish-grey Glauconitic sandy beds.	Bluish-green sandy beds.
Waiarekan	Sandy clays and sandstones.	Sandy beds and sandstones.	Sandy clays and sandstones.
Ngaparan	Quartzose sands, etc., with lignite.	Quartzose sands, etc., with lignite.	Quartzose sands, etc., with lignite.

Mr. Morgan, 1919, discussed the limestone and phosphate resources of New Zealand. He gives several analyses of the Waihao limestone which are quoted below.

Professor R. Speight and Mr. L. J. Wild, 1919, gave a useful discussion on the limestone and phosphate-bands developed in Canterbury. A phosphatic band is noted in the Waihao greensands at McCullough's Bridge (1919, p. 185). A full description of a section of the limestone exposed three-quarters of a mile East of McCulloughs Bridge is also given (p. 185). Most limestone-exposures were visited and phosphate-bands noted. It is pointed out that the Otaio limestone of the Pareora district resembles the Waihao stone in age and character.

The glauconitic sandstones (greensands) of Waihao were examined. They show a small percentage of P_2O_5 "not only distributed through the rock but concentrated at times into layers of phosphatic nodules." (1919, p. 187.)

Four analyses of the Waihao stone are given below which show "that the amount of phosphate contained in the rocks is nowhere large enough to warrant them being called high-grade phosphates." (1919, p. 189.)

Dr. Marshall, 1920, in a discussion on "the Hampden beds and the New Zealand Tertiary Limestones" tends to correlate the Waihao greensands, lithologically and palaeontologically, with the Hampden beds. "The Hampden beds may be considered as of much the same age as, though perhaps a little older than, those at Waihao." (1920, p. 112.) He further correlates the Waihao limestone with that of Otiake, Waitaki Valley and shows them to be of a similar origin. "The Waihao and Otiake limestones, were deposited nearer to the shore (than the Ototaran limestone), in an area to which terrigenous sediment was carried and where tidal scour disturbed the sea-floor." (1920, p. 112.)

Dr. Uttley, 1920, shows that the sequence of Notocene beds in the Upper Waitaki Valley—Wharekuri to Otiake—is similar to that at Waihao. He suggests that the greensands between the coal-measures and the limestone at Wharekuri and Waihao could be subdivided. Another paper by the same author is a criticism of Professor Park's Oamaru Bulletin No. 20, particularly his view of the occurrence of limestones belonging to two different stages. Dr. Uttley "after an excursion to the Waihao District of South Canterbury, was convinced that, where the full series was developed, there was but one limestone present." (1920, p. 171.) He concurs with Dr. Thomson's opinion that the fauna beneath the limestone (greensands) bears a remarkable resemblance to the fauna above the limestone (Mt. Harris beds) in the Waihao district. where the beds occur in the same section. This view the writer considers is now untenable.

In other respects Dr. Uttley's conclusions are strengthened by the present work. These include the following points:—(1920, p. 182.)

1. Professor Park's Lower Hutchinsonian is the true Hutchinsonian of Dr. Thomson.
2. Professor Park's Upper Hutchinsonian is really Awamoan.

These two points may be considered together. The beds from Waihao placed by the writer in the Hutchinsonian cannot be divided into two parts, either lithologically or palaeontologically. Dr. Thomson (*in litteris*) says that the brachiopods collected by the writer are all referable to species found in the Hutchinson Quarry beds at Kakanui and other localities near Oamaru. The evidence of the brachiopods would lead him to correlate the Waihao beds with the Kakanui greensands, *i.e.*, with Professor Park's Lower Hutchinsonian. Hence, since these beds at Waihao merge above into typical Awamoan clays, the Upper Hutchinsonian of Professor Park is not developed, at least not as a geological unit, with a lithological and palaeontological facies worthy of a sub-stage. If this sub-stage is present it is really the basal part of the Awamoan, Mt. Harris series.

3. Dr. Uttley deduces evidence to prove that the limestone in the Waitaki Valley is Ototaran and not as Professor Park suggests Hutchinsonian.

Professor Park himself correlates the Waihao limestone with that developed in the Waitaki Valley (1918, p. 110). But in the sequel the writer shows that the Waihao limestone is Ototaran but at the same time is not prepared to urge its correlation with all the limestones present in the Waitaki Valley.

Dr. Thomson, collected fossils from the Waihao greensands and from the Mt. Harris beds during the years 1913 and 1917. The molluscs were identified by Suter and the lists published in *N.Z. Geol. Surv. Pal. Bul.*, No. 8, 1921.

Dr. Cotton, 1922, cites an example of a fossil plain on "the westward slope of the Hunters Hills, with which are associated other similar slopes surrounding the depression that forms the Waihao basin, descending westward to the Hakataramea Valley, and extending as far as the Waitaki River" (1922, p. 141). He also demonstrates that the east side of the Hunters Hills is either a composite fault-scarp, or (being of no great height) possibly entirely a fault-line scarp (1922, pp. 171-2).

Dr. Marshall and Mr. Murdoch (1923) collected from the greensands at McCullough's Bridge. Four new species of Mollusca were described (1923, pp. 123-128). Dr. Marshall (1923) discusses the early Tertiary Faunas of New Zealand and he lists some 70 species from McCullough's Bridge, most of which were collected by Murdoch and himself. His analysis of this list is as follows:—

17% found in the Hampden beds only.
44% occur in the 96 species of the Hampden beds as well as various Tertiary deposits.
43% occur among the 215 species of the Target Gully species.
10%. are of Recent occurrence.

These figures will be substantially altered by the writer because of the revision of the fauna and additions made thereto. In particular he cannot recognise the presence of any recent species, but Dr. Marshall's conclusions are still valid. "These facts show how much more closely this fauna is related to the fossils of the Hampden strata than to those of Target Gully . . . the Waihao beds, though closely related to those at Hampden, are distinctly younger than them—a result that would be anticipated from the stratigraphy, and has already been stated as probable." (1923, p. 119.)

Professor Park, 1923, briefly answers the criticism of Dr. Uttley (1920). He has again visited the Waihao area and restates his argument of 1918 to prove that the Waihao stone is Hutchinsonian. "Clearly, if the Mt. Harris beds are Awamoan, the Waihao stone must be Hutchinsonian." (1923, p. 83).

The discovery of the *Liothyrella boehmi* assemblage of brachiopods in his "Lower Hutchinsonian" is used by him to strengthen the proof that in the Oamaru district there are limestones in two horizons. One—the upper Hutchinsonian, including the Kakanui, Deborah, Waitaki, Maruwhenua, Ngapara and Tokarahi limestones separated by the *Liothyrella boehmi* band from the lower horizon—the Ototaran, Oamaru stone. This conclusion may be valid for the Oamaru district south of the Waitaki Valley although it has been adversely criticised by Dr. Uttley and others; but the writer's work goes to show that it is not applicable to the Waihao area. The evidence to be given and the conclusions deduced from determinations by Dr. Thomson of brachiopods collected by the writer, seem to prove that the Waihao limestone is Ototaran. As a further piece of evidence for this conclusion, it is shown for the first time that Hutchinsonian beds with a characteristic brachiopod fauna are present in the area.

Dr. Marwick, 1924, described the Naticidae collected by the writer from the Waihao greensands. This family of gasteropods is well-represented in the Lower Tertiary beds of this district and it would seem that the species are valuable zonal indices.

General Account of the Geology of the Area.

Three classes of rocks are present in the district, viz.,

1. *Pre-Notocene*: greywacke and argillites, strongly folded and truncated by an erosion plane. These beds are well jointed, and partially altered. They are overlaid with marked unconformity by
2. "*Notocene*": (here Cainozoic beds only) forming an accordant rock series and making up a structural and physiographical unit. The rocks composing this unit are: conglomerates, sandstones, greensands, limestones, clays and sands. They are only gently folded or warped and much less hard and compact than the older rocks.
3. "Notopleistocene": horizontal uncemented gravels, silts and loess deposits, lying unconformably on 2.

The history of this area seems to have been as follows:—

Near the end of the Palaozoic era the sea advanced over the area and a great series of clays and muds was deposited. This sea does not seem to have been rich in organisms, for only traces of life can now be found. This period of sedimentation perhaps lasted intermittently until the end of Jurassic times.

In the early Cretaceous period, however, the land was subjected to intense orogenic movements—the post-Hokonui orogeny of Dr. Thomson (1917). No trace of the earliest beds of the Notocene succession, namely the Clarentian (Albian and Cenomanian) or Piripauan (Senonian) occur in the district. Hence it is concluded that while the "Cenomanian overlap"* and later the Senonian sea covered

*Phrase used by H. Woods, *N.Z. Geol. Surv. Pal. Bul., No. 4*, 1917, p. 4.

the area in North Canterbury and East Marlborough, the land in this region was still above sea-level. During this period the older rocks seem to have been greatly indurated and eroded to a peneplane.

At the beginning of "Eocene" times the land sank relatively to the sea. The movement seems to have been a sudden one. "The surface of the land before this (Oamaruvian) transgression is known to have been of very low relief,—*i.e.*, a peneplane—and the attainment of such a surface demands a period of standstill of the strand line." (Dr. Thomson, 1920, p. 411). The result was that a great sheet of conglomerates and quartz grits spread over the eroded surface of the Pre-Notocene rocks. Lagoonal conditions seem to have occurred and a flora flourished in the higher parts. These conditions lasted long enough for several feet of brown coals to be accumulated. The surface of the land appears to have fluctuated above and below sea-level, for coal seams are found at different horizons.

The sea now began to advance, and the marine beds of the Oamaruvian system were laid down. Over the fluvio-marine sands of the coal-measures greensands were deposited while the submerged area still formed a continental shelf.

The lower greensands contain a moderately rich molluscan fauna. After a considerable thickness of these beds had been deposited a period of standstill occurred, and the upper part of the greensands became phosphatized. This period seems to have been of some duration since the succeeding upper greensands contain a markedly different fauna from that which preceeded it.

These greensands become marly in their uppermost parts. In the sequel it will be shown that both series of greensands are best referred to the Bortonian stage of Park.

At McCulloughs Bridge the upper greensands are followed conformably by the Ototaran limestone but a marked palaeontological break is concealed. The whole of the Waiarekan tuffs are completely missing. It seems necessary to postulate local uplift during this time. With the transgression of the succeeding Ototaran sea glauconitic limestones were laid down. These beds are poor in mollusca but contain brachiopods and echinoderms.

It is clear that the deposition of the Oamaruvian limestones was not uninterrupted, because there is a phosphate band between the lower and upper parts of the limestone in the area. Dr. Thomson has shown that this contact is similar to that between the Ototara stone and the Hutchinson Quarry greensand; and to that between the Amuri limestone and the Weka Pass stone. For these three cases "a similar cause, viz., a sudden shallowing of the sea, followed by a period of standstill" (1920, p. 411) is suggested. However, such palaeontological evidence as is available shows that these three phosphatic layers are not of the same age. The limestone is considered to be laid down at the depth of maximum submergence. It is, however, of fairly shallow-water origin, and hence the depth of this sea cannot have been so great as that from which the Amuri limestone was deposited.

A further period of stand-still took place at the end of the Ototaran stage, for the junction between the limestone and the over-lying Hutchinsonian beds is marked by a band of rolled shells.

Later sedimentation continued in a shallower sea and blue clays (and locally greensands) were formed. A distinct brachiopod fauna. shows that rapid evolution or else a migration of forms occurred. As the sea retreated the clays gave way to more sandy beds forming the Awamoan stage. The brachiopod fauna became extinct or could not live in such shallow water, but its place was taken by a new molluscan fauna very distinct from that which inhabited the Bortonian sea.

