Divisions of the New Zealand Cretaceous

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Abstract

THE history of Cretaceous classification in New Zealand is outlined. The Cretaceous sequence is now considered to be substantially continuous from the base of the Tertiary down to the top of the Neocomian. Previous divisions are modified, ten new stage divisions being introduced. The Mata Series contains the Teurian (Danian), Haumurian (Maestrichtian), and Piripauan (upper Campanian) stages. The Haumurian Stage is new and corresponds to the upper part of the old Piripauan Stage, the name Piripauan being retained for the lower part. The Raukumara Series is divided into three stages: Teratan (upper Santonian to lower Campanian), Mangaotanean (upper Coniacian to lower Santonian), and Arowhanan (lower Coniacian). The Clarence Series is divided into four new stages: Ngaterian (upper Turonian), Motuan (lower Turonian and upper Cenomanian), Urutawan (Cenomanian) and Coverian (Cenomanian and Albian). The Taitai Series is redefined to include the Korangan and Mokoiwian stages. The Korangan Stage (Aptian) is based on fossiliferous sandstone and conglomerate at Koranga. The Mokoiwian (lower Aptian or upper Neocomian) is based on dark mudstone at Tapuwaeroa Valley. Important Cretaceous sections are described, and a brief account given of Cretaceous climate, igneous activity, and tectonics. Eleven new species of *Inoceramus* are described in an appendix.

CONTENTS

CLASSIFICATION OF CRETACEOUS STRATA

History of Classification

The history of Cretaceous classification in New Zealand is illustrated by two charts that relate the New Zealand formations and stages to the International Cretaceous divisions according to Muller and Schenk, 1943. In the first chart (Fig. 3) the ages are those they were considered to have when described: in the second (Fig. 4) the ages have been revised in the light of present knowledge.

Division of the uppermost Cretaceous progressed fairly steadily and was based on the sections at Amuri Bluff (Thomson, 1917) and Te Uri Stream (Finlay and Marwick, 1947), but division of the middle Cretaceous was held up because of unrealized complexities in the section at Coverham that had been considered the standard for the middle Cretaceous of New Zealand by Thomson. Thomson recognized six formations, of which only his three upper—Sawpit Mudstone,* Nidd Sandstone, and Cover Mudstone—are important in the present discussion.

The first age classification depended on the ages determined by Woods in 1917 for fossils from Coverham and Amuri Bluff. By chance he was not sent any diagnostic forms from the lower and middle Senonian. It thus appeared as though two distinct and limited periods of time were represented: upper Senonian by the fossils from the lower part of the Amuri Bluff Section, and Albian to Cenomanian by *Inoceramus concentricus* and *Turillites* from the Cover Mudstone of the Coverham Section (see Fig. 4, column 1). The non-diagnostic fossils that are actually intermediate in age were included by Woods in one of his two periods.

In 1917 Thomson based his Piripauan Stage on the Amuri Bluff Section and his Clarentian Stage on the Coverham Section, but he could not explain the apparent absence of the whole of the middle and upper Cretaceous from the supposed continuous section at Coverham. This difficulty seemed to be partly resolved when Marshall (1926) found that the *Gaudryceras*‡ from the Sawpit Mudstone matches exactly with his *G. subsacya* from Senonian or Maestrichtian beds at Western Northland, and when *Inoceramus bicorrugatus*—described by Marwick in 1926 and shown to occur in the Nidd Sandstone—was recognised by Heinz in 1928 as being post-Cenomanian and considered to be upper Turonian in age. Because of these determinations Marwick in 1934 suggested that the Turonian and Senonian gap in the Coverham section could be filled with the Nidd Sandstone and the Sawpit Mudstone (see Fig. 3, column 2).

Fossils from Koranga (Fig. 2) in the Raukumara Peninsula were recognised by Marwick in 1939 as being Aptian in age and older than any described from Coverham. Consequently in 1940, when Finlay and Marwick presented their first description of the New Zealand Tertiary and Cretaceous stages they showed the Cretaceous succession to be fairly continuous down to the Aptian (see Fig. 3, column 3).

The study of the New Zealand Foraminifera, started by Dr. H. J. Finlay in 1930, allowed him to define the top of the Cretaceous and to subdivide the lower

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* Thomson's formation names have been shortened in conformity with modern practice.

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‡ It is now known that this particular ammonite genus evolved slowly and is useless for close dating (Spath 1953: 43), unless the outer whorls, which are not represented by the New Zealand specimens, are preserved.

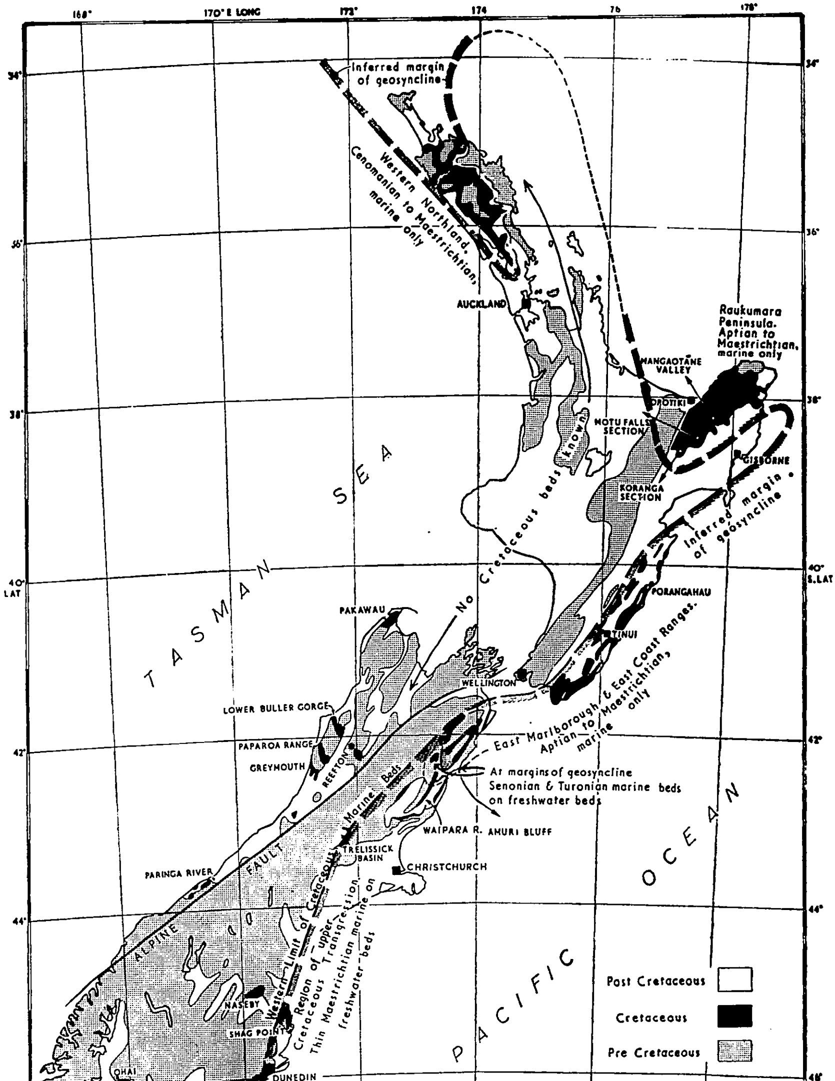

FIG. 1.—Map showing distribution of marine and non-marine Cretaceous rocks, inferred margins of geosynclines, position of type sections, and some other important Cretaceous localities.

Eocene, and to do this in critical regions with continuous sequences that are devoid of macrofossils. He was less successful with the type Clarentian and type Piripauan. He accepted Thomson's stratigraphic order for the Clarentian formations but because the order was wrong he could find no regular microfaunal change and assumed the age of all the formations to be the same. *Inoceramus concentricus* var. *porrectus* (now *I. tawhanus* n.sp.) had been described by Woods from the Sawpit Mudstone—Thomson's youngest formation—and as *I. concentricus* is typically Albian, this age was accepted by Finlay (1948: 293) for the whole of the Clarentian sequence at Coverham. Finlay was able to establish microfaunal correlation between the Nidd Sandstone—the formation thought by Thomson to be below the Sawpit Mudstone—and the Puketoro and Mangaotane mudstones of the Raukumara Peninsula and considered them to be Albian also.

The type Piripauan as defined by Thomson at Amuri Bluff (now the type for the restricted Piripauan and the overlying Haumurian stages) proved to be devoid of useful micro-fossils. Finlay found a distinctive microfauna in the Saurian beds of the mid-Waipara, a lithologic correlative of the Haumurian part of the Amuri Bluff section, and considered this fauna to be representative of the whole of the Piripauan as defined by Thomson. Mr. N. de B. Hornibrook has since found that the microfauna of a macrofaunal correlative of the lower part of Thomson's Piripauan (the restricted Piripauan of this paper) closely resembles that in the Nidd Sandstone and differs considerably from that in the Saurian beds of the Mid-Waipara. This microfaunal difference is one of the reasons why the upper and lower parts of Thomson's Piripauan are now given independent stage status. These upper Cretaceous problems were, however, relatively minor points when compared with the mid-Cretaceous problems that remained.

In 1947, largely as a result of Finlay's foraminiferal sequences, Finlay and Marwick were able to present a more detailed division of the New Zealand upper Cretaceous and Tertiary sediments. They introduced the Teurian stage for Cretaceous sediments younger than Thomson's Piripauan (post-Haumurian) and considered the Clarentian—as the Clarence Series—to be Albian in age and to be underlain by the Taitai Series of Aptian age (see Fig. 3, column 4). No middle Cretaceous sediments were recognised.

In 1952 while working on the problem of the Taitai Overthrust in the Raukumara Peninsula the writer discovered that *Inoceramus* is more widespread than had been supposed, and that successive horizons are marked by distinct species. The distinctive Senonian succession was first established in Raukumara Peninsula and checked in the central and southern parts of the east coast of the North Island. *Inoceramus australis* and *I. pacificus*—the key species in the lower part of Thomson's Piripauan—were found to be underlain by two undescribed species—*I. nukeus* n.sp. and *I. opetius* n.sp.—and these to be underlain by *I. bicorrugatus* Marwick which in turn is underlain by a huge species—*I. rangatira* n.sp.—also undescribed. The undescribed species had previously been collected from many parts of New Zealand, including the Nidd Sandstone of the Coverham district.

Close collecting then proved the Coverham section to be less simple than had been supposed by Thomson and established the order of formations shown in Fig. 3, column 5. The revision—described by Wellman in 1955—has made it possible to revise and extend the New Zealand Cretaceous stages.

Outline of Proposed Divisions

The grouping of stages into series and the system of two-letter stage-mapping symbols introduced by Finlay and Marwick in 1947 have proved to be extremely useful and are used for the new Cretaceous divisions. The complete list of Cretaceous series, stages, and mapping symbols is set out in Fig. 8. The symbol " U " is used for the Taitai Series to distinguish it from the Taranaki Series (Finlay and Marwick, 1947).

In order to avoid possible stage overlap, type localities have been chosen with as many stages in sequence as possible.