The absence of Wanganuian marine sediments in South Canterbury and the increasingly coarse nature of the later Awamoan beds suggest regression of the sea at the end of the Awamoan stage. At some time during the "Pliocene" or early Notopleistocene extensive block faulting occurred—the Kaikoura deformation of Dr. Cotton (1916). Whether or not the older gravels of the district were formed before or after this orogeny cannot be inferred from any evidence found in the area mapped. The Notocene beds were tilted mainly to the south during these movements. The elevation of the land thus brought about was associated with the Pleistocene glaciation. As the ice retreated, rock-waste from the glaciers was carried away and spread over the foot-hill areas by streams. This material was dried, and subsequently was blown by the wind to be laid down as an extensive loess deposit.

Since the Kaikoura movement the uplifted blocks of Notocene rocks have been eroded away for the most part and there remains of this formerly extensive covering sheet only the remnants which were preserved in down-faulted areas. Considerable changes in drainage must have occurred, for an example of stream piracy is illustrated by the Waihao Gorge.

In more Recent times the strand seems to have shown a tendency to rise relatively to the sea. This is shown in the entrenched course of the Waihao River, and in the formation of four major cycles of terraces formed at increasing heights above the present stream-level.

STRUCTURE.

The Notocene rocks in the Waihao area, and in the adjoining Waitaki Valley, are found in long narrow depressed areas. To explain this fact, most of the older geologists except McKay, and in particular von Haast and Hutton, conceived the idea that the beds were laid down in long narrow embayments in the early Tertiary coast-lines. This view was accepted by Suess (1906). "Modern workers (e.g., Cotton, 1913, 1916, and Speight, 1915, p. 153) confirm McKay's view (1892) that these narrow intermontane strips of younger rocks are but dislocated remnants of more extensive sheets which, at one time, covered nearly all of the area that is now New Zealand" (Benson, 1922, pp. 40-41).

The abundance of quartz pebbles in the coal-measures at Waihao supports the view that these beds were formerly more extensive. Although the limestone is probably of shallow-water origin, the nature of the marine beds as a whole shows that they could hardly have been deposited in a narrow trough-like basin where terrigenous sediments would almost certainly have accumulated in some bulk.

The structure at Waihao supports the view that uplifted blocks, e.g., the Hunters Hills, have been denuded of their Notocene sediments and that now these sediments are found only in down-faulted regions. In discussing part of the Waihao area outside of that here

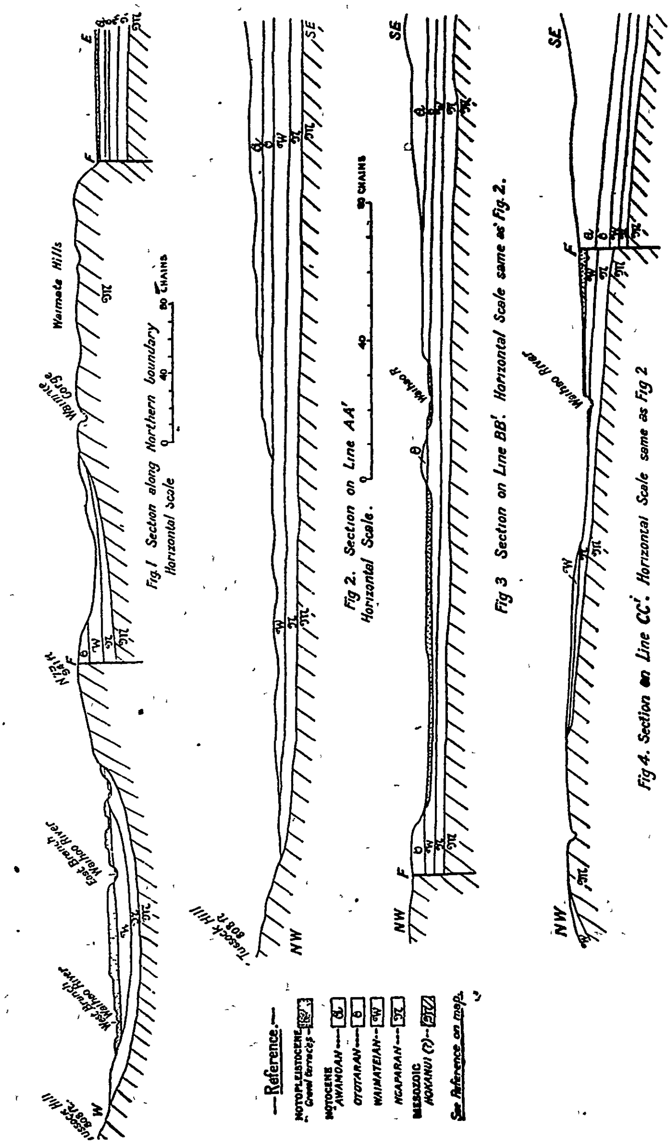


Fig. 1 Section along Northern boundary. Horizontal Scale 0 40 80 Chains

Fig. 2. Section on Line AA'. Horizontal Scale. 0 40 80 Chains

Fig 3 Section on Line BB'. Horizontal Scale same as Fig. 2.

Fig 4. Section on Line CC'. Horizontal Scale same as Fig 2

mapped Dr. Thomson remarks: "The disposition of the Tertiary beds at Waihao favours McKay's view, for the basal surface of the coal-measures is not plane, but gently curved, so that their outcrop is roughly semicircular between Elephant Hill and the Waimate Hills, while a minor basin occurs north of Tussock Hill in such a manner that it cannot be explained by original deposition. Further the great fault along the north-east side of the Waimate Hills is evidence of differenial movement since the deposition of the Tertiary beds" (1915, p. 160).

Sections across the area mapped are given to show that the structure of the area accords with the views expressed.

PHYSIOGRAPHY.

The topographical features of the area may be broadly considered as a belt of low country forming the lower Waihao basin separating two higher masses; the Waimate Hills and part of the Hunters Hills on the north side, from the Waikakahi downs on the south.

The Hunters Hills, from which Tussock Hill projects, and their easterly continuation, the Waimate Hills, form the eastern portion of a strong range which diverged from the Southern Alps and runs south as the Two Thumb Range, with peaks over 8,000 feet in height. Inland from Waimate this range divides, one branch continues south towards the Upper Waitaki valley as the Kirkliston range, while the other turns to the east, as the Hunters Hills. Facing Waimate and for a distance of 6 miles it presents a straight steep front which Dr. Cotton has noted as probably a fault line scarp. This range is truncated by the Lower Waihao River and further east is separated from the sea by the southern extension of the Canterbury Plains.

The Waimate Hills are cut off from the Hunters Hills by the Waimate Gorge, which is the most interesting topographical feature found in the district. It represents an old gorge cut by the Waihao River. McKay (1882) and Dr Thomson (1915) have both shown that this gorge has been the result of stream piracy. Two hypotheses might be suggested to account for it. One, it may be simply the result of the capture of the Upper Waihao by a small stream working up from the East; or, two, it is possible that after cutting the gorge to its present level the Waihao River may have been blocked by the last stages of the uplift of the Hunters Hills thus finding a readier outlet through the softer Notocene rocks beyond the end of the greywacke block further to the southeast. It might, of course, be due to a combination of both these factors. The former of these hypotheses seems to account for the phenomenon more simply. The river where it cut the gorge must have been established in that part of its course before the Hunters Hills block arose, i.e., it must have been an antecedent (or ante-consequent) stream.

The greywacke through which the gorge is cut is much more resistant than the Notocene sediments, and erosion of it must have been very slow. While this erosion was in process the upper Waihao area was reduced to a mature topography. A stream cutting back through the relatively soft rocks of the lower eastern area would progress comparatively quickly, and eventually capture was effected somewhere near the present site of Waihao Forks. Once capture was accomplished the stream was rejuvenated and easily deepened its beds and formed gorges through the old flood-plain. The tributaries became renewed in vigour, with the result that gorges now modify the mature slopes of the Hunters Hills. The fault which crosses the river at the lower gorge of the Waihao may have accentuated the activities of the small capturing stream, for the downthrow side is to the east, and if this fault preceded the capture it would have acceleraed the cutting-back process which occurred.

McKay (1882) has shown that the present drainage of the Arno terrace, almost from the banks of the Waihao still flows out to sea by the Waimate Gorge. This fact seems to negative the hypothesis that the tail-end of the uplift of he Hunters Hills caused the abandonment of the gorge. If this had been the case it seems reasonable to suppose that the water would have flowed north through the gorge until either end of it or one particular part of it, acted as a barrier. Then the water on the south side of this barrier would flow south across the Arno terrace to join the Waihao—a deduction not borne out by fact.

The Arno terrace represents part of the flood plain of the Waihao when it flowed through the gorge and McKay states "the banks of the old river-channel may in places yet be observed." (1882, p. 85.) The writer could not trace any old river bed, but the present relief seems to indicate that capture was effected at a spot just below Waihao Forks.

The southern mass of this area comprises the part of the Waikakahi downs, which have a breadth of six to nine miles between the Waihao and Waitaki Valleys. The highest point is Mt. Harris—927 feet above sea level. This is composed almost entirely of Awamoan beds forming downs country with mature topography. The streams are short and have little volume, but have cut gorges through the limestone just before entering the Waihao.

The largest part of the district forms the lower basin of the Waihao River. This river rises on the western slopes of the Hunters Hills, and in the upper part flows through gorges cut in the greywacke. At the Forks it receives a large tributary which drains the hills forming the watershed between the Waihao and Hakataramea Rivers.

The lower part of the stream passes in narrow gorges through the limestone formation, below which it opens out again only to be restricted between the east part of the Waimate Hills and the Waikakahi Downs. It then enters the alluvial plains and passes out to sea.

Above the Forks the river shows a meandering course and is deeply entrenched. Terraces are beautifully developed. Many irregularities in the terrace-formation are found, but generally any one terrace can be referred to one of four major terrace groups. The writer has attempted to map these different terraces, but no definite correlation over the whole area is claimed.

In the first series all terraces up to 20 feet above stream level have been mapped together. This group of terraces has a wide occurrence. In the east of the area is formed a wedge-shaped flood-plain now dissected by the river banks; this continues as the lower Canterbury Plains. From the lower gorge to McCullough's bridge a similar terrace has a wide development. It can thence be traced upstream and is particularly clear in both branches of the Waihao, and has been cut in the greensand. It appears on one side or the other of the meandering entrenched stream as it swings to the north or south. In the South branch a pretty example of a cut-off meander is found on the surface of this terrace.

The second series of terraces is at a height of approximately 60 feet above stream level in both branches of the Waihao. The village of Waihao Downs is built on this level.

The third terrace at 90 feet above stream level has a wide extent known as the Arno plain. It continues up the North branch of the Waihao and is clearly differentiated from the lower 60 foot terrace. It is again seen up the South branch but here the development is not so perfect.

The fourth and highest terrace is found between the branches of the Waihao. It is 120 feet above stream level.

Other physiographical features of interest are the fossil-plain forming the Western slopes of the Hunters Hills (Cotton, 1922) and the prominent fault-line escarpment North of Waihao Forks.

DETAILED STRATIGRAPHY AND TABLE OF CLASSIFICATIONS.

PRE-NOTOCENE ROCKS.

These rocks, which are greywackes and argillites, form three elevated parts of the district along the north boundary of the area. These are the Waimate Hills (an upraised block north of Waihao Forks), part of the Hunters Hills, and Tussock Hill which rises to a height of 808 feet. No variation in lithological character is seen in any of these three parts mapped.

These beds formed part of the Waihao Formation (Silurian) of von Haast (1879), the Maitai and Te Anau Series (Carboniferous and Upper Devonian) of McKay (1882); the Te Anau system (Carboniferous) of Professor Park (1910) and the Maitai Series (Trias-Jura) of Dr. Marshall (1912).

The beds dip at high angles and strike in a north-west direction. They are characteristically unfossiliferous, and are succeeded with great unconformity by the Notocene sediments.

In describing these rocks in the Hunters Hills and in the southern spurs, the Waimate Hills, McKay states "the rocks . . . . are mainly coarse grey, very hard sandstones, slaty breccias, and dark-blue, almost black, slates. The strike of the beds varies considerably, as a rule a little to the west of north, the dip being westwards at angles 60° to 85°. At various places in the more slaty beds indications of fossils were discovered" (1882, p. 78).

Age and correlations—The writer has found no evidence by which any correlation could be made, but follows Dr. Marshall (1912 and 1918) and Dr. Benson (1921) in placing these beds in the Permian-Trias-Jura Series.

TABLE OF CLASSIFICATIONS.

Sequence of beds with local names.	von Haast, 1879.	McKay, 1882.	Hutton, 1887.	Park, 1918.
a. Sands and gravels *b.* Loess. *c.* Older gravels.	Recent and quarternary.	Recent to Pliocene.	———	———
Clays and sands. "Mount Harris beds."	Pareora Formation. (U. Miocene or L. Pliocene.)	Pareora Formation. (L. Miocene).	Pareora Formation. (Miocene).	Awamoan.
Blue Calcareous Clays.	Not recognised.	Not recognised.	———	Not recognised.
Glauconitic limestones. "The Waihao Limestone."	Oamaru Formation. (Upper Eocene) or Lower Miocene).	*a.* Ototara limestone *b.* Chalk-marls (*)	Oamaru Formation. (Oligocene).	Upper Hutchinsonian.
Greensands. "Waihao Greensands."		*c.* Marly greensand *d.* Island Sandstone (*)	Pareora Formation. (Miocene).	Lower Hutchinsonian. Ototaran† Waiarekan Ngaparan
Coal-measures.		*e.* Coal beds. (*)	———	
Greywackes and argillites, etc.	Waihao Formation. (Silurian).	Matai and Te Anau Series (Carboniferous to U. Devonian).	———	(1910) Te Anau Series (Carboniferous).

*Cretaceo-Tertiary.

†The writer is not clear exactly what beds at Waihao Professor Park places in the Ototaran Stage.

Table of Classifications (Continued).

Thomson 1916 and 1920.		Marshall.	Morgan, 1922.			The Writer, 1923-24.		
Notopleistocene.		——	——			Notopleistocene.		
a. Awamoan (Upper Miocene)	Noto-cene		Awamoan.	(Miocene to Oligocene)	Noto-cene	*a.* Awamoan		"Miocene"
Not recognised.			——			*b.* Hutchinsonian		
b. Ototaran (Lower Miocene).			Ototaran			*c.* Ototaran		"Miocene" or "Oligocene"
c. Waiarekan (Oligocene)		(1923) Upper Eocene	Waiarekan			*d.* Waimateian	1. Tahuian 2. Bortonian	"Eocene"
d. Ngaparan.			Ngaparan			*e.* Coal Measures.		
		(1912) Matai series (Trias-jura).	——			Maitai Series (Permian to Jurassic).		

Coal Measures.

The coal-measures are found at three localities in the district, viz., an extensive outcrop bordering the south slopes of the Waimate Hills; a restricted occurrence developed in a small creek which enters the North Branch of the Waihao, about a mile upstream from the Forks; and a third exposure overlapping on to the base of Tussock Hill, in the north-west of the area. These three occurrences will be described in the order given.

Where the river impinges on the south flanks of the Waimate Hills, the coal-measures form high cliffs. The base of the series is not exposed, and the lowest beds visible are coarse quartz conglomerates. Alternating with these are carbonaceous layers and bands of fine quartz sands which are pure white in colour and very fine grained. Thin bands and lenses of quartz pebbles, the latter showing frayed ends, are common. In these thinner quartz bands the average size of the rounded pebbles is about ½ an inch; they are usually clear white but may be smoky.

The higher beds are quartz sands, containing carbonaceous layers and hard bands of brown iron-stained sandstones. The whole series appears to be unfossiliferous.

In a small creek which cuts through the cliff slightly lower beds are found—black coaly grits, dipping at 12° in a direction 172°S. They are succeeded by white quartz sands.

The beds here appear to have been laid down on a sloping surface of an old shore-line.

In the development found in the North branch of the stream the coal-measures appear to pass beneath the greensands. In the road-cutting where the road descends on to the low river-terrace, some 40 feet of the coal-measures are found. They dip 12° in a direction 210°S. The lower 35 feet is made up of coarse quartz grits and finer sandstones, which alternate in irregular thicknesses. The shaly layers are intercalated with thin seams of coal up to ½ an inch in thickness. The sandstone layers are well banded. Above, the beds are noticeably coarser and consist of relatively large, rounded, quartz pebbles set in a sandstone matrix. This band, unlike the sandstones, is not cemented, but crumbles easily. Following this is some 3 feet of carbonaceous sands with quartz pebbles—the coaly facies is banded with fine lamellae.

On the west side of the mouth of a small gully which enters here the coal-measures are again exposed. This time they are much more carbonaceous and a black tinge colours the quartz sands. Four bands are noticeably carbonaceous — the lowest being the thickest and developing into a poor lignite some 4 feet in thickness. It has apparently been tried for burning, but the size of the excavation would suggest that this was not a success. Higher up the creek the quartz sands rest on the older greywacke, which is light in colour and leached to a considerable depth by the effects of the oxidation of the iron sulphides contained in the coals.

Still further upstream the basal bed is a highly cemented ferruginous conglomerate of large angular greywacke boulders, with a matrix of quartz pebbles and iron oxides. The greywacke below is completely rotted and resembles very closely the normal sandstone above.

However, gradations can be traced between the altered surface and normal greywacke, while concretionary weathered boulders show a solid kernal.

The third development of these beds is found below Tussock Hill. They are well exposed on the south side of the creek which flows below Tussock Hill to enter the south branch of the Waihao. This exposure is not in visible contact with either the greywacke or the greensands.

The upper four feet are of reddish-brown sands containing large pebbles of greywacke. The lowest part of this band consists of a conglomerate ranging from 6 inches to several feet in thickness and made up of irregular blocks of greywacke set in a matrix of rolled quartz pebbles, the whole being strongly cemented and stained yellow and red with iron oxides.

Below this comes some 40 feet of white quartz sands, well bedded in places. Lenses of inferior coal and carbonaceous material were observed at different horizons.

In the area mapped no coal-seams of workable thickness form surface outcrops, but several shafts have been sunk and a fairly good coal is utilised for local consumption. Dr. Thomson, 1915, publishes 13 analyses of coals from the district; these are quoted below:—

—	1	2	3	4	5	6	7	8	9	10	11	12	13
Fixed Carbon	34·72	27·77	35·85	32·83	24·81	27·78	27·97	39·41	38·42	22·0	24·95	24·28	28·37
Hydrocarbon	22·83	31·06	43·02	47·24	54·41	49·84	31·06	28·40	29·53	52·8	36·41	36·16	43·22
Water ...	28·01	36·18	15·01	16·32	17·58	18·19	36·18	23·96	24·21	15·9	26·09	30·59	23·49
Ash ...	14·44	4·99	6·12	3·61	3·20	4·19	4·79	8·23	8·02	9·3	12·55	8·97	4·92
Calculated Evaporated Power (lb.)	4·5	3·6	4·30	3·90			3·6						
Sulphur ...											1·62	1·78	2·98

1. Waihao. Coal water-logged, but dried as powder for 48 hours. Average of four samples, 20th Ann. Rep. Col. Lab. (1886), p. 39.
2. Waihao. Ash contains alkaline carbonates. 21st Ann. Rep. Col. Lab. (1887), p. 35.
3–7. Waihao. 27th Ann. Rep. Col. Lab. (1893), pp. 21-22.
8, 9. Waihao Forks. 30th Ann. Rep. Col. Lab. (1897), p. 4.
10. Shale, Waihao Forks Coal-mine. 39th Ann. Rep. Col. Lab. (1906), p. 5.
11. Waihao Coal-mine. Rep. Analyses N.Z. Coal, etc., Mines Dept. (1907), p. 9.
12. Waihao Forks. 44th Ann. Rep. Dom. Lab. (1911), p. 9.
13. Elephant Hill Coal-mine. Collected by Dr. Thomson and analysed by Dominion Analyst, 1913.

The average composition of Waihao Coals calculated from the above table is as follows:—

Fixed Carbon	29.92
Hydrocarbons	38.92
Water	23.98
Ash	7.18

Dr. Thomson concludes, "These analyses show that the Waihao coals are of poor quality, being too low in fixed carbon, rather high in ash, and exceedingly high in water." (1915, p. 161.)

The abundance of rolled quartz pebbles in the coal-measures leads to interesting speculations, since they could not have been derived from the greywacke with which most outcrops are in contact. Hence it is surmised that before block-faulting took place, the coal-measures were of much greater extent, and, in company with the overlying beds, formed part of an extensive covering-stratum. It is only where the Notocene beds now occur in down-faulted areas that they have been preserved. The nearest source from which the quartz could be derived is the quartz-mica-schists of Central Otago, and hence they must have been carried a considerable distance, a conclusion which is borne out by the rounded nature and more or less uniform size of the pebbles themselves. However, when the quartz sands were laid down they must have been close to an eroding surface of greywacke, for angular boulders of this rock are common in the basal conglomerates.

Correlation:—The lack of fauna in these beds makes correlation difficult. However, they correlate lithologically with the coal-measures developed in other Oamaru localities, particularly with similar beds at Ngapara, Wharekuri, Pareora and Kakahu.

These beds have hitherto been referred to the Ngaparan Stage of Dr. Thomson, but this term has no exact time-significance. It may, however, be retained to denote a land or coal-measure facies which may range from Kaitangatan to Waiarekan in age. The age of the Waihao coal-measures is probably basal "Eocene."

Waimateian Stage.

The rocks placed into this stage are in ascending order:—

1. Hard sandstones and conglomerate with concretionary structure. The "Island Sandstone" beds of McKay.
2. Lower greensands with an upper phosphatic band.
3. Upper greensands.

In a paper read before the Adelaide Meeting of the Australasian Association for the Advancement of Science, 1924, the writer (1926, p. 324) has shown that the lower part of these beds is most fittingly correlated with the Bortonian Stage of Professor Park. Therefore the Waimateian stage has been subdivided into: A. The Bortonian substage which includes 1 and 2 above; and B. The Tahuian substage, including the upper greensands.

The reasons for the above innovations are briefly as follows:—Up till the present these greensands have been referred to the Waiarekan Stage of Dr. Thomson.

Recently Dr. Marwick, 1926, p. 307 *et seq.* has described the hitherto unknown fauna of the beds of the Lorne district in the Waiareka Valley, upon which the Waiarekan Stage is based. His work shows clearly that the fauna of the Waiarekan tuffs is very distinct from that of the typical Bortonian, therefore he restricts the term Waiarekan to the tuff-beds. Now Professor Park's Bortonian substage is based on the Lower Waiarekan beds in the Waitaki Valley and it is with these beds that the fossils from 1 and 2 are most allied.

The fossils of the Borton's Beds, the type locality, are very poor, being for the most part casts. Thus it is from the Waihao area, where the sequence is clear and where the beds are productive of numerous well-preserved fossils, that a palaeontological basis may be given to this stage.

The lowest bed exposed in this section forms a ledge which the greensands higher in the sequence and seem lithologically to be the closing facies of the coal-measures. However, since they contain the first marine fauna, they appear to mark the first advance of the succeeding marine conditions.