The Mata Series was introduced in 1947 by Finlay and Marwick to include the Wangaloan, Teurian, and Piripauan stages. The name was taken from Mata Survey District and Mata River in Raukumara Peninsula (Finlay and Marwick, 1948). The Wangaloan does not contain belemnites, ammonites, or *Inoceramus,* and is either Danian or lower Eocene in age (Finlay and Marwick, 1937). The section at Te Uri Stream—chosen by Finlay and Marwick as the type for the Teurian and for

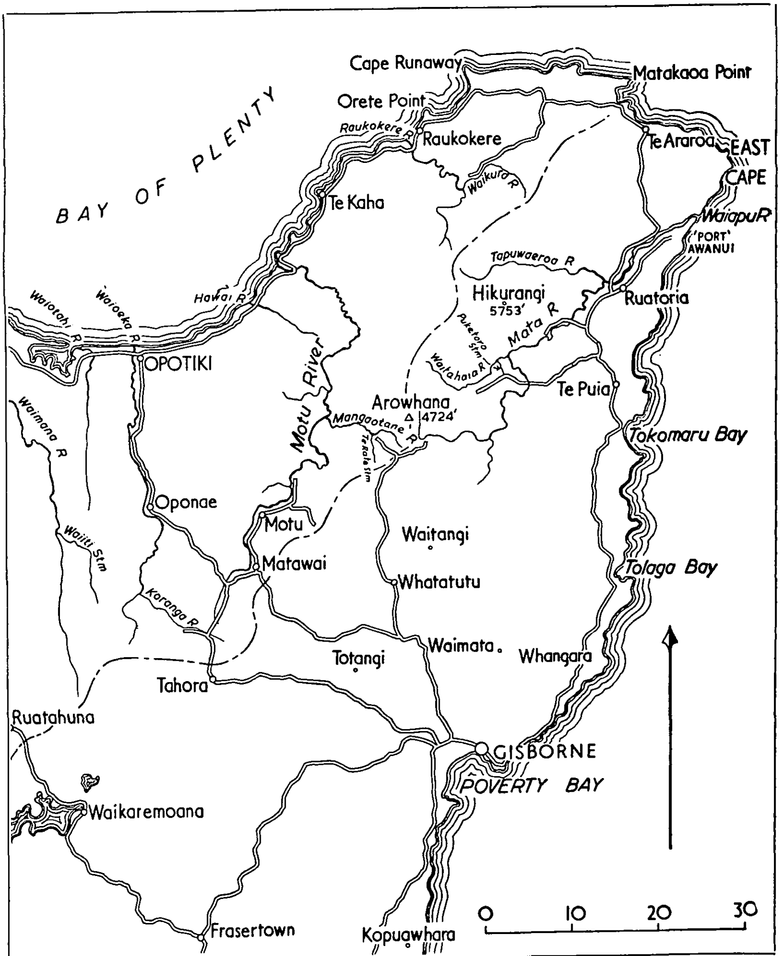

FIG. 2.—Locality map of Raukumara Peninsula showing main towns and important Cretaceous localities. The scale is in miles.

the four Dannevirke stages that overlie—extends from beds that are older than the Wangaloan to beds that are younger. The Wangaloan was considered to be represented by the black shale at the top of the Teurian. The evidence for this correlation is extremely indirect and it seems best to follow Hornibrook and Harrington (1957) and to include the black shale in the Teurian and to abandon the Wangaloan as a stage. The Mata Series is thus considered to extend to the top of the Teurian only.

The Piripauan of Thomson is divided into two stages, the name Piripauan being retained for the lower, which contains most of the fossils described by Woods (1917), and the name Haumurian proposed for the upper.

The Raukumara Series was introduced in a time-stratigraphic sense by Wellman in 1955 for the upper part of the old Clarence Series, the name being taken from the Raukumara Peninsula, where beds of this age are thick and well exposed. The Raukumara Series is Lower and Middle Senonian in age and is divided into three stages—the Teratan, the Mangaotanean, and the Arowhanan. The three stages with their diagnostic fossils are exposed in sequence at many places, but only at Mangaotane Valley is the complete Raukumara sequence known with fossiliferous Piripauan overlying it, and fossiliferous Ngaterian—the upper stage of the Clarence Series—underlying it. The Mangaotane Valley Section is thus chosen as the type locality for the three stages of the Raukumara Series. It is 35 miles north-north-west of Gisborne and about a mile by horse track from Mangaotane Homestead (Figs. 2 and 12).

The Clarence Series was introduced by Finlay and Marwick in 1947 as a more appropriate time-stratigraphic division for the Clarentian Stage of Thomson. Wellman (1955b) restricted it to the lower part of the type Clarentian as defined by Thomson—the part that includes the fossils described by Woods on which the accepted Albian to Cenomanian age had been based.

The Clarence Series is here divided into four stages—Ngaterian, Motuan, Urutawan, and Coverian. No section is known in which all four stages are fossiliferous and exposed in sequence, but the three upper stages and the lowest Raukumara stage are clearly exposed in the Motu Falls section at Raukumara Peninsula (Fig. 14), which is adopted as the type section for the three upper Clarence Stages. The lower part of the Coverham section is made the type for the Coverian Stage.

The base of the Motu Falls section is two miles from Motu Village and 40 miles north-west of Gisborne. It was first mapped geologically by Ongley (1930A) as part of the Wairoa Subdivision, and lies within Ngateretere and Urutawa Survey Districts.

The Taitai Series was proposed by Finlay and Marwick in 1947, and considered to be Aptian in age. The name was based on unfossiliferous sandstone at Tapuwaeroa Valley, near Ruatoria (Fig. 17), and the age on fossils (Marwick 1939) from a somewhat similar sandstone at Koranga, 50 miles north-west of Mt. Taitai and 10 miles south of Matawai on the main road from Gisborne to Opotiki (Fig. 15). In 1956 Wellman (1956b) proposed "Urewera" as a series name for the sandstone at Koranga and for fossiliferous mudstone beneath the Taitai Sandstone. The new name was proposed because the Taitai Sandstone is unfossiliferous and its age uncertain. Dr. Fleming has since drawn the attention of the writer to the first use of "Taitai" by McKay in 1886 for a formation that includes both the fossiliferous mudstone and the sandstone. As the fossiliferous mudstone was originally included it seems advisable to retain Taitai as a series name for Cretaceous rocks of pre-Clarence age. It should be noted, however, that the Taitai Sandstone itself is unfossiliferous, and that the generally accepted correlation with the sandstone at Koranga is based solely on lithology.

Two new stages are introduced within the Taitai Series. The Korangan for the fossiliferous sandstone at Koranga, and the Mokoiwian for the mudstone beneath the Taitai Sandstone. In a table showing the proposed divisions (Wellman, 1956b) the Coverian was wrongly shown as being the upper stage of the Urewera (Taitai) Series. It is actually the lowest of the Clarence Series.

DISTRIBUTION OF CRETACEOUS ROCKS

Outline of Paleogeography

The distribution of the Cretaceous rocks of New Zealand is illustrated by Fig. 1. Outcrops are shown in black. Most have been known for many years (Benson, 1923) and the general distribution is unlikely to be significantly changed. The boundaries of the area of marine geosynclinal deposition are tentative. During the upper Cretaceous and lower Tertiary the sea steadily transgressed west across what is now the eastern side of the South Island and deposited marine sediments on slightly older freshwater beds. Sufficient outliers remain to define the position of the shoreline at the end of the Cretaceous (Wilson, 1955; Wellman, 1956, Fig. 3).

The original limits of Cretaceous sedimentation are not as well known in the North Island. Coal-measures of Eocene age rest directly on pre-Cretaceous greywacke along the north-eastern side of Northland Peninsula, and by analogy with the east coast of the South Island it is assumed that the sea did not transgress this area until after the Cretaceous and that the eastern limit of Cretaceous sedimentation is between the Eocene coal measures and the Cretaceous marine rocks to the west. The western limit of Cretaceous sedimentation in Northland is even more uncertain. The line shown on the map is based on the assumption that the Jurassic rocks of west Auckland extend north-west along their strike and that they continue to be unconformably overlain by lower Tertiary non-marine and marine beds.

The north-western limit of Cretaceous transgression across the east side of the North Island cannot be closely defined, because middle and upper Tertiary erosion has removed any post-Jurassic sediments from the central and southern parts of the main range. A few outliers of upper Cretaceous shelf sediments remain in the northern part of the range. Although the original limit of the sediments is uncertain, the direction and approximate position of Cretaceous land are inferred from facies changes within the marine sediments and from flute-cast directions. The flute casts show the direction in which the turbidity currents flowed (Kuenen, 1957), and it is assumed that the flow was into deeper water from the shelf.

Non-marine Cretaceous sediments are confined to the South Island. They occur as relatively thin deposits conformably below the transgressive marine beds on the east coast, and as relatively thick deposits that unconformably underlie Tertiary coal-measures on both sides of the Island. The thick deposits probably accumulated in isolated basins, and appear to have been derived from nearby areas of high relief.

Important Localities and Sections

Cretaceous rocks cover a large part of Northland Peninsula. At most places they are deeply weathered and poorly exposed. No good sections are known, but scattered fossils show that most of the Cretaceous stages are represented. The structure is complex and not well understood. Haumurian ammonites, which were described by Marshall in 1926, are probably the most important fossils.

Raukumara Peninsula, at the eastern corner of the North Island, is the largest compact Cretaceous area. The structure is relatively complex in the central part but is simpler to the south. Sedimentation was largely geosynclinal, the geosynclinal axis being probably along the present crest of the peninsula. The sediments are remarkably similar to those in Northland (Macpherson 1946), but the two basins of deposition could not have been closely connected and there is no obvious reason for the similarity. The important sections and structure are described later.

The remaining North Island area includes the ranges of the south-east coast from the southern shore of Hawke's Bay to the northern shore of Cook Strait, and is conveniently described as the " East Coast Ranges " (Wellman, 1956a). Outcrops are discontinuous and the structure complex. The sediments probably formed the western side of a geosyncline that extended south-west into what is now the north-east corner of the South Island and north-east along the present east coast of the North Island. Indirect evidence from flute-cast directions and facies changes suggest that the geosyncline did not connect directly with that along the site of the present Raukumara Peninsula but was separated from it by a low ridge that may

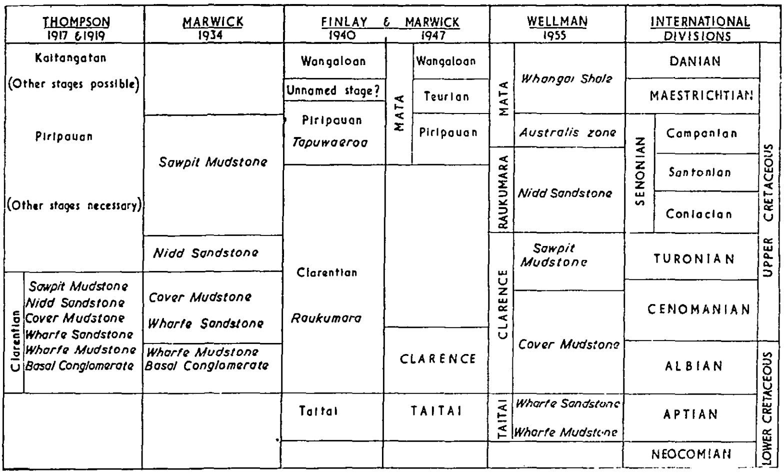

FIG. 3.—Chart of historically successive divisions of the New Zealand Cretaceous arranged to show ages adopted by previous workers. New Zealand formations in Italics, series in capitals. International Divisions according to Muller, S. W. and Schenk, H. G., 1943.

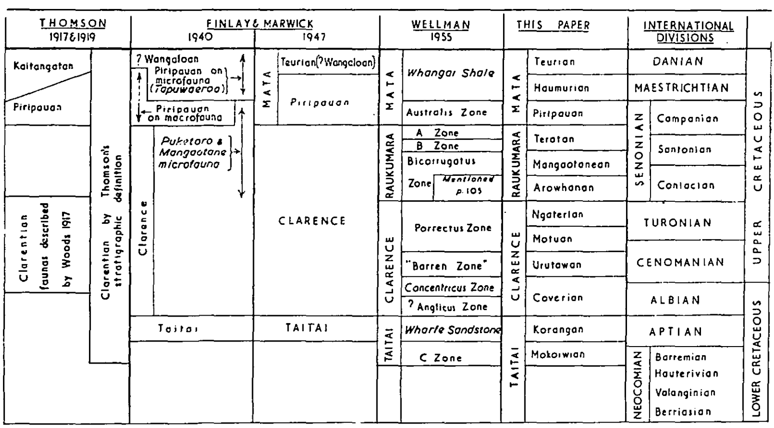

FIG. 4.—Chart as in Fig. 3, but arranged to show ages of successive divisions in the light of present knowledge.

have persisted until the upper Cretaceous. The ridge is now hidden by upper Tertiary sediments. The important sections are described later.

East Marlborough, in the north-east corner of the South Island, was one of the first Cretaceous areas to be studied, but is still not well known. Thick redeposited sediments in the central part pass west and south into marine shelf sediments that overlie fresh-water beds, and thus link the thick geosynclinal sequences of the North Island with the thin South Island sections that were deposited during the upper Cretaceous transgression.

The thin sections of the South Island in north and central Canterbury and eastern Otago were the first to be described in detail. Except for the Piripauan at and near Amuri Bluff, they are entirely Haumurian and Teurian in age, and are overlain by Paleocene marine sediments and underlain by freshwater beds that rest unconformably on considerably older greywacke or schist. The beds are mostly gently dipping and the structure simple.

Important north Canterbury sections are at Amuri Bluff (McKay, 1886, and Thomson, 1917) and Waipara River (Thomson, 1920). The central Canterbury sections lie on the west side of the Canterbury Plains at Malvern Hills (Speight, 1928), nearby in the lowest gorge of the Waimakariri River, and ten miles north-west at the Trelissick Basin inlier (Speight, 1935). Fossils from Selwyn Rapids, in the Malvern Hills, were described by Trechmann in 1917. At the Waimakariri Gorge a bed with abundant *Conchothyra parasitica* and well preserved fish teeth is exposed on the south side of the river. Cretaceous marine beds appear to be confined to the east side of Trelissick Basin and contain the most southerly Cretaceous *Inoceramus* recorded in New Zealand.

The eastern Otago sections are near Hampden (Brown, 1938) a few miles south at Shag Point (Service, 1934) and south-west of Dunedin at Brighton, Barrons Hill, Boulder Hill, and Wangaloa (Ongley, 1939; Finlay and Marwick, 1937 and 1948; Hornibrook and Harrington, 1957). The Canterbury and Otago sections are well known, and with the exception of that at Amuri Bluff, will not be described further.

The Cretaceous freshwater beds include coal-measures of considerable economic importance. Most have been mapped in detail, but until recently their ages have been uncertain. The study of spores and pollens by Couper (1953) has made it possible to correlate the coal-measures and to determine their ages in terms of the marine succession.

The most extensive Cretaceous freshwater deposit is probably that beneath the Haumurian marine beds of Canterbury and Otago. In north Canterbury the freshwater beds are thin and do not contain workable seams. Coalfields that have been mined for many years and are now largely worked out occur in Canterbury at Trelissick Basin (Speight, 1920) and Malvern Hills (Speight, 1928); and in Otago at Shag Point (Brown, 1938) and a few miles south of Dunedin (Ongley, 1939). The most important coalfield at present is near Kaitangata, 40 miles south of Dunedin (Harrington, 1958).

The freshwater beds conformably underlie Haumurian or Wangaloan marine sediments and rest on a peneplain cut across pre-Cretaceous rocks. They are probably all either Piripauan or Haumurian in age. Coal measures of about the same age occur at Ohai, 45 miles north-west of Invercargill, and at Pakawau, in the northern extremity of the South Island (Couper, 1953). The Ohai Coalfield covers a small area but the seams are unusually thick and the field is important. Only the lower of three divisions of the coal measures is certainly Cretaceous. The conformably overlying middle division is probably Dannevirke (basal Tertiary), and the unconformable upper division probably Oligocene (Couper, 1953). The Pakawau Coalfield is of interest because of well preserved leaf impressions that were described by Ettingshausen in 1890 and have not been fully redescribed since.

Important bituminous coal-measures of about Raukumara age cover about ten square miles near Greymouth on the west coast of the South Island. They are about 5,000 feet thick and have been divided into seven formations by Gage (1952). Freshwater beds of about the same age with thin coal seams are known to the south of Koiterangi Hill (Gage and Wellman, 1944), and near Paringa River in South Westland (Wellman, 1955a). Older Cretaceous freshwater beds are more widely distributed but do not contain coal seams of economic importance. They are mentioned later in the discussion of Cretaceous diastrophism.

Raukumara Peninsula

OUTLINE OF STRUCTURE. The main structural features of the Peninsula are shown by the 1: two million geological map of New Zealand (1958). The important localities are shown on a larger scale in Fig. 2. The high ranges behind the Bay of Plenty coast are formed of lower Cretaceous greywacke that constitutes the structural core of the peninsula. Fossils, known only from the mouth of Hawai River, are probably Korangan in age, and are described under that stage.

The most striking tectonic features are the eastward extension of the lower Cretaceous rocks along the Tapuwaeroa Valley to within ten miles of the east coast and their occurrence within the centre of three domes near Te Puia a few miles to the south of the east end of the valley.

The Raukumara Dome, on the north side of Tapuwaeroa Valley, has a core of greywacke of Clarence age flanked by Raukumara, Mata, and Dannevirke sediments and several good sections are exposed by streams radiating from it. The south side of the Raukumara Dome and the Tapuwaeroa Valley are illustrated in Fig. 17, and the structure and key sections are described later.

To the north-west, and separated from the Raukumara Dome by a syncline of middle Tertiary sediments, Cretaceous sections are well exposed on the Bay of Plenty coast at Orete Point and Raukokere Village. The key fossils occur in regular sequence, and although the strata are mainly overturned, the sections appear to be intact and to contain the thickest known Raukumara sequences. A large part of all the stages is formed of bands of redeposited sandstone. The Raukokere section contains 5,000ft of Raukumara sediments. On the west, at the mouth of Raukokere River, Haumurian sediments at the top of the section are faulted against Taitai Sandstone. On the east, Clarence sediments at the base of the section are faulted against Haumurian sediments at the top of the Orete Point Section. Key *Inoceramus* species define the Raukumara stages and the Piripauan, but the Clarence stages and the Haumurian contain few fossils. The facies and thicknesses of the stages are compared with those of the other important sections in Fig. 20. Orete Point Section is similar in attitude and lithology, but only half as thick. Key fossils occur in the Haumurian as well as in the underlying Mata and Raukumara stages.

South of Tapuwaeroa Valley the structure is somewhat simpler, the lower Cretaceous greywacke core being flanked by fairly continuous but strongly folded belts of upper Cretaceous and lower Tertiary sediments. Good sections are exposed at Mangaotane Valley, Motu Falls, and Koranga, and of these the Mangaotane (Fig. 11) is chosen as the type for the three Raukumara Stages, the Motu Falls (Fig. 13) as the type for three of the four Clarence stages, and the Koranga (Fig. 15) as the type for the Korangan Stage. Sections are described later under the individual stages.

As the Raukumara sediments are traced south from Raukokere River they thin and gradually change from siltstone with numerous bands of redeposited sandstone, through massive siltstone, to shelf sandstone. The underlying Clarence sediments show a similar but less extreme change in facies. West of Koranga, shelf sediments of Raukumara and Mata age extend north as a dissected plateau between Waioeka and Waimana rivers. In the Waimana Valley they probably rest unconformably on

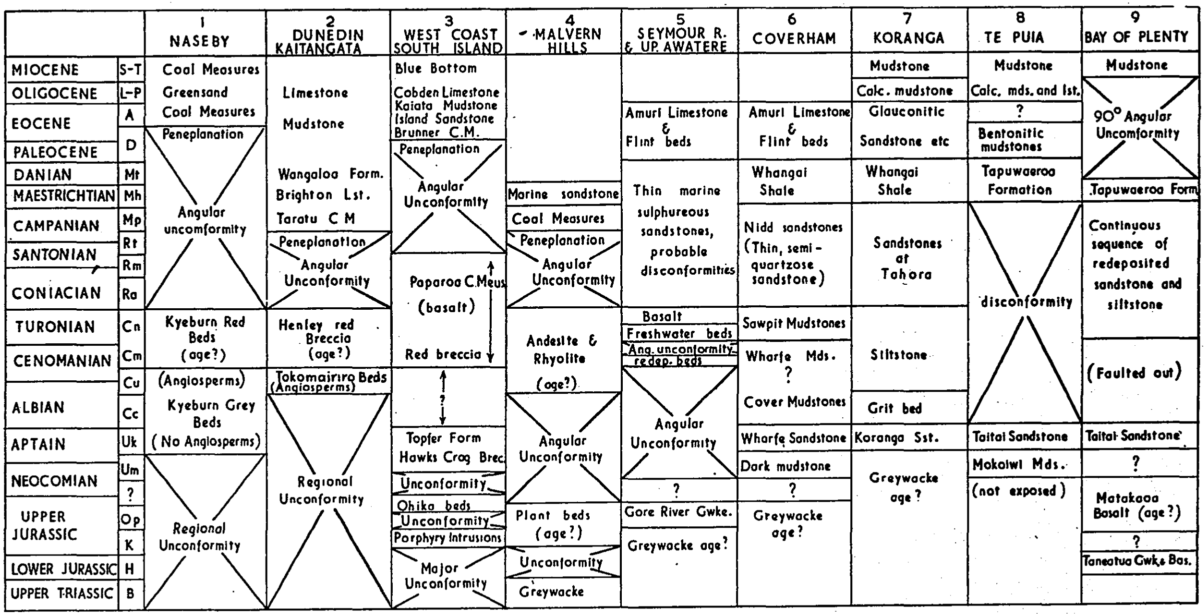

FIG. 5.—Chart showing important Cretaceous unconformities and tentative correlation of freshwater beds.

pre-Cretaceous greywacke, but the contact is not clearly exposed. To the south an unconformity is almost certainly present on the west side of Waikaremoana, fossiliferous Piripauan shelf sediments like those at Amuri Bluff overlying probable Jurassic greywacke at Hook Stream and in the headwaters of Ruatahuna Stream.

The most rapid change in facies is probably south-east from the crest of the Raukumara Range and at right angles to the axis of the Raukumara geosyncline, but the Raukumara belt is too narrow to provide comparative sections in this direction. The Raukumara beds of the Puketoro Stream Section are only 1,000ft thick and contain a smaller proportion of redeposited bands than do the sections at Mangaotane Valley and Lower Mata River (Fig. 2). Poorly fossiliferous Clarence beds, probably of Ngaterian age, lie at the base. They are well exposed at the mouth of the stream in Waitahaia River and contain strongly compacted siltstone with numerous bands of redeposited sandstone. The Arowhanan overlies with an angular unconformity of 30°, the unconformity being well exposed near the mouth of Puketoro Stream. The Arowhanan contains a few bands of redeposited sandstone in its basal part, but the bulk of the stage and the whole of the overlying Mangaotanean and Teratan stages are composed of massive siltstone with large calcareous concretions and a few red bands of uncertain origin. *Inoceramus* is well preserved and defines the three Raukumara stages. The massive siltstone is less compacted than massive siltstone of this age in other parts of the Peninsula, and provided the well preserved Puketoro microfauna described by Finlay (1939). Although mapped as Mangatu Formation (uppermost Cretaceous and lower Tertiary) by Ongley and Macpherson (1928), probably because of its relatively low degree of compaction, the Puketoro Mudstone is clearly Raukumara (lower Senonian) in age, and should have been mapped as Mangaotane Mudstone, this being the name given by those authors to the massive siltstone part of the Raukumara Series of the present writer (Fig. 20). The overlying part of the Puketoro Section is not well exposed.

CRETACEOUS INLIERS. Inliers of Cretaceous sediments and inliers with loose Cretaceous fossils occur at several places south-east of the main Cretaceous mass. The oldest rock exposed in most of the inliers is the Whangai Shale of Haumurian age. Pre-Haumurian sediments are known in stratigraphic order only at the Tahora Dome, four miles south of Koranga. The exposed section is only a few hundred feet thick and extends up from massive siltstone with *Inoceramus rangatira* to a massive sandstone with *I. bicorrugatus* at its base that is overlain by the Whangai Shale. The Teratan and Piripauan stages are probably represented by the unfossiliferous part of the massive sandstone.