They outcrop at one place only—on the right bank of the Waihao River about four miles East from Waihao Forks. These beds formed the "Island-sandstone" of McKay, 1882.

The lowest bed exposed in this section forms a ledge which crosses the river causing a rapid. It is very hard and silicious, being studded with quartz pebbles. Concretionary structures are beautifully developed. Some of these have been weathered out to leave large cup-shaped basins with a shell-in-shell structure. These occur up to 4 feet in diameter.

This band is followed by 6 inches of a poorly fossiliferous quartz conglomerate. Both these beds strike at 210° and dip at an angle of 5°. Calcareous worm-tubes are very abundant in places at this horizon. The succeeding beds are black carbonaceous grits, with quartz pebbles and a pungent odour. Still higher the beds appear to be slightly glauconitic. The sequence is capped by 12 feet of river gravels.

Fauna: The molluscs collected were for the most part fragmentary and very poorly preserved. Shark's teeth are present.

Forms worthy of specific determination were:—

Notoplejona n. sp.
Marshallena uttleyi (Allan).
Clavatula mackayi Suter.

Other generic determinations include:—

Acteon ? sp.
Natica sp.
Ostrea sp.
Phos ? sp. cf. *P. ordinarius* Marshall.
Turritella sp.

Dr. J. Marwick notes the following forms:—

Sinum fornicatum Suter.
Uber (*Euspira*) *firmus* (Marwick).
Turia sp.

Suter cites some further species from the locality in *N.Z. Geol. Surv. Pal. Bull.* No. 5, (1917):—

Euthriofusus spinosus Suter.
Fulgoraria (*Alcithoe*) *biconica* Suter.
Harpa (*Eocithara*) *neozelanica* Suter.
Lapparia hebes (Hutton).
Rapana waihaoensis Suter.

The lower greensands proper, or the Bortonian beds, are typically developed in the fine natural sections in the river-cliffs opposite Waihao Downs. Greensands, generally, have a wide distribution in the area and have been mapped as a whole. Owing to the fact that these beds are fossiliferous in few localities it is extremely difficult to assign any particular outcrop to either of the two substages. For this reason the greensands will be treated as a unit, and finally the type-localities which are richly fossiliferous and on which the substages are based will be described. For the most part the greensands are covered by Pleistocene gravels, but are well exposed in many fine river-cliffs and terraces.

Near Waihao Forks these beds are clearly seen on the river banks and in the railway cuttings as one approaches the Forks from Waimate. Following downstream the greensands outcrop on both sides of the river, at first prominently, but later the development is restricted to small exposures below limestone cliffs. The actual contact is obscured by river gravels and limestone talus.

At McCulloughs Bridge, about three miles East of the Forks, the greensands are well exposed by river erosion, and the only contact with the overlying limestone in the district is clearly seen. This section is the type one for the Tahuian substage, and will be described in detail in the sequel.

Below McCulloughs Bridge the Greensands appear again on the north side of the river. From here they pass away towards the Waimate Hills, making a bold escarpment. Their contact with the coal-measures (or with the greywacke?) is obscured by ploughed paddocks.

West of the Waimate Gorge greensands again appear either overlapping the greywacke or faulted against it (the crucial evidence could not be obtained) and they appear to pass under the limestone.

The structure of the area between this limestone and the Waimate Hills would lead one to believe that the gravels forming the Arno Terrace act as a thin covering to the greensands series. This hypothesis is borne out by cuttings in the railway line between McLeans Railway Station and the Forks.

Commencing again at Waihao Forks one can trace the greensands, as cliff-faces, up both branches of the stream. Further, all the area enclosed by these branches is covered by a gravel veneer overlying the terraced surface of the greensand. Following first the north branch of the Waihao one sees the greensands on both banks of the meandering stream, but these do not call for special mention except that they are practically unfossiliferous. In the second big bend of the river to the north, where the road crosses the low-lying gravels, the coal-measures are seen to pass beneath the greensands. The lower parts of the latter are more coarse grained, tending to be concretionary, and show marked iron staining. They are again unfossiliferous.

Between the road from Waihao Downs to Waihaorunga and that from the Downs towards Elephant Hill greensands have a wide extension. The country is of rolling downs and few outcrops are to be seen. In places clays and gravels hide the rich soil derived from the greensands so that their boundaries cannot be traced with certainty.

A further greensand-outcrop is of special interest. It occurs in the extreme east of the area where the Waihao River leaves its gorge and enters the alluvial plains. McKay, 1882, describes the sequence there developed and gives a section.

"The marly greensands are overlaid by dark foraminiferous clay-marls, containing one or two thin bands of decomposed tufa. This is overlain by a tuffaceous fine-grained breccia-conglomerate, and this, in turn, by a marly calcareous greensand. Where these beds rest on the marly greensand they dip east at a comparatively low angle, but the dip rapidly increases, till the breccia conglomerate is found standing almost vertical; and the higher part of the beds have a decided dip in the opposite direction, and are seemingly underlain by the fossiliferous Pareora (Mt. Harris) beds, which show in the banks of the River a westerly dip." (1882, p. 71.)

McKay further points out that the higher beds are highly fossiliferous, the variety of species being considerable. With this view the writer cannot agree. A careful search was made for fossils, but only a few corals and some fragments of brachiopods could be discovered. A fault is postulated to explain the contact of the Mt. Harris beds with the greensands. McKay, 1882, was of the opinion that the higher beds of the greensand series found here were the time-equivalents of his "chalk-marls" or the lower limestone, and that the volcanic action which gave rise to the tuffaceous beds would stop the deposition of limestone. However, in his later report he rejects this hypothesis. The limestone is missing from the section.

It now remains to discuss the type localities of the two substages of the Waimatean. The Bortonian substage is represented by the exposures displayed in the river-cliffs at Waihao Downs.

Commencing at the Forks and following up the south branch one sees some fine exposures. The greensands form high cliffs and are richly fossiliferous in a few places. The sporadic occurrence of fossils in the greensands is a noteworthy feature. In the first bend upstream from the railway bridge steep cliffs form the left bank, while the right bank is little above stream level and shows a thin veneer of gravels over an eroded surface of greensand. The strike of the beds is 98°E and they dip at low angles up to 6° to the south, obviously passing under the limestone escarpment facing north along the railway line. The lowest beds are dark bluish-green in colour and fairly soft and friable. Bands of rounded concretions occur at some four or five horizons, but only the lowest band, fifteen feet above the creek at the head of the bend, is well developed. The boulders project from the cliff-face and from the majority of the talus with which the base is littered. These concretions, which are up to two feet six inches in diameter, often contain fossils, but they are difficult to extract in a complete state. *Limopsis* is abundant, and is associated with *Venericardia, Cucullaea,* and *Pecten.* Worm-borings are common in the lower bands, and calcareous worm-tubes were found abundantly in one concretion.

The upper parts of the cliff are inaccessible, but there appears to be a decided difference in lithological characters between the upper and lower greensands. The former are much lighter in colour and seem to resemble the facies forming the fossiliferous rocks at McCulloughs Bridge. This band appears to be about thirty feet in thickness, and is capped by twelve to fifteen feet of coarse gravels.

Continuing upstream one finds a similar lithological series clearly shown in the second great bend to the north. Here at one small exposure marked "fossils" on the map, an excellent molluscan fauna was collected. This collection is taken as typical of the Bortonian beds. The forms from this spot show many differences from those occurring at McCulloughs Bridge. The shells are rather fragile but the matrix is soft and disintegrates easily. *Limopsis* is again very plentiful.

Near the north-east corner of the area a small creek enters on the right side of the south branch of the Waihao. The lower greensands are well developed here and can be traced down, as one goes upstream, to the coal-measures beneath Tussock Hill. These beds are here rather coarse-grained and inclined to be gritty, containing as they do many small rounded quartz pebbles and small tubelike iron concretions. Small plates of mica give the rock a noticeable glitter. They are unfossiliferous, and at the base strongly cemented with iron oxides which give a reddish tinge to the beds. They strike 45°E and dip south-east at an angle of 6°. Further upstream the coal-measures appear and seem to dip beneath the greensands.

From Waihao Downs it was once proposed to continue the railway line toward Waihaorunga. However, the scheme was dropped but not before some fine cuttings had been made through the greensands on the south side of the river. Above the Downs (Farm) Station these beds are fossiliferous—Limopsis being particularly abundant. The variety of forms here is very limited, and is in marked contrast with that of the more highly productive beds of apparently the same horizon which occur in the field only about a quarter of a mile distant.

The greensands are seen in the road-cuttings near the Downs Station. They are overlain by twelve feet of old river gravels which are in turn followed by nearly forty feet of loess and clays. The loess beds are very similar to those found near the breakwater at Cape Wanbrow, Oamaru.

The fauna of these beds is as follows:—

Antigona n. sp.
Architectonica marwicki Allan.
Austrofusus (*s. str.*) *acuticostata* (Suter).
Baryspira morgani (Allan).
Carinacca allani Marwick.
Cirsostrema cf. *lyrata* (Zittel).
Clavatula mackayi Suter.
Colus bensoni Allan.
Cucullaea waihaoensis Allan.
Cymatium decagonium Finlay.
Dentalium n. sp.
Dentalium n. sp.
Friginatica prisca (Marwick).
Galeodea aff. *senex* (Hutton).
Globisinum cf. *elegans* (Suter).
Hemifusus goniodes Suter.
Insolentia laciniata (Suter).
Insolentia mordax (Suter).
Insolentia (?) *sertula* (Suter).
Latirus (*Peristernia*) *neozelanica* (Suter).
Limopsis campa Allan.
Marshallena serotina (Suter).
Mauia curvispina Marwick.
Monalaria concinna (Suter).
Notoplejona necopinata (Suter).
Ostrea mackayi Suter.
Pecten devinctus Suter.
Pecten huttoni (Park).
Pecten waihaoensis Suter.
Perissoptera (*Hemichenopus*) *thomsoni* Allan.
Rapana neozelanica Suter (cast only).
Speightia spinosa (Suter).
Spirocolpus waihaoensis (Marwick.
Turricula antegypsata (Suter).
Venericardia acanthodes Suter.
Waihaoia thomsoni Marwick.
Waimatea inconspicua (Hutton).
Zemacies cf. *torticostata* (Marshall).

An analysis of this fauna shows several important facts. Thirty-eight species, including nine new species, are recorded. No Recent species are present, indicating that the beds are probably of "Eocene" age. It is remarkable that the oldest Tertiary beds in New Zealand, viz., the Wangaloan Series, have no species in common with this fauna. In consideration of this fact, and also of the fact that the overlying beds have likewise no Recent species, perhaps "Middle Eocene" would be most appropriate.

When compared with the fauna of the Hampden beds seven speices (or 18%) of this Bortonian fauna are found to be common. Hence the relationship is not so close as is that of the Tahuian which has 27% or twenty species of its fauna in common with Hampden. The Bortonian then may be considered older than the Hampden beds.

A comparison with the overlying Tahuian fauna is of interest. Eight species or only 21% of the Bortonian fauna pass up into the Tahuian. Hence the faunas, although closely related in some respects, are really very distinct and seem perfectly to justify the subdivision proposed. Certain genera here present do not seem to occur in the Tahuian; the most noteworthy being:—*Notoplejona, Speightia, Hemifusus,* and *Perissoptera.* Certain species too are highly characteristic, and of these we may note *Mauia curvispina, Notoplejona necopinata, Speightia spinosa, Colus bensoni, Latirus (Peristernia) neozelanica, Monalaria concinna, Carinacca allani, Pecten devinctus,* and *Venericardia acanthodes.* Of the Turrids the *Turricula* group is abundant, being represented by six species whereas in the Tahuian only one is found. The absence of certain genera, such as *Borsonia* and *Vexillum*, well developed in the Tahuian is equally striking.