Pre-Haumurian macrofossils have been collected from concretionary boulders at several small but complex inliers that are largely composed of lower Tertiary bentonitic mudstones, and are without any definite pre-Haumurian sediments. Deep and extensive slumping makes structural interpretation difficult. Conglomerates containing concretionary pebbles with *Inoceramus* fragments have been found in most of the inliers, and it is probable that the fossiliferous boulders are from these conglomerates. The conglomerates are probably either uppermost Cretaceous or lower Tertiary in age. They represent an important but poorly dated period of erosion that may explain the derived Cretaceous Foraminifera in the Eocene of the east coast of the North Island that puzzled Finlay (1939: 537). Fossiliferous Cretaceous boulders in conglomerates of about the same age are known outside the Raukumara Peninsula near Porangahau in Hawke's Bay (GS 2030), and in Northland (Mason, 1953).

The first known, and most northerly of these fossiliferous boulder localities at Raukumara Peninsula, is at " Port " Awanui, an abandoned shipping point four miles south of the mouth of Waiapu River, and not far from the town of Ruatoria. In 1886 McKay collected *Aucellina euglypha, Inoceramus tawhanus* n.sp., *I.* aff.

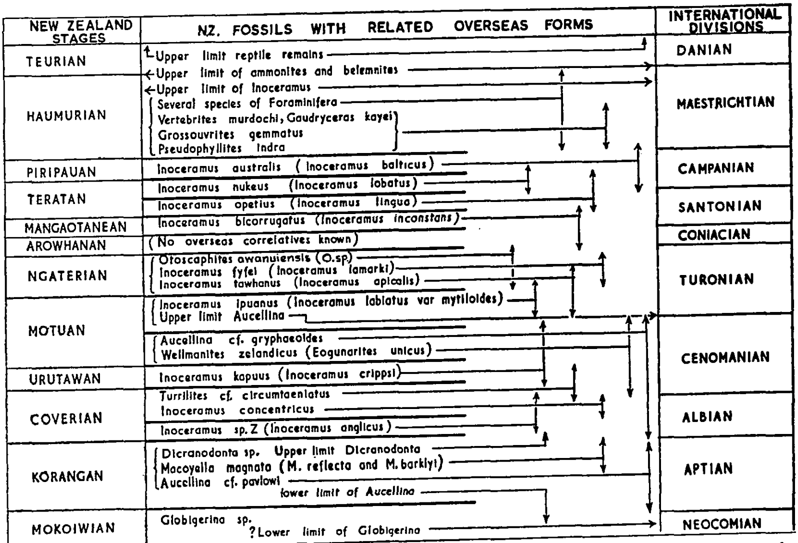

FIG. 6.—Chart showing evidence for dating New Zealand Cretaceous stages. Correlatives of New Zealand fossils shown in parentheses with ranges in terms of International Divisions on right. Adopted correlation of New Zealand stages on left.

bicorrugatus, I. aff. *nukeus*, a few ammonites (Marshall, 1926), and other mollusca. *Inoceramus ipuanus* n.sp., and the diagnostic upper Turonian ammonite *Otoscaphites awanuiensis* (Wright, 1957) are recent finds. The fossils represent the Motuan, Ngaterian, Mangaotanean, and Teratan stages, but beds of these ages are not now exposed, and it is inferred that the fossils were derived from a fairly complete upper Cretaceous sequence during the uppermost Cretaceous or lower Tertiary. The boulders are up to three feet in length, and judging from their lithology were once part of a shallower-water sequence than that in the main Cretaceous mass to the west.

The boulders of the other diapiric inliers contain a smaller range of fossils, and none older than Arowhanan. *Inoceramus bicorrugatus* occurs near Whangara; *I. rangatira* and *I. bicorrugatus* at the head of Waimata River; and *I. matatorus* n.sp. at Kopuawhara Valley near the neck of Mahia Peninsula.

TAPUWAEROA VALLEY (Fig. 17): The widely different interpretations that have been proposed for the stratigraphic succession give particular interest to the geology of Tapuwaeroa Valley. Within the valley, isolated and randomly spaced mountains of Taitai Sandstone rise steeply above more gentle mudstone slopes of the valley bottom, and give the impression of being exotic blocks that are perched on the mudstone. The sandstone is unfossiliferous but looks old, and all geologists who have seen it agree that it is either lower Cretaceous or older. It closely resembles the fossiliferous sandstone at Koranga and may be Korangan in age. The main stratigraphic problem is the age of the mudstone below the Taitai Sandstone. The mudstone was considered by Ongley and Macpherson (1928) to be near the top of a thick continuous south-dipping sequence that extends back into the Raukumara Dome, and to be high in the Cretaceous succession (Fig. 18A). It forms part of their Tapuwaeroa Formation. The Taitai Sandstone overlies the mudstone, but they realized that its appearance is anomalous for such a high position in the Cretaceous. A thrust at the base of the Taitai Sandstone, first proposed in print by Morgan (in Ongley and Macpherson, 1928), seemed to explain the stratigraphic problem and the peculiar topography. The thrust hypothesis was developed by Ongley in 1930, and by Macpherson in 1946.

In 1953 the writer visited Mt Taitai, the lowest and most accessible of the Taitai Sandstone masses. The contact of the sandstone with the underlying mudstone was found to be an unfaulted conformable contact. The stratigraphic problem then lay within the mudstone, and it was found that two mudstones had been confused. They are separated by a major fault along the north side of Tapuwaeroa Valley, which is well exposed near the mouth of Wairongamai Stream (Fig. 17). The mudstone on the north side of the fault includes some bentonitic beds that slump readily and is uppermost Cretaceous and basal Tertiary in age. The mudstone on the south side is a strongly compacted but severely crushed lower Cretaceous sediment that is being rapidly eroded and appears softer and younger than it actually is. It was originally a dark mud with a high organic content. Rapid erosion and conspicuous slumping are common to both mudstones, and the stratigraphic confusion was due largely to the similarity of the topography on each side of the fault.

The name Tapuwaeroa, having been applied to what are now known to be two formations, has to be restricted to one of them. Because of its later use for upper Cretaceous sediments in Hawke's Bay by Lillie in 1953 it is convenient to apply the name to the upper Cretaceous sediments on the north side of the fault, and to use a new name for the lower Cretaceous mudstone on the south side. The name Mokoiwi is proposed, its origin and definition being given later under "Mokoiwian Stage".

The main geological features of the Tapuwaeroa Valley are shown by a sketch map (Fig. 17) based on Ongley and Macpherson's topography, dips, and outcrop observations. Divisions are in terms of the revised stratigraphy. Sketch sections Figs. 18A and 18B contrast the structural interpretations.

Sections in Mangaoporo and Wairongamai rivers on the north side of Tapuwaeroa Valley are substantially continuous and extend from Clarence greywacke in the centre of the Raukumara Dome to basal Tertiary mudstone near the main fault. The Ngaterian, Mangaotanean, Teratan, Piripauan, and Haumurian are represented by their key fossils, but the Arowhanan is unfossiliferous. The stage thicknesses are shown in Fig. 20. The beds dip at 30° to 60° and are interrupted by several minor faults and folds. The streams on the north side of the main fault to the west of Wairongamai Stream have not been followed up beyond the Piripauan.

The structure of the Mokoiwian Mudstone has not been fully interpreted. A steeply-dipping continuous band of pillow basalt and tuff extends along the north side of the valley (Fig. 17). The continuity and regularity of this band indicates that the structure is reasonably simple and suggests that the irregular dips and strikes that have been recorded in the adjoining sediments are due to slumping.

Although the discovery of the fault along the north side of the valley has apparently explained the outstanding problem of the relation of the Taitai Sandstone to the upper Cretaceous sediments, it is difficult to understand why the sandstone should be exposed as isolated masses and not as a continuous band like the pillow basalt. The sandstone is an unusually massive formation, bedding being indicated only where lenses of conglomerate are present. There is no obvious direct evidence for its mode of deposition, but the conformably underlying Mokoiwian Mudstone contains bands of redeposited sandstone that become more abundant in the upper part of the valley. It is suggested that the Taitai Sandstone is also a redeposited sediment, and that instead of the sand forming a continuous sheet as it would have if it had been deposited slowly on normal siltstone, the redeposited sand sank into the dark, organic, and doubtless soft mud that is now compacted into the Mokoiwi Mudstone, to accumulate as discontinuous lenses. Differential erosion would expose the sandstone lenses as isolated perched masses. A well exposed contact in the upper reaches of Tapuwaeroa River shows the mudstone to be strongly contorted, and to have been squeezed and displaced by the sandstone.

Mt Hikurangi, the highest non-volcanic mountain in the North Island, lies on the south side of Tapuwaeroa Valley. It is composed of dark sandstone, somewhat better bedded but otherwise similar to the Taitai Sandstone of the mountains within the valley. The structure is different and instead of being surrounded by the older Mokoiwi Mudstone it is surrounded by younger sediments of Clarence age, and is thus anticlinal and not synclinal in structure. A narrow infaulted strip of bentonitic lower Tertiary mudstone separates the Clarence beds on the north flank of Mt Hikurangi from the lower Cretaceous sediments of the Tapuwaeroa Valley.

The most accessible of the well exposed fossiliferous Raukumara sections lies to the south of Tapuwaeroa Valley in the lower reaches of Mata River. The section, on the west side of a small and irregular Raukumara dome, is almost continuously exposed in the bed of Mata River. The Haumurian, the Piripauan, and the three Raukumara stages are represented by their key macrofossils (Fig. 17). Although the structure of the dome itself is well known, the relation of the dome to the surrounding area is unresolved; it is a good example of the unusual tectonics of many parts of the Raukumara Peninsula. The first problem encountered is that of the domal form of the structures themselves. The domes range from two to twenty miles in diameter and have no well defined structural axes. They thus differ from almost all other New Zealand structures, with the exception of the Tangihua Basalt domes of western Northland. Interpretation in terms of directed horizontal stresses is difficult, and the obvious explanation of underlying intrusive masses is unlikely. That they were caused by two periods of folding at right angles is also unlikely because of their regularity.

The other problem is that of the fault contacts at the margins of the domes. At many contacts the uppermost Cretaceous or basal Tertiary is faulted against the lower Cretaceous, and it is difficult to understand why beds of these particular ages are more often brought into fault contact than others. Related problems are the apparently diapiric inliers of Taitai Sandstone that form small isolated hills at several places to the south-east of the lower Cretaceous core of the main range, and the absence of Raukumara and Clarence sediments from the Cretaceous domes near Te Puia (Macpherson, 1945). The nature of the last problem is illustrated in Fig. 17. The most southerly area of Mokoiwi Mudstone comprises the northern part of one of the Te Puia domes. It would be natural to map a fault between the lower Cretaceous mudstone and the adjoining Haumurian in the southern part of the dome where the Raukumara and Clarence beds are absent, but the contact when traced south has all the appearance of being a major disconformity and not a fault.

Several of the problems related to the Haumurian may be explained by events during that time. Strong faulting followed by erosion and transgression would explain several of the anomalous stratigraphic relations. Direct evidence for Haumurian deformation is provided by conglomerates of that age that extend over much of the Raukumara Peninsula and are particularly thick and coarse where the Raukumara and Clarence beds are absent.

East Coast Ranges of North Island

STRUCTURE AND PREVIOUS ACCOUNTS. Cretaceous rocks cover large areas in the coastal ranges of the eastern part of Hawke's Bay and Wellington land districts, and their general distribution is shown on the 1: two million geological map of New Zealand (1958). The district is less mountainous than the Cretaceous part of the

Raukumara Peninsula, and the Cretaceous rocks are less well exposed. The structure is complex and the sections less continuous than those in the Raukumara Peninsula, but the strikes are fairly uniformly north-east, and the domal structures of the peninsula are absent. All the Cretaceous stages are probably represented, but no diagnostic Korangan or Urutawan fossils are known.