Correlation:—Although the surface exposure of Bortonian rocks is limited the horizon appears to have a wide geograpical range in South Canterbury and North Otago. Tentatively the following beds may be grouped together into this substage:—The basal fossiliferous sandstone at Borton's, Waitaki River; the basal fossiliferous beds at Pareora; and the basal sandstone at Kakahu. The presence of this horizon is not yet proved at Ngapara, Wharekuri or Hampden.

The Tahuian beds are typically developed and are fossiliferous only at McCulloughs Bridge, in the Waihao Area. The section is capped by some eight feet of river gravels lying uncomformably on the bevelled surface of the limestone and greensands. Below this is a small wedge of the lower limestone, itself a calcareous greensand. It is here very fine-grained and light greyish-white in colour. McKay collected some rare foraminifera, but otherwise it is unfossiliferous. Next below this comes the uppermost part of the greensand series and exhibits, as it does further upstream, a marly facies, and is not fossiliferous. The contact between marl and limestone is sharp, but no erosion surface or angular unconformity could be observed. The marl grades down into a richly glauconitic greensand which is a rich chocolate-brown colour when freshly disturbed, but weathers to a drab grey with evidence of iron stainings. This band is some twenty feet thick and richly fossiliferous, the fossils being well preserved. Any one species is not abundant, but the remarkable feature is the great variety of forms, chiefly gasteropods, which one can obtain from the small section exposed. Mollusca are the most plentiful fossils, but corals, foraminifera, and brachiopods also occur. The coral is a pretty little cup-shaped structure but has not been identified. From comparison with figures in Zittel's Textbook (1913) the writer would suggest that this form is related to the genus *Trochocyathus*. *Nodosaria* was collected by the writer. The brachiopods were rare and are referred to *Thomsonica gaulteri* (Morris) by Dr. J. A. Thomson.

Below this again a hard, dark-green greensand is exposed which appears to be similar to the Lower greensands which are seen upstream from the Forks in both branches of the river. Speight and Wild (1919) comment on this lower facies and note a hard concretionary band, ten inches to twelve inches in thickness. "The upper part of this is bored with tubes, and shows irregular-shaped (phosphatic) nodules and borings in the upper layer, closely resembling those found in connection with the nodular layer of the Amuri limestone of North Canterbury." (1919, p. 185.)

In the identification of the species listed from the Waimateian the writer collaborated with Mr. H. J. Finlay, M.Sc., Otago University, and Dr. J. Marwick, M.A., Palaeontologist to the New Zealand Geological Survey. The writer acknowledges the debt he owes to these gentlemen for their help and kindness.

The mollusca of the Tahuian beds are enumerated below:—

Acteon n. sp.
Acuminia sulcata (Marshall)
Austrofusus (s.str.) *acuticostata* (Suter).
Amusium (Propeamusium) n. sp.
Baryspira morgani (Allan).
Architectonica ngaparaensis Suter.
Borsonia haasti Allan MS.
Borsonia huttoni Allan MS.
Borsonia verrucosa Allan MS.
Borsonia rudis (Hutton).
(?) *Bullinella enysi* (Hutton)
Carinacca haasti Marwick.
Carinacca waihaoensis (Suter).
Cirsostrema cf. *lyrata* (Zittel).
Claviscala (?) n. sp.
Cochlis notocenica Finlay.
Cochlis praeconsors Finlay.
Colus delicatulus (Marshall and Murdoch)
(?) *Colus modestus* (Marshall and Murdoch) (*nomen nudum*)
Colus solidus (Suter).
Coluzea climacota (Suter).
Conus (Conospira) tahuensis Allan.
Corbula pumila Hutton.
Corbula speighti Allan MS.
Cucullaea waihaoensis Allan.
Cymatium marwicki Finlay.
Dentalium n. sp. A.
Dentalium n. sp. B.
Dentalium n. sp. C.
Erato antiqua Marshall.
Eulima waihaoensis Allan
Friginatica prisca (Marwick).
Friginatica suturalis (Hutton).
Gemmula bimarginata Suter.
Gemmula complicata Suter.
Gemmula duplex (Suter).
Gemmula waihaoensis Finlay.
Gilbertia tertiaria (Marshall.)
Globisinum elegans (Suter).
Inglisella anomala (Marshall and Murdoch).
Latirofusus optatus (Marshall and Murdoch).
"*Latirus*" *mysticus* Allan MS.
Limea neozelanica Allan MS.
Limopsis waihaoensis Allan.
Marshallena formosa (Allan).
**Marshallena neozelanica* (Suter)
Marshallena spiralis (Allan).
Mitra hectori Hutton.
Nassicola cf. *costata* Hutton.
Notoseila attenuissima (Marshall and Murdoch).
Notacirsa elata (Suter).
†*Nuculana semiteres* (Hutton).
Nuculana solenelloides (Marshall).
Ostrea mackayi Suter.
Parasyrinx finlayi Allan.
Pecten cf. *chathamensis* Hutton.
Pecten huttoni (Park).
Pecten waihaoensis Suter.
Proximitra parki (Allan).
Proximitra (?) *plicatellum* (Marshall and Murdoch).
Triploca waihaoensis Marshall and Murdoch.
‡*Turbonilla hampdenensis* Finlay.
Turbonilla tahuensis Allan MS.
Uber (Neverita) pontis Marwick.
Uxia (?) *marshalli* Allan.
Waihaoia allani Marwick.
Waimatea apicicostata (Suter).
Waimatea inconspicua (Hutton).
Waimatea opima Allan MS.
Zaclys (Miopila) tricincta (Marshall).
Zeacolpus n. sp.
Zemacies aff. *marginata* (Marshall).
Zexilia crassicostata (Suter).
Zexilia waihaoensis (Suter).

**Daphnella neozelanica* Suter = *Belophos incertus* Marshall. For this and many other name changes and generic placings in this list, refer to Finlay. "A Further Commentary on New Zealand Molluscan Systematics," *antea* this volume.

†The type specimens of *Nuculana belluloides* Allan and *N. semiteres* Hutton are the same species, ancestral to the Recent *N. bellula* A.Ad., vide Finlay, *loc. cit.*

‡New name for *Turbonilla antiqua* Marshall, preoccupied; see Finlay, "New Specific Names for Austral Mollusca," *antea* this volume.

Seventy-five species are recorded, of which twenty-six are new to science. No Recent species are present. Taking the stratigraphical position and the above fact into consideration, the age may best be considered as "Upper Eocene." Forty-two species (including twenty-six new species) are restricted to this sub-stage.

Eight species, or 11% of the fauna, are common to the Tahuian and the Bortonian. It has already been shown that certain characteristic Bortonian species are absent. Twenty-eight genera of this list have no representatives in the Bortonian; the most noteworthy (having regard to the number of species in each genus) are:—*Marshallena, Borsonia, Corbula, Zexilia* and *Nuculana,* all of which have at least two species in the Tahuian. Of the Turrids (other than *Marshallena* and *Borsonia*) *Gemmula* (with four species) takes the place of *Insolentia,* and is accompanied by *Parasyrinx.*

The most characteristic species include:—*Baryspira morgani, Marshallena neozelanica, Borsonia rudis, Waimatea inconspicua, Zexilia waihaoensis, Colus solidus, Carinacca waihaoensis, Nuculana semiteres, Friginatica suturalis,* and *Spirocolpus waihaoensis.*

Of the beds outside the Waihao area the first comparison may be made with the fauna of the Hampden beds which has been made known to us by the enthusiastic and arduous research of Dr. Marshall, who has shown that that fauna is closely related to the one under consideration. He cites 44% of the forms as common to both localities. The writer, however, has found that only twenty species (or 27%) of the Tahuian fauna occur at Hampden also. In making this comparison, however, it must be understood that the personal equation in the species determination is an important factor. The writer is of the opinion that many of his new species occur also at Hampden, but unfortunately the Hampden forms have not been available to him for personal study. The nomenclature of these has not been since revised and the changes subsequent on revision of other lists during the past two years (the Hampden list though published in 1923, was prepared in 1921), have been considerable; it is thus not improbable that the same might prove the case in regard to the Hampden beds and might explain the apparent divergence in the figures noted above.

The species common to the Tahuian substage and the Hampden beds are:—*Austrofusus acuticostatus* (Suter), *Marshallena neozelanica* (Suter), *Zaclys tricincta* (Marshall), *Cirsostrema* cf. *lyrata* (Zittel), *Erato antiqua* Marshall, *Zexilia waihaoensis* (Suter), *Colus solidus* (Suter), *Gemmula waihaoensis* Finlay, *Gilbertia tertiaria* Marshall, *Globisinum elegans* (Suter), *Inglisella anomala* (M. and M.), *Carinacca haasti* Marwick, *Nuculana semiteres* (Hutton), *N. solenelloides* (Marshall), *Pecten huttoni* (Park), *Notoseila attenuissima* (M. and M.), *Acuminia sulcata* (Marshall), *Turbonilla hampdenensis* Finlay, *Gemmula complicatus* (Suter), and *Gemmula duplex* (Suter).

Dr. Marwick (1924) in his revision of the Naticidae does not give *Carinacca waihaoensis* (Suter) from Hampden; nor does he record *Friginatica suturalis* (Hutton); both of which (under *Ampullina*) were listed by Dr. Marshall. In this connection it seems advisable to note the members of this family determined by Dr. Marwick, from Hampden. They are:—

Natica bacca Marwick;
Natica (*Carinacca*) *allani* Marwick (= *A. waihaoensis* of Marshall);
Natica (*Carinacca*) *haasti* Marwick (= *A. suturalis* of Marshall);
Globisinum elegans Suter may, perhaps be added, for it is listed by Dr. Marshall, and Dr. Marwick does not give localities.

The alterations entailed by the systematic work, however, do not invalidate, but if anything strengthen the conclusion of Dr. Marshall that the Tahuian beds of McCulloughs Bridge are most closely related to the Hampden Beds. They are here correlated.

It may be noted, however, that some of the genera, such as *Dicroloma* and *Trigonia,* which give a peculiarity to the Hampden beds, have not yet been found at Waihao.

In an attempted classification on a palaeontological basis of the strata near Oamaru, Dr. Marshall has proposed the Wharekuri Series, with 20–25% of Recent Species of Mollusca, and has suggested that the Waihao Greensands are probably to be placed therein (*Trans. N.Z. Inst., 51* (*1919*) *250*). He states "If the general relationship of this (Wharekuri) fauna and the percentage of Recent species can be taken as a guide it can be clearly shown that the horizon is lower than that of the Ototaran limestone and higher than the Bortonian of Park." (*loc. cit.* p. 242.) The writer has in preparation a revised list of the Wharekuri fauna (based on further collecting in 1924) and provisionally it may be stated that it has little in common with that of the Waihao greensands On the other hand, its affinities with the beds above the limestone at Trig. Z., Otiake, are very marked.

With the Awamoan horizons the Waimateian of Waihao has little in common as far as the mollusca are concerned. The two are distinct,—a conclusion much at variance with that arrived at by Dr. Thomson and Dr. Uttley from a consideration of Suter's determinations. Some of the species whose range extends to the Awamoan may be noted. *Nassicola costata* (Hutton) (the type is from Mount Harris and this determination for the Tahuian shell is provisional); *Corbula pumila* Hutton (the type is from White Rock River and the species is common in Awamoan localities; again the determination is doubtful); *Pecten huttoni* (Park) (a third doubtful determination of a wide ranging shell); *Cirsostrema lyrata* (Zittel) (another wide ranging species which also occurs in the Waihao limestone and in the Mt. Harris beds); *Cochlis notocenica* (Finlay) (type from Awamoa—throughout the Oamaruian); and *Notacirsa elata* (Suter) (which has the holotype from Blue-cliffs).