The latest detailed account, by Lillie (1953), covers the Dannevirke Subdivision in the southern part of the Hawke's Bay Land District. The Ekatahuna Subdivision, to the south of the Dannevirke Subdivision, has been briefly described and illustrated by a small-scale map by Ongley (1934). The remainder of the eastern part of the Wellington Land District, which is commonly referred to as the Wairarapa, has not been recently described in detail.

The Whangai Shale and the Taitai Sandstone cover the largest areas, but the other Cretaceous rocks are more fossiliferous and varied and will be described more fully.

WAIMARAMA TO RED ISLAND. The most northerly section within the East Coast Ranges is from Waimarama, 10 miles south of Cape Kidnappers, south along the coast to the conspicuous basalt promontory of Red Island. The Piripauan and the three Raukumara stages are represented by their key fossils, but the section is disturbed by slumping and the stage thicknesses are uncertain. The Raukumara sediments contain bands of redeposited sandstone that are most abundant in the Mangaotanean and Teratan. The most conspicuous redeposited band is a layer of fossiliferous grit that contains *I. bicorrugatus* and several other poorly preserved mollusca that have not been fully described. The Teratan contains well preserved *I. opetius* and provides the type for that species. At the top of the section the Whangai Shale is overlain by lower Tertiary mudstone. The bottom of the section is probably faulted against the basalt of Red Island. The age of the basalt is uncertain, but it contains a band of tuffaceous limestone with *Inoceramus* prisms and an *Aucellina*-like pelecypod and is unlikely to be younger than Motuan and is more probably either upper Jurassic or lower Cretaceous and about the same age as the Matakaoa Basalt of Raukumara Peninsula and the Tangihua Basalt of Northland.

DANNEVIRKE SUBDIVISION. The Cretaceous rocks were grouped by Lillie (1953) into the Raukumara, Tapuwaeroa, and Whangai formations. Fossils from the Raukumara Series as now defined are known from the fossiliferous boulders near Porangahau (GS 2030) that have already been mentioned, and from coastal sections in Pourerere Survey District that are the southern continuation of these at Waimarama. As at Waimarama, the Raukumara sediments are overlain by Piripauan Sandstone with *Inoceramus australis* and *I. pacificus* (Fleming and Marwick in Lillie, 1953: 129, footnote). All the other sediments mapped by Lillie as Raukumara Formation are probably Clarence in age.

One of the most interesting Cretaceous sections is that well inland at the Waikopiro High four miles east of Ormondville on the east coast railway (Lillie, 1953: 27). At the top massive siltstone with *Inoceramus ipuanus* lies unconformably below Miocene sandstone. The age is Motuan, but the sediments are only slightly compacted and resemble Tertiary mudstone, with which they seem to have been confused (Lillie, 1953: 27, footnote). Underlying mudstones and sandstones contain *Aucellina* sp. and a few other undescribed mollusca and pass down into dark compacted sandstone (greywacke) that is probably lower Cretaceous in age.

To the south-east several fairly good sections are exposed in the cores of Whangai-flanked anticlines at Mangaotoro and Porangahau survey districts. At Tangaruhe and Mangangarara streams grey calcareous mudstone with large calcareous concretions contain *Inoceramus tawhanus* and *I.* aff. *striatus* Woods and is Ngaterian in age. The mudstone closely resembles the Sawpit Mudstone and contains similar foraminifera (Hornibrook, in Wellman, 1955: 111). The mudstone is unconformably overlain by Haumurian sediments that were mapped by

STAGE	SYMBOL	TYPE LOCALITY	SHEET DISTRICT	NAMED FROM	LITHOLOGY OR FORMATION AT TYPE LOCALITY	STRATIGRAPHIC POSITION	
						BEDS ABOVE	BEDS BELOW
Teurian	Mt	Te Uri Stream	N150	Te Uri Stream	Upper part Whangai Shale	Black Shale then type Waipawan	Haumurian
Haumurian	Mh	Haumuri Bluff (=Amuri Bluff)	S56	Haumuri Bluff	Sulphur Sand & Black Grit	Teredo Limestone (unfossiliferous)	Type Piripauan
Piripauan	Mp	Haumuri Bluff (=Piripaua)	S56	Piripaua	Concretionary Sandstone	Type Haumurian	Jurassic ? greywacke
Teratan	Rt	Mangaotane Valley	N79	Te Rata Stream	Upper part of Mangaotane Mudstone	Piripauan	Type Mangaotanean
Mangaotanean	Rm	Mangaotane Valley	N79	Mangaotane River	Middle part of Mangaotane Mudstone	Type Teratan	Type Arowhanan
Arowhanan	Ra	Mangaotane Valley	N79	Arowhana S.D.	Lower part Mangaotane Mudstone and lower beds	Type Mangaotanean	Ngaterian
Ngaterian	Cn	Motu Falls Section	N88	Ngateretere S.D.	Siltstone with bands of redeposited sandstone	Arowhanan	Type Motuan
Motuan	Cm	Motu Falls Section	N88	Motu River	Siltstone with bands of redeposited sandstone	Type Ngaterian	Type Urutawan
Urutawan	Cu	Motu Falls Section	N88	Urutawa S.D.	Siltstone with bands of redeposited sandstone	Type Motuan	Alternating beds, then unfossiliferous sst. probably Korangan
Coverian	Cc	Cover Stream, Coverham	S35	Cover Stream	Dark mudstone with concretionary bands	Unfossiliferous, possibly Urutawan	Wharfe Sandstone
Korangan	Uk	Koranga Section	N88	Koranga S.D	Massive sandstone with bands of conglomerate	Possibly Coverian	Unfossiliferous greywacke
Mokoiwian	Um	Tapuwaeroa Valley	N71	Mokoiwi Stream	Dark mudstone with bands of redeposited sandstone	Taitai Sandstone = Korangan?	Unfossiliferous greywacke

FIG. 7.—Chart showing locality and stratigraphic position of Cretaceous type sections, and origin of name of stages.

	INTERNATIONAL DIVISIONS		NZ Series	NZ Stage & Symbol	INOCERAMUS	AMMONITES	OTHER FOSSILS
UPPER CRETACEOUS	DANIAN		MATA	TEURIAN Mt	None	None	Defined by foraminifera
UPPER CRETACEOUS	MAESTRICHTIAN		MATA	HAUMURIAN* Mh	matatorus	Vertebrites murdochi Diplomoceras cf. cylindraceum Maorites cumshewaensis etc.	Lahillia Ostrea lapillicola Conchothyra parasitica
UPPER CRETACEOUS	CAMPANIAN	SENONIAN	MATA	PIRIPAUAN Mp	australis pacificus	Kossmaticeras haumuriensis Baculites cf. vagina	Trigonia pseudocaudata Trigonia hanetiana
UPPER CRETACEOUS	SANTONIAN	SENONIAN	RAUKUMARA	TERATAN* Rt	nukeus opetius	Gaudryceras sp.	
UPPER CRETACEOUS	SANTONIAN / CONIACIAN	SENONIAN	RAUKUMARA	MANGAOTANEAN* Rm	bicorrugatus		Not yet described
UPPER CRETACEOUS	CONIACIAN	SENONIAN	RAUKUMARA	AROWHANAN* Ra	rangatira		Trigonia meridiana Trigonia glyptica
UPPER CRETACEOUS	TURONIAN		CLARENCE	NGATERIAN* Cn	fyfei tawhanus = porrectus hakarius	Gaudryceras subsacya Hyphantoceras cf. reussianum Otoscaphites awanuiensis	Trigonia meridiana
UPPER CRETACEOUS	CENOMANIAN		CLARENCE	MOTUAN* Cm	ipuanus urius	Puzosia sp. Pachydesmoceras Wellmanites zelandicus	Aucellina sp. Aucellina euglypha Aucellina cf. gryphaeoides
UPPER CRETACEOUS	CENOMANIAN		CLARENCE	URUTAWAN* Cu	kapuus		
LOWER CRETACEOUS	ALBIAN		CLARENCE	COVERIAN* Cc	concentricus sp.Z	Turrilites circumtaeniatus ? Myloceras sp.	? Aucellina cf. gryphaeoides
LOWER CRETACEOUS	APTIAN		TAITAI	KORANGAN* Uk	(fragments only)		Macoyella magnata Aucellina aff. pavlowi Dicranodonta sp. Aucellina cf. aptiensis
LOWER CRETACEOUS	NEOCOMIAN		TAITAI	MOKOIWIAN* Um	warakius		

FIG. 8.—Chart showing New Zealand Cretaceous series, stages, mapping symbols, and important fossils. New stages marked by an asterisk.

Lillie as Tapuwaeroa Formation but which do not closely resemble the redeposited Tapuwaeroa beds of the type locality.

The sections at Mangawarawara and Mangawhero streams have cores of dark sandstone that is probably lower Cretaceous or older. The poorly exposed overlying sediments may not be older than Haumurian.

EKETAHUNA SUBDIVISION. Ongley (1933) described the section at Mataikona River, ten miles north of Tinui Village, as being the most complete in the Eketahuna Subdivision, but it is faulted and disappointing. At the headwaters of the river at the west end of the section massive dark sandstone that is probably Taitai in age is faulted against Haumurian sediments with *Ostrea lapillicola* that pass east in the middle reaches of the stream into Raukumara mudstone with *Inoceramus opetius* and *I. bicorrugatus*.. No Piripauan fossils are known. *Inoceramus bicorrugatus* also occurs in coastal cliffs two miles north of the mouth of the river within a redeposited sandstone and siltstone sequence and still farther to the north in boulders in a tributary of Aohanga River. *I. warakius* occurs in compacted dark siltstone about five miles from the mouth of Aohanga River but no clear sections connect with the *I. bicorrugatus* localities.

The best sections in the Eketahuna Subdivision are probably those near Tinui Village. At Makirikiri Stream five miles north of Tinui an apparently unfaulted section extends up from dark compact lower Cretaceous sandstone through redeposited Motuan sediments with *Aucellina* sp. and *Inoceramus ipuanus* and dark Ngaterian mudstone with *I. fyfei* to Arowhanan massive siltstone with *I. rangatira*. The Clarence part of this section is about 3,000ft thick. A few miles south the two upper Raukumara stages and the Piripauan are represented by fossiliferous sediments. Five miles west of Tinui ammonites that have recently been described by Wright (1957) are not uncommon within concretions of Motuan age. At Bushgrove Stream the ammonite beds are overlain by redeposited beds with *I. ipuanus* and overlie poorly exposed sandstone and siltstone that pass down into Taitai Sandstone. At Gentle Annie Stream the ammonites together with *Aucellina* cf. *euglypha*, *Inoceramus* aff. *urius* and saurian remains were collected from a 6ft concretionary boulder about 300ft downstream from a waterfall in the headwaters of the stream.

SOUTHERN WAIRARAPA. Igneous rocks of the Cretaceous age have been described by Hutton (1943) from the Ngahape district 20 miles south of Tinui village. They consist of a circular intrusive mass of teschenite within Taitai Sandstone, a sill of olivine dolerite within upper Cretaceous redeposited beds, and variolitic pillow lavas at the top of the redeposited beds. According to Hutton the igneous rocks, being chemically similar, were derived from a single magma and probably emplaced at the same time. The stratigraphy was described and illustrated by a sketch map by Brown in 1943. The best section, in Kaiwhata Stream to the east of Ngahape Settlement, was re-examined in 1952. *Inoceramus pacificus* was collected from massive sandstone a mile and a quarter from the mouth of the stream and indicates a Piripauan age for the sandstone. The overlying redeposited beds dip downstream fairly regularly at about 30° and are probably largely Haumurian in age. They continue to near the mouth of the stream and contain the dolerite sill described. The conglomerate contains boulders of well-sorted sandstone with *Megatrigonia* (*Iotrigonia*) *glyptica* that have probably been derived from shelf sandstone of Arowhanan age. Brown (1943: 350) reported *Inoceramus bicorrugatus* from black mudstone interbedded with the conglomerates. The fossil has been re-examined but is not well enough preserved to be specifically identified. The redeposited beds continue to near the mouth of the stream and contain the dolerite sill described by Hutton. The variolitic pillow lavas at the top of the redeposited beds are overlain by pink argillite (Brown, 1943: 351) that is probably the Whangai Shale. The lavas are probably Haumurian in age, and according to the evidence presented by Hutton the intrusive rocks are of this age also.