Hence few species conflict with the dictum that the Waimateian fauna may be considered as a palaeontological entity. The great difference shown by the later Awamoan fauna may be explained in two ways. The first hypothesis is that the Awamoan fauna may represent a new migration of mollusca. This suggestion seems uncalled for in the present state of our knowledge. While there is a marked specific dissimilarity the genera are in most cases allied or identical. The second hypothesis, and the one favoured by the writer, is that the period represented by beds between those referred to the Awamoan and those referred to the Bortonian or Waiarekan is of great duration and still imperfectly known. To add to the difficulty this period is the one during which the deposition of limestone has been at a maximum in the South Canterbury-North Otago area, with a resultant paucity of mollusca. However, the fossiliferous beds at Otiake and Wharekuri seem in part to fill the gap and with the stricter definition of species and the rejection of erroneous identifications from existing lists the ideal of a classification based on purely palaeontological lines seems within the realms of possibility.

It should be noted that the new substages herein proposed are based solely on the contained mollusca. In each case the characteristic mollusca have been cited, but this does not mean that these species are necessarily restricted to these substages; merely that the assemblage of species is characteristic and is worthy of recognition as such.

Correlation:—The Tahuian beds are correlated with the Hampden beds of Dr. Marshall. If present, they have not yet been recognised at Kakahu, Pareora, Borton's, Wharekuri, or Ngapara.

The study of this Bortonian fauna is considered to be important in that it helps to solve a problem which has not yet been considered by New Zealand geologists. It is this: Is there a gradual increase in age of the basal beds of the Notocene from Mount Somers, in the North, south through Kakahu, Pareora, Waihao, Waitaki, and Oamaru, down to Hampden and Shag Point; or are there separate Piripauan, Hampden, and Oamaruian transgressions with the basal Oamaruian beds the same age from the Kakanui River to Mt. Somers? This interesting problem, which Dr. Thomson pointed out to the writer, cannot be solved until the faunas of the basal beds at the various districts are completely collected.

The correlations herein suggested might be expected to throw some light on this problem. The Bortonian seems to succeed the coal-measures at Kakahu, Pareora, Waihao, and at Bortons, in the Waitaki Valley. Hence no increase in age of the basal beds can be cited over that area. At Oamaru, in the Waiareka Valley, and at Ngapara, the basal marine beds have been considered Waiarekan (see Park and Uttley); but Bortonian horizons seem to be indicated. At Hampden the Bortonian has not been noted, but the Tahuian is underlaid by some 1500 feet of Notocene sediments (McKay, 1887). Wilckens (1924) has shown that the basal beds at Shag Point are of Upper Senonian (Piripauan) age. At Wharekuri in the Upper Waitaki Valley the greensands are divisable into two lithological horizons. The higher is abundantly fossiliferous, and the age is certainly younger than either Bortonian or Tahuian. The lower greensands which overlie the coal-measures in Wharekuri Creek may prove to be Bortonian.

Hence it seems that in the South Canterbury-North Otago area the basal marine beds are generally Bortonian, but may in some cases be Waiarekan, the Hampden-Shag Point area being the single exception. Sedimentation then may be considered to have commenced in the Upper Senonian at Shag Point and with further submergence during the Tertiary the Oamaruian sediments overlapped on to the Piripauan beds and on to a surface of varied relief which extended from Shag Point to Mount Somers. The series at Hampden may conceal a break between Cretaceous and Eocene, but this has not been detected.

There seem then to have been but two transgressions during the Notocene in this area, the first Piripauan and the second Oamaruian. The second of these was discontinuous; the evidence being phosphate-bands at different horizons due to standstill conditions; local disconformity, e.g., as at McCulloughs Bridge; and interruption by volcanic activity.

OTOTARAN STAGE.

The Waihao limestone is here divided into three lithological zones—the whole being placed in the Ototaran Stage of the Oamaruian System. The threefold division seems to be fairly constant over most of the area mapped. The zones are in descending order:—

1. Fluted glauconitic limestone.
2. Nodular phosphate band.
3. Calcareous greensand grading into glauconitic limestone in the upper part.

The lower member forms the "grey-marl" of McKay (1882). Both Hutton and von Haast place this formation, the Waihao limestone, at the top of their Oamaru System. McKay (1882) places it in his Cretaceo-tertiary Series and correlates it with the Ototaran stone. Dr. Thomson (1916), Dr. Marshall, and others refer the Waihao limestone to the Ototaran Stage, while Prof. Park (1918), considers it to be Hutchinsonian. Thus all authorities are agreed with the single exception of Prof. Park.

The limestone occurs as a narrow strip running east from Waihao Downs along the stream for a distance of some five miles. Between Waihao Downs and Waihao Forks it forms a prominent escarpment which runs parallel to the railway. From the Forks bold and jagged cliffs follow the river bank. The cliffs are perpendicular in the upper parts but slope below into talus composed of large and small blocks of fallen limestone. The presence of this talus is unfortunate from the geologist's point of view since it completely obscures the junction of the limestone with the greensands below. The general strike of the beds is nearly east and west, hence practically the same horizon is exposed for the whole length of the outcrop. However, where small creeks enter the river, and where the talus accumulation is lower or has been cut away by the stream, the lower facies of the limestone is well exposed. Only at McCulloughs Bridge is an actual junction with the greensand observed and, as has been pointed out here, there is a clear cut lithological separation with, however, angular conformity and no sign of an erosion surface.

The limestone continues south-west of Waihao Downs, but the escarpment is broken and the boundaries are difficult to trace with certainty. The beds appear to strike west-south-west towards Elephant Hill.

About two miles east of Waihao Forks an outcrop of limestone crosses the river, and for nearly a mile this horizon forms both banks of the river. This outlier extends for nearly one mile in a north-easterly direction. It has been extensively eroded and now lies, for the most part, as a great litter of broken blocks of all sizes.

A third mass, which for clearness, is here called the Fault limestone, lies to the north-north-east of the Forks, and is faulted against the secondary greywacke.

Detailed Sections:—Speight and Wild describe a section seen in an old quarry about three-quarters of a mile east of McCulloughs Bridge—in fact the most easterly part of the continuous outcrop. Their descripion is quoted in full.

"1. Whitish calcareous sandstone, quarried for building, and passing up into:—
2. Glauconitic sandstone, with nodules scattered through it, the upper part with passage beds into the overlying formation.
3. Limestone, marked by hard concretionary bands alternating with bands of more glauconitic character, which are softer. It is full of fossils, notably brachiopods and sea-urchins, and the limestone is largely made up of shell fragments. There is one distinctly marked layer of well-rolled shell fragments, with occasional rounded quartz-pebbles, and the beds below this are richest in nodules, some of which are based on fragments of bone, and some are almost pure phosphorite in appearance. Worm tubes are very evident in this layer." (1919, p. 185).

With this description the writer agrees but would suggest the following grouping of beds as being more natural and one which accords well with other sections in the area:—

1. Calcareous greensands or sandstones (i.e. Beds (1) and (2) of above are combined).
2. Phosphate band—comprising the nodular layer and shelly layer of above.
3. Fluted Upper limestone.

Some thirty feet of the lower beds are exposed. The upper six feet are more glauconitic and rich in fossils. Brachiopods are abundant (but were absent from the base of the section). Echinoid plates and spines are relatively plentiful. *Cirsostrema lyrata* (Zittel), and *Pecten huttoni* (Park) occur sparingly.

This is followed by some two feet of dark calcareous greensand—the nodular layer of Speight and Wild—rich in phosphatic nodules. Above this is some eight inches of a rolled shell-band composed chiefly of broken shells of brachiopods, and echinoderms. It is extremely hard and dark yellow when freshly broken. It weathers in a characteristic honey-comb fashion. It is followed by a fluted limestone—hard and soft bands alternating. The softer bands are noticeably more glauconitic and show signs of current-bedding. It is fossiliferous, containing similar forms to those of the lower beds. This upper limestone band can be traced as a continuous escarpment as far as the huge fall of debris at McCulloughs Bridge and in fact continues from there with few interruptions and without much variation in facies as far as Waihao Forks.

The beds of this section dip south at a low angle (8°–10°). They appear to pass under the Mt. Harris Clays.

Further east of this quarry two small outcrops of the limestone are found. In a small creek some 200 yards further east, the phosphate shelly band is again exposed. Still further along the escarpment the lower sandstone appears and worm-tubes filled with glauconite were observed. These beds are then obscured by drift and clays derived from the overlying Mt. Harris beds.

From McCulloughs Bridge upstream as far as the second small creek east of the Forks the limestone forms prominent cliffs and the three-fold division holds good. The lower beds are pale greyish-green calcareous greensands and contain numerous brachiopods. Echinoderm fragments are common while as before *Cirsostrema lyrata* (Zittel) and *Pecten huttoni* (Park) are found. Foraminifera occur but are rare. Then follows the phosphate band— yellow in colour, and this is succeeded by the fluted limestone. The greatest development of the limestone facies occurs at about the middle of this line of section. Here the beds are considerably thicker than elsewhere, and appear to represent the rock formed at the time of maximum submergence. Between the ford over the Waihao and the second creek east of that, this fuller series is accessible. The upper greensands are exposed on the river bank—they are here very dark green and apparently rich in glauconite. These grade up into a few feet of marly rock which has a greasy feel. Its weathering is markedly different from that of the typical greensands. It breaks into small rectangular blocks with a conchoidal fracture, and is reminiscent of the Burnside marl developed near Dunedin. Immediately above this the sequence is obliterated by gravels and limestone talus. The base of the limestone, some fifteen feet higher, shows the typical lower calcareous greensand with its brachiopods and echinoderm fragments and spines. Here these grade into a fluted limestone very like that above the phosphate band. Some thirty to forty feet of this is present but unfortunately is inaccessible. *Dentalium* sp. was collected here. Slightly further east the upper parts of the cliff are accessible. The limestone described is followed by a more glauconitic bed (still below the phosphate band) which shows current-bedding. This, in turn, is succeeded by another banded glauconitic limestone, which is followed by some eighteen inches of bright yellow phosphate rock which again shows the honey-comb weathering. The lower part of the limestone is here almost twice as thick as that shown at the East and West extremities of the outcrop. The phosphate band is covered by some two feet of a very fine-grained rock which exhibits abnormal bedding. The deposition planes are distinctly undulose and suggest wave-scouring. It is quite distinct from the usual current-bedding of the upper beds.

Next comes the upper limestone, which is at first fluted but higher up apears to be a series of concretions set in a limestone matrix. The concretions are up to eighteen inches in greatest length and are more ellipsoidal than spherical. The average diameter is about six inches. The long axis may lie in any direction, but the concretions as a whole appear to be very roughly grouped as a band parallel to the bedding-plane.

These upper layers appear to be unfossiliferous except for a few echinoid plates or spines. No rolled shell-band nor any worm-tubes were found in this part of the series.

What the writer considers to be perhaps the most important section found occurs in the second small creek East of the Forks. It shows clearly the junction of the upper limestone with the succeeding beds. It is described under the Hutchinsonian Stage.

From this section past the Forks to a little beyond the Downs we again have the escarpment of limestone. This section shows marked variation in its lithological character, and exhibits current-bedding very clearly. Between the Forks and the Downs the beds are more glauconitic and entirely unfossiliferous. No trace of a phosphate band could be found and it is probable that only the upper limestone is here developed. Hard bands alternate with soft almost greensand layers and the latter show the current-bedding most conspicuously. From the railway-line a well-developed talus slope is formed and this, as elsewhere, hides the lower beds of this series and obscures the junction with the greensands.

Opposite the Forks the harder bands are intercalated with fine-grained cemented sandstones. It is less glauconitic than calcareous. The surface is remarkably smooth, and although it is fluted horizontally it does not show the ragged projections of the limestone proper. These sandstones exhibit current-bedding less markedly than do the greensand layers, and further they appear in lenses rather than in bands. Honey-comb weathering occurs here but on a grander scale than in the phosphate horizon. Speight and Wild (p. 186, 1919) note a curious occurrence in these beds. "The greensands are here full of the remains of worm-borings and what look like the casts of fish-intestines, some of them 2 feet in length, 1½ inches thick, elliptical or flattened in cross section, with peculiar transverse curvilinear marking, which is not spiral however. They show a marked reaction for phosphate, and also when broken exhibit the peculiar and characteristic surface appearance of phosphatized limestone, are slightly pinkish in colour, but are composed essentially of calcareous greensand."

South-west of the Downs the escarpment continues for some 800 yards. Further on it becomes vague and limestone is found exposed only on the cap of some small hillocks. On the highest part of the hill on the road from the Downs to Elephant Hill, the country is of the nature of rolling downs, and the boundaries are difficult to trace.

In the outlier or the north bank of the river the limestone outcrop is divided into two by a decided break in feature. A low saddle, which may have been stream-cut, separates the Arno terrace from the river bed. The limestone east of this, where it is found *in situ*, appears to represent the upper beds only. It is fossiliferous containing brachiopods, a few foraminifera, the two molluscs already noted and many specimens of echinoderms. These last are certainly divisible into two genera, but they are not here classified. No trace of the phosphate band was found.

The remaining exposure is that of the Fault limestone. This shows the three-fold division, elsewhere noted. The phosphate band is well developed just above the top of the talus slope. It is composed chiefly of large fragments of echinoderms and brachiopods, and some specimens of a cirriped, probably *Balanus*, were found in it.

Considered as a whole the limestone is clearly a shallow-water deposit. Criteria for this conclusion are: the marked current bedding and wave-scourings; the richness in glauconite and the impure state of the deposits. This conclusion has already been reached by several geologists, notably Speight and Wild (1919) and also Marshall (1920).

Speight and Wild (1919) give four analyses of the Waihao limestone which are here reproduced.

	Sand and insoluble	$CaCO_3$	P_2O_5
No. 1	19.98	70.98	1.57
No. 2	26.12	57.77	3.14
No. 3	40.44	52.68	0.86
No. 4	18.42	72.60	1.34

No. 1. Upper hard band of limestone in gully south of Waihao River, near Waihao Forks.
No. 2. Lower band of limestone, same locality.
No. 3. Composite sample, outcrop parallel to railway, Waihao Downs.
No. 4. Calcareous greensand, along the railway between Waihao Forks and Waihao Downs; sample 8-10 ft. above the greensand; rock filled with casts.

Morgan (1919) gives some further analyses from the district as follows:—

	(1)	(2)	(3)	(4)	(5)	(6)
Matter insoluble in acid	25.42	6.01	—	—	—	16.3
Alumina and iron oxides	1.82	1.64	—	—	—	
Calcium carbonate	69.69	89.04	90.25	64.58	29.10	81.0
Magnesium carbonate	2.43	2.98	—	—	—	0.8
Water	0.64	0.33	—	—	—	1.0
	100.00	100.00	—	—	—	99.1
Specific gravity, calculated from weight of 6 inch cube						1.65

References:

(1) Limestone with siliceous bands from Waihao Downs, forwarded by Mr. T. L. Douglas, *Col. Lab. 28th Ann. Rep.*, 1894, p. 11.
(2) Limestone free from siliceous bands. Same contributor and references as No. 1.
(3) (4) From Waihao Downs. Aston, B. C., *Jour. Agric.*, vol. 11, No. 4, Oct. 1915, p. 331.
(5) From McCullough's Bridge, Waihao River. Same reference as Nos. (3) and (4).
(6) Fine grained limestone from Waihao Downs, exhibited by J. Douglas. Black, J. G., in *Official Record of the N.Z. and South Seas Exhibition*, Dunedin, 1889-90, (Wellington, 1891), pp. 369, 371.

Fauna:—The fauna of these beds consists of brachiopods, echinoderms, foraminifera, mollusca, shark's teeth, and a cirriped. Of these only the brachiopods and mollusca have been identified.

The molluscs are:—*Dentalium* sp.
Cirsostrema lyrata (Zittel)
Pecten huttoni (Park)

These forms give practically no help in the matter of correlation. That an extensive molluscan fauna must have existed in the Oligocene sea while the limestone was being deposited is shown by the richness of the distinct molluscan faunas found above and below the limestone. Unsuitable station is the reason advanced for its absence from this horizon.

Brachiopods:—These were sent to Dr. J. A. Thomson, Director of the Dominion Museum, for identification. My best thanks are due to him for his kindness.

Species.	(1)	(2)	*Range elsewhere and Remarks*
Thomsonica gaulteri (Morris).	×	×	Waiarekan to Awamoan; and a closely related form below the Amuri limestone.
Liothyrella landonensis Thomson.	×	×	Ototaran. (Landon Creek, Papakaio, etc., Duntroon greensands, i.e., Park's *L. boehmi* fauna).
Rhizothyris sp. A.	×	×	A dwarf form between *R. lateralis* Th. and *R. pirum* Th. in shape. Probably could be matched in the Duntroon greensands.
Rhizothyris sp. B.	×		A dwarf form comparable to *R. media* Th.; also in Duntroon greensands.
Stethothyris tapirina (Hutton).		×	Ototaran. (including Duntroon greensand and greensand at base of Ngapara limestone.)
Pachymagas ellipticus (Thomson).	×	×	Ototaran. This is rather a series of species than a single species. The Waihao specimens show much the same range of variation as those from the Ototaran of Landon Creek and Papakaio and the Duntroon Greensands.
Pachymagas cf. *clarkei* Thomson	×		With a smaller foramen. *P. clarkei* is lowest Mt. Brown limestone, correlated with Ototaran.
Pachymagas n. sp. A.	×		
Pachymagas n. sp. B.	×		
Pachymagas n. sp. C.	×		

Column (1) Upper Limestone, i.e., above phosphate band.
Column (2) Lower calcareous greensands.

Dr. Thomson remarks (*in litteris*) "Your collections from the limestone are all Ototaran species found in the upper part of the limestone at Landon Creek and in the greensands at the immediate base of the Duntroon and Ngapara limestones, i.e., Park's *L boehmi* fauna; but there are some of the less common species of that fauna not in your collections from Waihao, viz., *Tegulorhynchia* sp. cf. *squamosa*, *Murravia catinuliformis*, *Liothyrella boehmi*, and *Campages* n. sp. Of your collection the association *L. landonensis*, *S. tapirina and P. ellipticus* definitely places the limestone in the Ototaran. Moreover, the upper limestone as well as your lower limestone is Ototaran and this proves that the phosphatic horizon is not that of the Hutchinson Quarry horizon."

Chapman, 1918, cites one species of fish from the Waihao Forks. It is apparently not known from which horizon this tooth came, but it was probably from the limestone or from the greensands. The writer has found shark's teeth from the lower greensands and from the Hutchinsonian beds but they have not been determined. The species recorded by Chapman is *Carcharodon auriculatus* Blainville sp. This form ranges in New Zealand from Upper Cretaceous (Danian) to Tertiary (Eocene to Miocene).

Chapman comments "This species appears to have had an earlier origin in New Zealand than in any other part of the world." (1918, p. 18.)

Correlation:—Gudex (1918) and Speight and Wild (1919) correlate this limestone with that of the Pareora district. McKay (1882), Park (1905), and Marshall (1920) have correlated it with limestones developed in the Waitaki Valley. Neither of these correlations has been proved to date. Dr. Thomson's brachiopod determinations, however, would tend to correlate the beds with the following horizons:—

(1) The upper part of the limestone at Landon Creek;
(2) The Duntroon greensands; and
(3) The greensands at the base of the Ngapara limestone.

HUTCHINSONIAN STAGE.

Hutchinsonian beds are here recorded from Waihao for the first time. All geologists who have written on the area, except McKay, have considered that the limestone was conformably overlain by the Mt. Harris Awamoan beds. The Hutchinsonian stage is restricted in occurrence, and nowhere forms a surface outcrop. The section is exposed on the west side of the second small creek which enters the Waihao from the south, three-quarters of a mile east of the Forks. About 200 yards upstream a huge block has become detached from the cliff, but still stands upright and exhibits a similar sequence to that found in the main cliff.

The lowest member of the section is the normal upper fluted limestone which is here very dark in colour and richly glauconitic, being almost a cemented greensand. It is again exposed on the east side of the creek and there forms the top bed. The limestone dips south at an angle of 5° and shows the usual alternative bands of hard and soft material, the latter showing numerous worm-borings.

The limestone is succeeded by a wedge of dark greensand which is 20 feet thick at the extreme north of the section, and gradually thins down to a few inches at the south end. This bed shows marked current-bedding and consists of very fine, dark-black, friable greensands which exhibit up to 25 laminations per inch.

At the base of this bed, i.e., in contact with the limestone, a shelly surface is shown; another is found at the upper surface immediately beneath the succeeding beds. No identifiable brachiopods were collected, but fragments occur. When observed under the microscope, after treatment with hydrochloric acid, the sediment is seen to be composed of rounded grains of dark-green glauconite, a small amount of quartz grains and, rarely, flakes of mica. No feldspar was found. In addition the glauconite frequently takes the form of moulds of foraminifera, particularly of forms which agree in outline with *Textularia* and *Cristellaria*. Minute fish-teeth are also present.

When traced further upstream this band is thinned down to a layer of shell-fragments, from a few inches to 2 feet in thickness. It contains a varied assemblage of forms, among which are corals, sharks' teeth, fragments of brachiopods and echinoderms, portions of the stems of a crinoid, a cirriped like *Balanus*, and a *Pecten* allied to the *P. burnetti* group. Nodules of a black, resinous substance are common.

The next bed in the sequence is marked off from the lower one last described by a clear cut line marking a decided change (and probably pause) in sedimentation. The upper bed is sandy-clay, approximately 40 feet in thickness, is roughly banded, and is pale blue-grey in colour. Most of the section, however, appears yellow, but this is due to a film of clay descending from the brown clays above. From this bed typical Hutchinsonian brachiopods were collected. It also contains echinoderms. It dips south, but at an angle of 10°. Hence there is a slight angular unconformity between these clays and the limestone. This point is not stressed and can probably be explained by the introduction of the wedge of greensand.

These clays grade imperceptibly up into typical yellow-brown sands and clays of the Mt. Harris beds, which are here, as in almost all other exposures of the lower parts of the Awamoan beds, in the district, devoid of fossils.

The brachiopods have been determined by Dr. J. A. Thomson.

Species.	*Range elsewhere and remarks.*
Liothyrella n. sp.	Not *L. landonensis* nor *L. neglecta*, (Hutton).
Pachymagas cf. marshalli (Andrew).	*Pachymagus parki* series—can be matched in the Hutchinsonian greensands of Kakanui and other Oamaru localities.
P. cf. *hectori* Thomson	
P. cf. *haasti* Thomson	
?*Pachymagas* n. sp. A.	Waihao Limestone—Ototaran.
?*Pachymagas* n. sp. B.	Waihao Limestone—Ototaran.