To the south the most important localities are those with lower Cretaceous fossils. *Inoceramus warakius* occurs in the headwaters and near the mouth of Pahau River in dark mudstone similar to the Mokoiwian of the type locality. According to Dr. J. B. Waterhouse (pers. comm.) the Mokoiwian mudstone is overlain by some 4,000ft of coarse sandstone with lenses of igneous conglomerate which from its appearance and stratigraphic position is probably Korangan in age. Above that comes compacted dark siltstone with an indeterminate species of *Myloceras* that is most probably Albian (pers. comm., Mr. C. W. Wright).

North-East Marlborough

STRUCTURE AND PREVIOUS ACCOUNTS. The Cretaceous sediments of north-east Marlborough that had accumulated at the south-east end of the east coast geosyncline were strongly deformed during the later Tertiary. The greater part was uplifted and eroded away (Cotton, 1913). The part that remains is preserved in the complex fault-angle depressions of the Awatere and Clarence valleys, and in small outliers to the south and east. Thick continuous sections that are largely of redeposited sediments are assumed to mark the axial part of the geosyncline. They outcrop in the extreme north-east end of the lower Clarence Valley and in the nearby valley of Kekerengu River (Macpherson, 1951; Wellman, 1955). To the west, south-west, and south the upper Cretaceous sediments thin, and unconformities appear that cut out the whole or parts of the middle and lower Cretaceous (Suggate, 1958).

The Awatere Valley was described by McKay in 1886. It has not been described since, and a short account of the stratigraphy is given later. The Clarence Valley, first described by McKay, was described in greater detail by Thomson in 1919 when he set up the Coverham section as the type for the New Zealand middle Cretaceous. The Coverham section was revised by Wellman in 1955, and although now known to be strongly deformed it is still one of the most complete fossiliferous sections. Cretaceous sections in the mid-Clarence Valley have recently been described by Suggate (1958).

The outliers to the south have not previously been described. At Wharekiri Stream near the mouth of Clarence River thick redeposited Motuan beds with *Inoceramus* cf. *urius, Aucellina* cf. *euglypha* and a few other molluscs pass down into unfossiliferous greywacke of probable lower Cretaceous age, and are overlain by thin Raukumara and probably by Piripauan sandstone. Haumurian beds were not seen.

At Moririmu Stream near the coast five miles south of Clarence River fossiliferous Motuan beds are in fault contact with greywacke of probable Jurassic age and are overlain by Ngaterian mudstone and by 50ft of Raukumara Sandstone with *Inoceramus rangatira* and *I. bicorrugatus.* Thin Piripauan sandstone with *I. pacificus* overlies and passes up into Sulphur Sands of probable Haumurian age. Amuri Limestone and Flint Beds form the top of the section.

At Towy River, between the inland Kaikoura Road and the Seaward Kaikoura Range the Motuan is again the lower fossiliferous Cretaceous stage, and passes down without obvious unconformity into unfossiliferous greywacke. Sandstone with *Megatrigonia glyptica* of probable Arowhanan age occur higher in the stream (Finlay and Marwick, 1948) but the contact with the Motuan was not seen.

Two other outcrops deserve mention. At Haupuka River, seven miles north of Kaikoura Town, Arowhanan sandstone contains abundant and well preserved fragments of *Inoceramus rangatira* and fairly complete *Belemnites superstes.* The contacts with the Whangai Shale above and the unfossiliferous greywacke below appear to be faulted.

AWATERE VALLEY. The following generalized section is based on exposures in the middle Awatere Valley between Glenlee Homestead and Penk River.

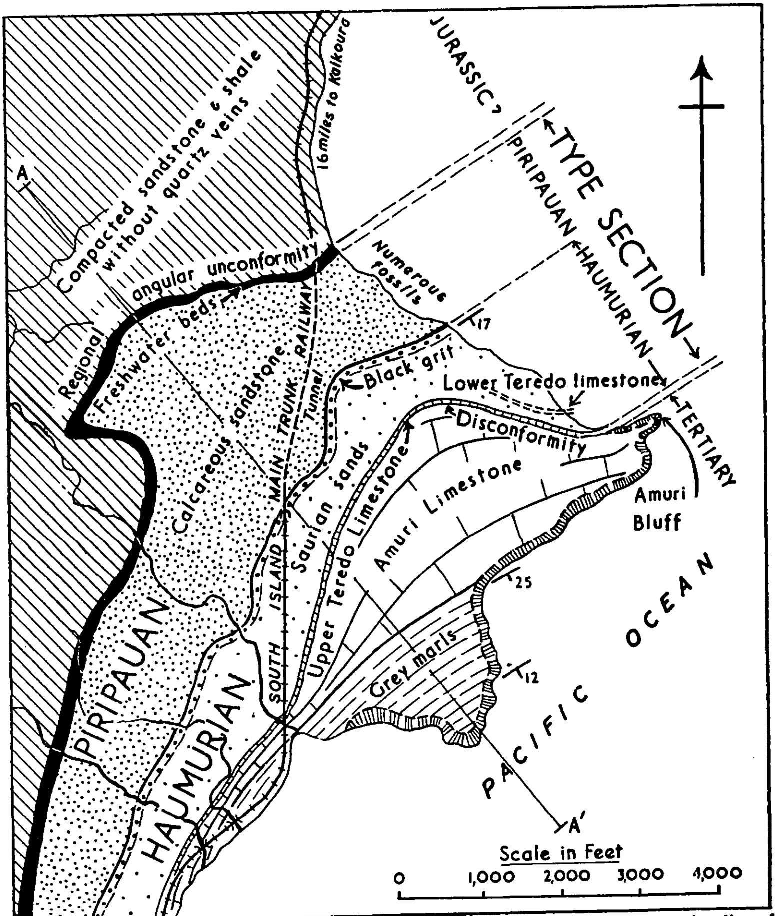

FIG. 9.—Sketch map from air photographs of the Amuri Bluff Section, the type locality of the Haumurian and Piripauan stages.

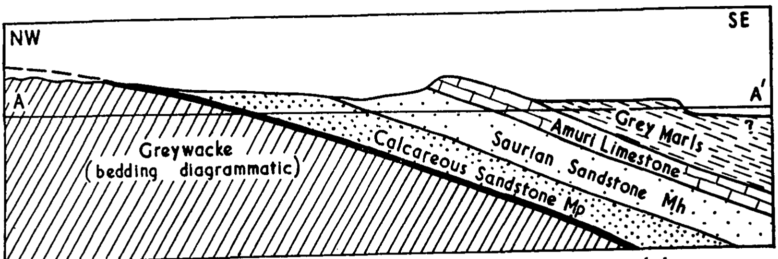

FIG. 10.—Sketch cross section through the Amuri Bluff Section. Stage symbols as on map (Fig. 9). Length of section about 10,000ft. Horizontal and vertical scales are the same.

GENERALIZED SECTION, MIDDLE AWATERE RIVER

	Feet, Approx.
DANNEVIRKE SERIES (Basal Tertiary)	
1. Soft flaky green-grey calcareous bentonitic mudstone (Dm)	20
2. Limestone, hard, green-grey, well bedded (Amuri Lst.)	15
3. Siltstone, dark and sulphureous	30
4. Flint, well bedded (age uncertain)	30
MATA SERIES (CRETACEOUS)	
5. Siltstone, dark and sulphureous, Haumurian foraminifera	40
6. Glauconitic hard sandstone (age uncertain)	50
RAUKUMARA SERIES	
7. Siltstone with calcareous concretions with *I.* aff. *opetius*	5
CLARENCE SERIES (NGATERIAN AND MOTUAN)	
8. Siltstone, concretions with *I. tawhanus*	300
9. Basalt and tuff with interbedded flows and agglomerates (GS. 741)	500
10. Redeposited sandstone and siltstone with *Aucellina* sp.	500
11. As above with *I. ipuanus*	1,500
12. Muddy conglomerate with *I.* cf. *urius* and ammonite	500
AGE UNCERTAIN	
13. Greywacke, more strongly compacted and contorted than beds above	3,000+

Steep dips and closely spaced faults make it difficult to interpret the stratigraphy. Amuri limestone, flint beds, and underlying Haumurian siltstone are confined to a narrow infaulted strip that extends north-east for four miles from the Awatere Bridge at Glenlee to Clyde River. The best section is on the north bank of Awatere River half a mile downstream from the bridge. Foraminiferal samples show the bentonitic mudstone at the top of of the limestone to be Mangaorapan and the sulphureous siltstone to be probably Haumurian in age (pers. comm., Mr. N. de B. Hornibrook). The top and bottom of the section are faulted; the top against fossiliferous tuffs, and the bottom against greywacke. Glauconitic hard sandstone appears to underlie the Haumurian siltstone on the track from Ribble River to Clyde River, but it is not well exposed and its stratigraphic position is uncertain. Concretionary siltstone with *Inoceramus* aff. *opetius* and a small variety of *I. tawhanus* is poorly exposed in Ribble River below the Haumurian siltstone in fault contact with greywacke, and probably represents a condensed Raukumara and upper Ngaterian section. Similar concretionary siltstone with the same small variety of *I. tawhanus* is better exposed in Bolton River, 500ft downstream from the Awatere Fault, and appears to pass down comformably into fossiliferous basaltic tuffs.

The fossiliferous tuffs are best exposed on the Awatere Road at Limestone Creek, a quarter of a mile downstream from the Glenlee Bridge. The tuffs contain a moderately well preserved fauna (GS 741) that has been described by Woods (1917), includes *I. tawhanus,* and is thus Ngaterian in age. Basalt underlies the tuffs and is faulted against greywacke. The Cretaceous beds that are cut out by the fault at Limestone Creek appear a mile north-east and continue for seven miles near the line of Awatere River to just beyond Penk River. They are almost vertical and at places slightly overturned, but well developed graded bedding and flute casts show that they become younger towards the basalt.

The upper beds at the mouth of Clyde River consist of redeposited sandstone with abundant *Aucellina* sp. Redeposited sandstone below, interpedded with siltstone with *I. ipuanus,* is exposed in Awatere River near the mouths of Cam and Clyde rivers. A peculiar muddy conglomerate underlies and extends for the whole length of the belt. It also crops out in Winterton River, in the upper valley of Awatere River. *Aucellina* sp. and a *Puzosia* similar to that described by Wright (1957: 807) from Motuan beds at Bushgrove Stream have been collected from the mouth of Isis Stream, and *I.* aff. *urius* and *Aucellina* sp. from Winterton River. The sediments below the basalt are thus Motuan in age, and are the oldest fossiliferous beds exposed. The contact between the Motuan and the underlying unfossiliferous sediments is of considerable stratigraphic importance and is described later.

Basalt is the youngest rock exposed in the upper Awatere Valley. It directly overlies a few feet of freshwater beds that pass down into 50ft of shelf sandstone and conglomerate. Motuan concretionary siltstone with ***Aucellina euglypha*** underlie and rest uncomformably on unfossiliferous greywacke at George River (McKay, 1886 and pers. comm. Mr. B. Webby).

MIDDLE CLARENCE VALLEY. The following extremely generalized section is based on descriptions by Thomson (1919) and Suggate (1958). It matches closely that already given of the middle Awatere River, except that the upper divisions are considerably thicker.

GENERALIZED SECTION, MIDDLE CLARENCE VALLEY

	Feet.
DANNEVIRKE SERIES (BASAL TERTIARY)	
Lower part of Amuri Limestone	200
Flint beds (age uncertain)	100
MATA SERIES (CRETACEOUS)	
Greensands and glauconitic sandstone (age uncertain)	300
Siltstone, dark and sulphureous (Haumurian)	600
Bentonitic sandstone and fine conglomerate (age uncertain)	150
RAUKUMARA SERIES	
Concretionary green sandstone. *Inoceramus rangatira,* etc.	100
CLARENCE SERIES, NGATERIAN STAGE	
Basalt flows and agglomerates, interbedded sandstone. Up to	1,200
Sandstone with pebble bands and concretions with *Inoceramus fyfei* and *I. tawhanus.* Angular unconformity at base. Up to	500
CLARENCE SERIES, MOTUAN STAGE	
Redeposited sandstone and siltstone with *Aucellina* sp. and *Inoceramus ipuanus.* Angular unconformity at base	300
AGE UNCERTAIN	
Greywacke and argillite. At least	3,000

As in the Awatere Valley the sediments immediately below the basalt change from marine to non-marine as they are traced south-west. The line marking the old shoreline strikes north from the Clarence to the Awatere Valley and defines the west side of the Cretaceous geosyncline.

FACIES, FOSSILS, AGE, AND CLIMATE

Facies of Sediments

The marine Cretaceous beds of New Zealand include a wide range of sediments that can be divided into shelf, transitional, and redeposited facies groups. The beds of shelf facies were deposited in relatively shallow water and at many places pass down into freshwater beds. They contain siltstones, sandstones, grits and conglomerates that are usually well sorted. Abundant and varied molluscan faunas such as those at Selwyn Rapids (Haumurian), Amuri Bluff (Piripauan), Seymour River (Arowhanan), Limestone Creek (Ngaterian), and possibly Koranga River (probably Coverian) are from shelf sediments. On the other hand fossils of all kinds are rare in some well sorted shelf sandstones of the Haumurian and Piripauan. Foraminifera are extremely rare in all the shelf sediments with abundant and varied mollusca. Until the facies-tolerant *Inoceramus* were studied, this made it difficult to correlate the macrofaunas of the shelf sediments with the microfaunas of the transitional and redeposited sediments.

The beds of the redeposited facies are considered to have been deposited in deep water. Layers of graded-bedded and poorly sorted sandstone, from one to ten feet thick, are interbedded with siltstone. The sandstones are considered to have been transported from the shelf by turbidity currents (Kuenen, 1957) and the siltstones to have been deposited directly. Layers of conglomerate within the redeposited facies are thought to have been deposited either by turbidity currents or by submarine landslides (Crowell, 1957). The redeposited sediments are mostly extremely thick and strongly compacted. They are represented by the Tapuwaeroa Beds of Haumurian age, by thick Piripauan to Arowhanan sequences in the northern part of the Raukumara Peninsula and along the south-east coast of the North Island, by Ngaterian and Motuan beds at the type locality and at many other places on the east coast of the North Island and at a few places in Marlborough, by the Urutawan beds at the type locality, by the Wharfe Sandstone at Coverham, and by the Mokoiwian at all known localities. Broken plant fragments are abundant in many of the sandstone bands. *Inoceramus* and *Aucellina* are the only abundant macrofossils. Layers of complete *Inoceramus* shells are not uncommon at the top of the siltstone bands, but only fragments occur in most of the sandstones. *Aucellina* is less widely distributed and most commonly occurs closely packed in calcareous concretions within the siltstone bands, or in the redeposited bands of sandstone. Other macrofossils include rare belemnites in the Wharfe Sandstone, rare starfish and brittle stars in the basal Motuan of the Motu Falls Section, and rare solitary corals at several places. The foraminiferal faunas are small in number and species and usually poorly preserved.

All other marine sediments are considered to belong to the transitional facies, and to have been deposited in moderately deep water between the shelf facies and the redeposited facies. Typical representatives are massive mudstones and siltstones usually with large concretions, such as the Whangai Shale (Haumurian), the Mangaotane Mudstone (all stages of the Raukumara Series), the Sawpit Mudstone and the mudstone at Tangaruhe Stream (Ngaterian), and the Cover and Wharfe mudstones of Coverham (Albian to Cenomanian). *Inoceramus* is the most widely distributed macrofossil, and is usually better preserved in sediments of the transitional than in those of the redeposited facies. Other macrofossils are rare corals. The sediments of the transitional facies contain the largest and best preserved foraminiferal faunas. Macrofossils are best preserved in concretions which are not uncommon.

Key Fossils

Inoceramus occurs in shelf, transitional, and redepoisted sediments. It is the only macrofossil found at most places, and is the most valuable guide to the division of the New Zealand Cretaceous. All the eighteen species recognized have short ranges (Fig. 8). Only three endemic species have been previously described, and three are overseas forms. The remaining species are described in an appendix to this paper.

Almost all the New Zealand ammonites have been collected from loose concretions. They are extremely rare except at a few localities in western Northland (Marshall, 1926 and Mason, 1953) and at Bushgrove and Gentle Annie streams near Tinui, 70 miles north-east of Wellington City. Most of the non-endemic species from Western Northland were revised by Spath in 1953. They are considered to be Haumurian or slightly older, and together with the other Haumurian ammonites are listed under that stage. Several ammonites found during the last few years and a few from older collections have recently been described by Wright (1957).

The following list includes all New Zealand species except those from western Northland. Numbers prefixed by CE refer to the Geological Survey Cephalopod Register.

HAUMURIAN

CE 979	*Diplomoceras* cf. *cylindraceum* (Defrance in d'Orbigny)
CE 794	*Maorites mckayi* (Hector)
CE 985–7	*Kitchinites* ? sp.
	Grossouvrites gemmatus (Huppe)
CE 1077	*Grossouvrites* sp.
	Gunnarites zelandicus Marshall
CE 980	*Gaudryceras* sp.
CE 826–7	Kossmaticerid
	Diplomoceras sp.

	PIRIPAUAN
CE 890, 1021	*Kossmaticeras haumuriensis* (Hector)
CE 1139	? Pachydiscidae
CE 886	*Gaudryceras* sp. aff. *jukesi* (Whiteaves)
CE 888–9	*Hamites* (*Anisoceras* ?) sp.
CE 887, 1134	*Baculites* sp. cf. *vagina* Forbes
	TERATAN
CE 1064	*Gaudryceras* sp.
	NGATERIAN
CE 1379, 1380	*Otoscaphites awanuiensis* Wright
CE 885	*Gaudryceras subsacya* Marshall
CE 1695	*Mariella* aff. *cenomanensis* (Schlüter)
	MOTUAN
CE 105	? *Puzosia* sp.
CE 977	*Puzosia* (s. str.) sp.
	Gaudrycerid
CE 1065–7, 1069–1072, 1074	*Wellmanites zelandicus Wright*
CE 1068, 1073	*Phyllopachyceras* sp.
CE 868	*Pachydesmoceras* ? sp.
CE 1076	*Pachydesmoceras* sp.
CE 1141	? Puzosiinae
CE 1073	*Anagaudryceras* sp.
	COVERIAN
CE 919–21	*Turrilites circumtaeniatus* (Kossmat) (*Mariella* sp., according to C. W. Wright, pers. comm.)
	CLARENCE SERIES (stage uncertain)
CE 101	? *Myloceras* sp.
CE 102	Puzosiinae gen. et. sp. indet.
CE 1062	*Pseudoxybeloceras* sp. aff. *quadrinodosum* (Jimbo)
CE 1063	*Hyphantoceras* cf. *reussianum* (d'Orbigny)

No ammonites are known from the Teurian, Mangaotanean, Arowhanan, Urutawan, Korangan, or Mokoiwian stages.

Overseas Correlation

Correlation with the overseas Cretaceous divisions is based on relatively few species, of which about half are sufficiently abundant to be used as key species within New Zealand. That the correlation is far from exact can be seen from Fig. 6, in which the overlapping ranges of all the useful correlatives of the New Zealand species are shown.

The *Teurian* passes down gradationally at many places into the Haumurian. Its Foraminifera lack the Maestrichtian key species but are otherwise similar to those in the Haumurian (Hornibrook, 1958). A Danian age is probable.

The *Haumurian* is Maestrichtian and is more certainly correlated than most of the other stages. Its top marks the upper limit of ammonites and belemites and can be correlated with the top of the Maestrichtian. The upper limit of *Inoceramus* is slightly lower both in New Zealand and overseas (Seitz, 1956). The presence of some key Maestrichtian Foraminifera in the Haumurian has already been mentioned. The ammonites from Northland described by Marshall in 1926 and recently commented on by Spath (1953) and Matsumotu (1955) are either upper Campanian or lower Maestrichtian, and contain some key lower Maestrichtian forms. They probably all come from about the same horizon (Mason, 1953), but being from conglomerates, some may be significantly older than the beds in which they are found.

The *Piripauan* is best correlated with the middle and upper Campanian. The correlation depends largely on the resemblance of *I. australis* Woods with *I. balticus* J. Böhm, a widely distributed form that is limited to the Campanian in Germany

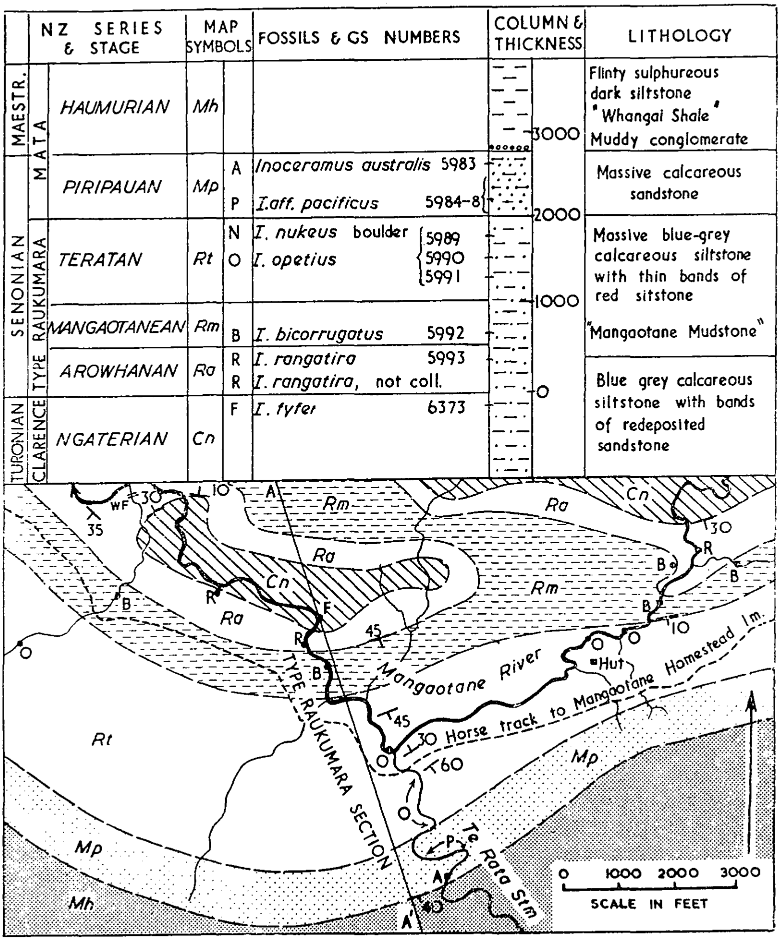

FIG. 11.—Sketch map from air photographs of the Mangaotane Valley section, the type locality for the Teratan, Mangaotanean, and Arowhanan stages. Column shows lithology and approximate thickness of stages. *Inoceramus nukeus* was found in a boulder in Te Rata Stream about 300ft below the base of the Piripauan.