Of the forms Dr. Thomson says *(in litteris)* that the beds above the Upper Limestone contain no Ototaran species; the forms being all referable to species found in the Hutchinson Quarry beds of Kakanui and other Oamaru localities; though the special species of Hutchinson Quarry itself, viz., *P. parki* and *R. rhizoida*, etc., are absent as they are in most of the Hutchinson Quarry greensands round Oamaru. The beds here considered correlate with the Kakanui greensands.

Correlations—These beds as Dr. Thomson states above are correlated with the Kakanui greensands, i.e., the Lower Hutchinsonian of Park (1918)or the true Hutchinsonian as recognised by Thomson and Uttley. No two-fold division, in the usage employed by Professor Park, is present at Waihao. In other words if the Upper Hutchinsonian of Park (1918) is present, it is basal Awamoan, as Dr. Uttley, 1920, contends for the Oamaru district, and has no lithological or palaeontological features which would serve to make it a useful substage.

AWAMOAN STAGE.

The Awamoan beds are found over a wide area in the district between the Waihao and the Waitaki Rivers. They have not been examined by the writer as fully as the lower beds. The reason is two-fold; first, these beds, in the area mapped, are covered for the most part by low grassy downs and outcrops are relatively few; second, the Awamoan stage is perhaps that most fully described in the Notocene of New Zealand, and hence more attention has been given to the lower, less-known stages. The fossils collected by the writer from this stage were in beds just outside the area mapped, viz., the summit of Mt. Harris, where fine exposures are found. However, the fossils are not well preserved, and are sporadic in occurrence, being for the most part confined to narow bands.

Von Haast describes this series as consisting "mostly of bluish or greenish argillaceous sands, with harder, calcareous, mostly fossiliferous beds interstratified with them." (1879, p. 317.)

McKay gives this description: "In their lower beds they consist of sands and sandy clays, passing upwards into marly clays of a light-grey colour. At many places in the middle part of the beds, fine-grained blue concretions are abundant, crowded with fossil shells, generally in the conditions of casts." (1882, p. 64.)

Whenever a section was found in the area mapped the beds had a low southerly dip. Where the Waihao leaves its gorge and enters the alluvial plains, is an interesting section of the Notocene beds which is described elsewhere in this paper. Here the Mt. Harris beds appear to underlie the greensands, but are apparently faulted against them. The fault strikes across the river, but cannot be traced for any distance away from the section exposed on the bank of the river. The beds here are fossiliferous and contain fine-grained blue-grey concretions crowded with fossils. These are, however, difficult to collect.

In the following list of Mollusca several alterations (consequent on revision of the fossils) have been made in the names assigned to forms previously stated to occur here, and a number of new records have been added. The identifications have been checked by Mr. H. J. Finlay.

Baryspira robusta (Marwick).
Bathytoma haasti (Hutton).
Cirsostrema lyrata (Zittel).
Cochlis notocenica (Finlay).
Comitas oamarutica (Suter).
Corbula humerosa Hutton.
Cucullaea worthingtoni Hutton.
Dentalium mantelli Zittel
**Dentalium nanum* Hutton.
Dentalium solidum Hutton.
Inquisitor awamoaensis (Hutton).
Linemera pukeuriensis (Finlay).
Lissotesta n. sp.
Maoricolpus cavershamensis (Harris).
Maorivetia brevirostris (Hutton).
Marginella fraudulenta Suter.
Mesalia striolata (Hutton).
Monia incisura (Hutton).
Nassarius socialis (Hutton).
Nassicola costata (Hutton).
Neilo awamoana Finlay.
Pecten huttoni (Park).
**Sigapatella novaezelandiae* Lesson.
Spinomelon parki (Suter).
Spissatella trailli (Hutton).
Stiracolpus n. sp.
Syrnola semiconcava Marshall & Murdoch.
†*Therasia thaisa* Hutton.
Typhis maccoyi Ten.-Woods.
Venericardia awamoaensis Harris.
Venericardia zelandica (Deshayes).
Venustas fragilis (Finlay).
Verconella n. sp.
Xymenella lepida (Suter).
**Zeacrypta monoxyla* (Lesson).
**Zenatia acinaces* Q. & G.

The following species originally described from this locality may be added:—

Coluzea dentata (Hutton) (as *Fusus*).
Cominula (*Procominula*) *exsculpta* (Suter) (as *Cominella*).
Phenatoma (*Cryptomella*) *transenna* (Suter) (as *Lencosyrinx*).

In his revision of the Naticidae and Struthiolariidae Dr. Marwick notes the following additional forms: —

Natica harrisensis Marwick.
Uber lobatus Marwick
Globisinum miocaenicum (Suter).
Struthiolaria subspinosa Marwick.
S. spinifera Marwick.

Forty-four species are here recorded of which four are Recent species, a percentage of 9. This list does not give a complete account of the fauna of the Mt. Harris beds, which were incompletely collected. However, the lists in *N.Z. Geol. Surv. Pal. Bull.* No. 8, pp. 64-67, contain so many errors that it is considered inadvisable to take them into consideration.

An analysis of this list shows clearly that the fauna as a whole is closely related to that found in other Awamoan beds in the type district. The percentage of Recent species (and it is probably excessive) is lower than those given for the type Awamoan beds in *Pal. Bul.* No. 8, 1921, but this result was not unexpected. As the nomenclature is revised and "group-series" are subdivided reductions in the percentage of Recent forms as given by Suter are inevitable. The

*Recent forms.
†This land-shell was determined by the late Mr. R. Murdoch to whom my thanks are due.

figures given by Suter are: for Pukeuri, 29%; for Awamoa, 38%; and for Target Gully, 33%.

Only two species on this list occur also in the Waihao greensands —these are *Pecten huttoni* Park and *Nassicola costata* (Hutton). Both of these identifications from the greensands may be considered doubtful, hence the faunas are practically distinct. This fact leads the writer to suppose either that disconformities not at present apparent must occur, or that the deposition of the intermediate beds—the Hutchinsonian clays and the Ototaran limestones—which have no molluscan fauna, must have taken an immense period of time—a conclusion which is apparently at variance with the obvious shallow-water origin of these beds but one which Dr. Marshall has arrived at from faunal studies. "The time that elapsed was sufficiently long to allow of a large number of species, and even genera, becoming extinct, and of the development (or at least of the migration) of a large number of other species." (1923, p. 119.)

The presence of two fossil land-shells, *Thalassohelix igniflua* (Reeve) found by Dr. Uttley, and *Therasia thaisa* Hutton, found by the writer, is of interest. The specimens found by the writer were distinctly embedded in the sandy matrix in a cliff face. However it is possible that they are of more Recent age and have become embedded during floods or old slips. Recent members of both these species are found in the Canterbury district, and are restricted to the South Island (Suter, 1913, pp. 628-9 and 660-661).

Correlation:—The Mt. Harris beds, then, are to be correlated with other typical Awamoan horizons near Oamaru, particularly with those beds at Awamoa, and Pukeuri. They are also correlated by Gudex, 1918, with the Pareora blue-clays and red sands above the limestone in the Pareora district.

NOTOPLEISTOCENE.

(*a*) Recent River Gravels, talus and silts.
(*b*) Loess.
(*c*) Older gravels.

(*a*) The Recent gravels cannot be distinguished except in position, from the older gravel terraces, in fact they are probably formed in part by the re-sorting of the older terraines by fluvial action. They consist of greywacke boulders of various sizes in a matrix of sands and clays derived from the Notocene sediments.

At one exposure below the ford over the Waihao they are of interest in that they contain derived fossils from the Mt. Harris beds, together with many fossil land-shells. The latter have probably been carried down by the stream and have become embedded in the silts. The derived fossils collected were:—

Dentalium solidum Hutt.
Comitas oamarutica (Suter).
Spissatella trailli (Hutt.).
Limopsis zealandica Hutt.

The land-shells have been identified through the kindness of the late Mr. R. Murdoch, of Wanganui. They are:—

Allodiscus planulatus Hutt.
Allodiscus ? sp.
Charopa coma Gray var.
Charopa longstaffae Suter (?).
Thalassohelix igniflua Reeve.

These forms do not throw any light on the Pleistocene range of the species in question. As Recent forms, *A. planulatus* and *C. coma* are found fairly plentifully over both Islands and the latter species has been noted from the Pleistocene beds at Petane, near Napier, *T. igniflua* is found only in the south half of the South Island. *C. longstaffae* is in the Suter collection, Wanganui Museum, but is not cited in Suter's Manual, 1913.

(*b*). *Loess deposits*:—These beds occur at two places in the district and both occurrences appear to be the remnants of much wider outcrops. The larger covers the older gravels where the Waihao River leaves its lower gorge and this deposit is probably part of the greater extent of loess which spreads over the Canterbury Plains from Timaru southwards. The second outcrop is found in a road-cutting near the Waihao Downs Farm Station.

Wild, 1919, gives a compact summary of the various opinions which have been expressed as to the origin of this formation.

"Haast (1879) was of the opinion that the deposit is similar in origin to the loess of China described by Baron von Richthofen—that is to say, it is an aeolian deposit. In this opinion he has been supported by Hardcastle (1890), by Speight (1908 and 1917), and by Professor A. Heim (quoted by Speight, 1908), of the University of Zurich. Marshall (1912) has also declared his adhesion to Haast's view. Hutton (1905) always strenuously opposed this theory, maintaining the deposit to be a marine silt laid down during a period of submergence of the plains; and he quotes Professor Boehm, of Freiberg, in support of his arguments." (1919, p. 286.)

Wild's contribution to the problem lends some support to Hutton's hypothesis, since he shows that whereas according to Udden* the average largest size of quartz-particles sustained in air by strong winds is 0.1 m.m. in diameter, the composition of the loess shows that from 28 to 40 per cent. of the particles have a diameter ranging from 0.04 m.m. to 0.2 m.m., while there is also a certain small quantity of material over 0.2 m.m. in diameter.

Hence Wild concludes "we have here, therefore, a very strong argument against the aeolian hypothesis." (1919, page 287.)

Wild further stresses the absence of organic matter in this deposit. Richthofen had postulated vegetation to fix the wind-blown waste as it settled.

However if, as Hutton and Wild suppose, this loess is a marine silt, surely some evidence of organic origin other than *Dinornis* and other land birds would be preserved. If submergence did occur the

*J. A. Udden, *Journ. Geol.*, vol. 2, page 323, 1894.

sunken area must have formed the littoral zone where molluscan and other marine life usually abounds.

(*c*) *Older Gravels*:—These beds were placed by McKay (1882) as the upper part of the Pareora System. However, they do not appear to be an integral part of the "Miocene" beds, and are here treated as the lowest member of the Notopleistocene. These gravels overlie the Notocene beds with marked unconformity, except where it so happens that they cover an eroded surface parallel to the strike of the beds. Then a disconformity is present.

They are extensively developed in the area, chiefly as terraces which run back from the river-bed. Most of the gravel-capped terraces may be referred to one or other of four major terrace formations which are discussed in more detail in the topographical section.

They consist of boulders, up to 2 feet or more in diameter, of greywacke with a rubbly matrix of limestone, greensands, quartz pebbles, etc., the whole being loosely put together. For the most part they appear to be younger than the block-faulting movements. In the faulted section these gravels overlie both formations along the fault-contact and do not enter into the vertical movement. However, in a section given by McKay (1882) near Elephant Hill the gravels appear to have taken part in the faulting.

This paper gives a complete account of the molluscan fauna of the various beds at Waihao, with the exception of a few species still to be described from the Waimateian stage. Most of these are badly preserved, and suitable illustrations could not be obtained for the present paper. They have all been included as n. sp. or "Allan MS" in the lists given in this paper.

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