(Seitz, 1956). The ammonites and other molluscs from Amuri Bluff were described by Woods (1917) as being upper Senonian (probably Campanian and Maestrichtian in terms of the divisions used in this paper). The ammonites need re-examination in the light of the new stratigraphic information .

The *Teratan* contains two related key species in sequence, *Inoceramus nukeus* occurring regularly above *I. opetius*. *I. opetius* resembles *I. lingua* Goldfuss, a form shown by Seitz (1956) to range from upper Santonian to lower Campanian. *I. nukeus* resembles *I. lobatus* Goldfuss, which according to Woods (1912) ranges up into the Campanian in England. The age is thus probably upper Santonian to lower Campanian. The single ammonite from the Teratan—*Gaudryceras* sp.—is related to forms that range from Turonian to Campanian (Wright, 1957: 806).

The *Mangaotanean* cannot be closely correlated. The key species, *I. bicorrugatus*, is not close to any known overseas form but has a general resemblance in adult ornament and in sudden change of form during growth to some members of the large species-complex described under *I. inconstans* Woods (1912) that range from Coniacian to middle Santonian. The juvenile part of the shell is similar to a British Museum specimen (BM L87635) identified as *I. inconstans* Woods from the lower Coniacian of England. The underlying Arowhanan stage being post-Turonian probably represents part of the Coniacian and the most probable age for the Mangaotanean is upper Coniacian to lower Santonian. No diagnostic ammonites are known from this stage.

The *Arowhanan* is without any good overseas fossil correlatives, and its age is inferred as lower Coniacian from its stratigraphic position. The writer's previous correlation of *I. rangatira* (*I.* sp. R of Wellman, 1956) with *I. undulato-plicatus* Roemer of the lower Santonian was based on illustrations. Comparison of actual specimens has made this correlation unlikely. A possible correlation on description and illustration only is with *I. guerichi* Heinz (1928) from the top of the lower Emscher (mid-Coniacian) of Germany. No ammonites are known from the Arowhanan.

The *Ngaterian* is fairly certainly middle to upper Turonian in age, the three key *Inoceramus* species that occur together being members of the *I. lamarcki* Parkinson species complex that is known in beds of this age at several places overseas. *I. fyfei* has the characteristic irregular growth lamella of *I. lamarcki* shown by Seitz as being mid-Turonian and by Woods (1912) as ranging from Turonian to Coniacian. *I. tawhanus*, considered a variety of *I. concentricus* by Woods in 1917, appears to be closer to *I. lamarcki* var. *apicalis* (Woods, 1912) which ranges through

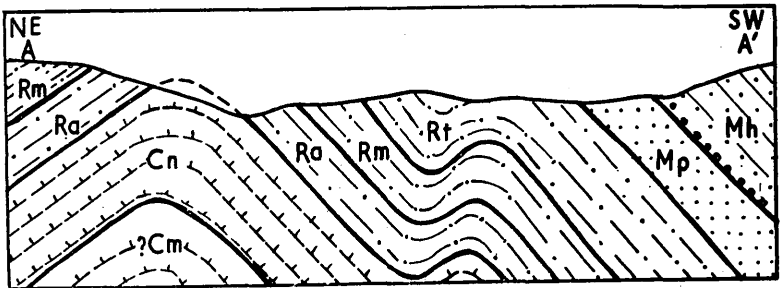

FIG. 12.—Sketch cross-section through the Mangaotane Valley section. Stage symbols as on map. Length of section about 8,000ft. Horizontal and vertical scales are the same.

the Turonian of England, to *I. coulthardi* and *I. selwyni* of the upper Turonian of Canada (McLearn, 1926), and to *I. concentricus costatus* N. & M. and *I. teshioensis* N. & M. of the Turonian of Japan (Nagao and Matumotu, 1939). *I. hakarius* is similar to specimens of *I. lamarcki* from the middle Turonian of England (Woods, 1912) and to *I. corpulentis* McLearn, 1956 from the upper Turonian of Canada. A definite age is given by the ammonite *Otoscaphites awanuiensis* Wright found with *I. tawhanus* in a boulder at " Port " Awanui. According to Wright (1957) the age is " undoubtedly Upper Turonian ". An anomalous Cenomanian or upper Albian age is indicated by *Mariella* aff. *cenomanensis* found in dark mudstone near Matawai 200ft below *Inoceramus fyfei* and *I. hakarius.*

The *Motuan* is probably upper Cenomanian to lower Turonian. The top of the Motuan is the upper limit for *Aucellina,* a genus not known above Cenomanian outside New Zealand. On the other hand *Inoceramus ipuanus* closely resembles *I. labiatus* var. *mytiloides* Mantell in shape, but has better defined and more regular ribs. *I. labiatus* being a widely distributed lower Turonian key species, it seems likely that the upper part of the Motuan is lower Turonian. Some small forms of *I. urius*—the lower of the two Motuan key species—closely resemble unnamed species (BM L31220 and Sedgwick Museum B50800) from the Cenomanian of England. Three ammonites described by Wright (1957) from the Motuan, are useful for overseas correlation:

Puzosia sp.	Upper Albian to Cenomanian
Pachydesmoceras sp.	Upper Albian to at least upper Turonian
Wellmanites zelandicus Wright (cf. *Eogunarites unicus*)	Upper Albian to Cenomanian

The range is consistent with, but somewhat wider than, that suggested by the *Inoceramus* species.

The *Urutawan* is probably lower Cenomanian. The age is determined from its position below the Motuan and by the affinity of the key species *Inoceramus kapuus* with *I. crippsi* Mantell given by Seitz (1956) and by Woods (1912) as being Cenomanian.

The *Coverian* fossils were the first from the New Zealand Cretaceous to be closely dated, *Inoceramus concentricus* and *Turrilites circumtaeniatus* from the beds that now form the type Coverian being considered Albian to Cenomanian by Woods in 1917. *Inoceramus* sp. Z from immediately below *I. concentricus* is possibly related to *I. anglicus* Woods, and is evidence for an Albian age for the lower part. It should be noted that the Coverian fossils have not been found in the Motu Falls section or the Motuan key fossil in the Coverham section and that the stratigraphic relation of the Motuan and Coverian is consequently uncertain. The extremely low proportion of angiosperm pollens to spores in microfaunal preparations from the Coverian (Couper in Wellman, 1955: 108) indicates that angiosperms are very scarce and suggests that the Coverian is pre-Cenomanian and considerably older than the Ngaterian of the Mid-Clarence Valley in which angiosperm leaves and pollens are relatively abundant (McQueen, 1957).

The *Korangan* is definitely pre-Motuan and probably pre-Coverian at the type locality. A lithologic correlative of the Korangan is pre-Urutawan in the Motu Falls section. An Aptian age indicated by *Maccoyella magnata* (Marwick, 1939) is supported by *Aucellina* aff. *pavlowi* and by the overlap of the ranges of *Aucellina* and *Dicranodonta.* Only non-diagnostic fragments of *Inoceramus* and ammonites are known.

The *Mokoiwian* is probably either lower Aptian or upper Neocomian, but the age is not well known. No overseas correlative is known for the key species *Inoceramus warakius,* which occurs in the Coverham section immediately below the Wharfe Sandstone and about 1,000ft stratigraphically below the base of the Coverian, and is almost certainly pre-Albian. A possible lower limit for the Mokoiwian is set by *Globigerina,* described in a manuscript report by Finlay as being found at the type locality and not known with certainty overseas before the upper Neocomian (Glaessner, 1945: 203). The Mokoiwian underlies a lithologic correlative of the Korangan, but nowhere are the two stages in sequence and fossiliferous, and overlap is possible. No ammonites are known.

Climate

There is nothing to suggest that the climate in New Zealand during the Cretaceous was either tropical or cold. That it was temperate is based on negative rather than

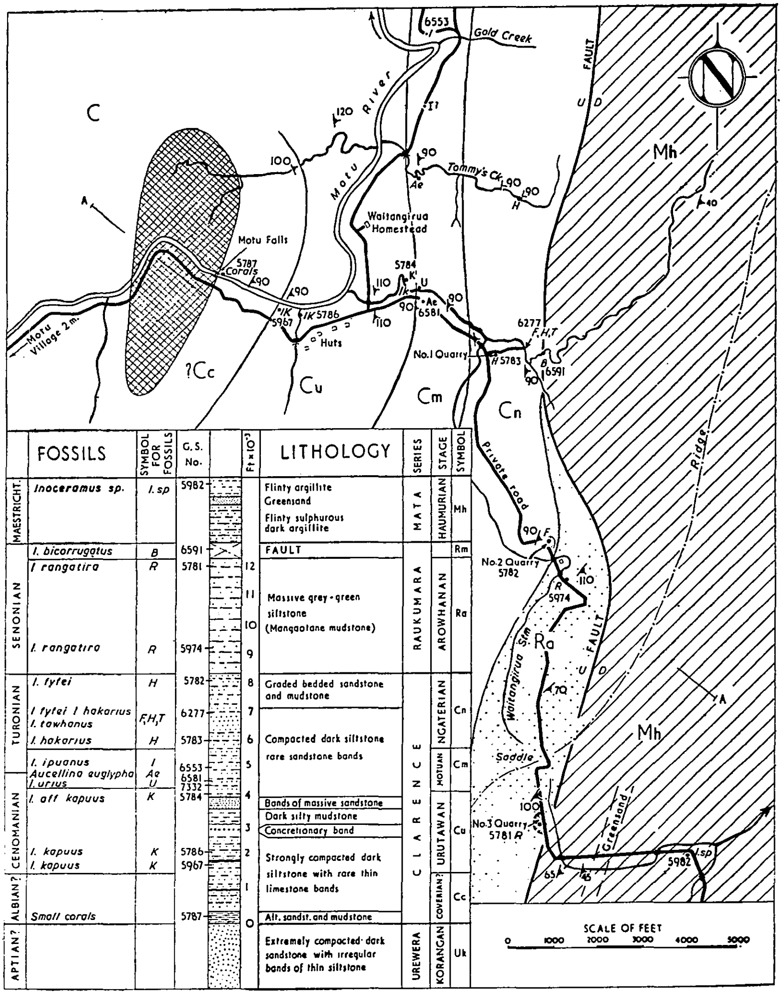

FIG. 13.—Sketch map of Motu Falls section, the type locality of the Ngaterian, Motuan and Urutawan stages. Column shows lithology and approximate thickness of stages. Arrows are shown on strike symbols where direction of younging has been determined from outcrops, and point towards younger beds. Angles greater than 90° indicate overturned beds.

In the Series column Urewera should be replaced by Taitai and refers to the cross-hatched oval area to the north-west.

positive evidence. Rudistids, reef corals (Squires, 1958), large Foraminifera, and other tropical forms are absent, but beds of the shelf facies in which they would be likely to occur are not represented in the middle and lower Cretaceous of the northern part of New Zealand. On the other hand the climate is unlikely to have been much cooler than at present, at least for parts of the Cretaceous, as saurian bones occur in the Motuan (Cenomanian) of the North Island and are relatively abundant in the shelf facies of the Haumurian (Maestrichtian) in the South Island.

The Cretaceous floras provide little climatic information. Cycads are known from the Coverian and Ngaterian (McQueen, 1956), and Araucarias with well defined annual rings in sub-Piripauan freshwater beds (Stopes, 1914). The plants are from the South Island and the climate may have been slightly warmer then than it is now.

The non-marine beds of the west coast of the South Island present more problems than they solve. The red colour of the conspicuous breccias of the lower and middle Cretaceous has often been discussed but never satisfactorily explained (see Gage, 1952). It is probably a climatic indicator. The rock fragments are fresh and the red colour cannot be due to tropical or sub-tropical lateritic weathering. They have been superficially oxidised, and are red only where carbonaceous material that acts as a reducing agent is absent. Surface conditions would favour oxidisation only if plant cover was scanty or absent. This could have been caused either by cold or

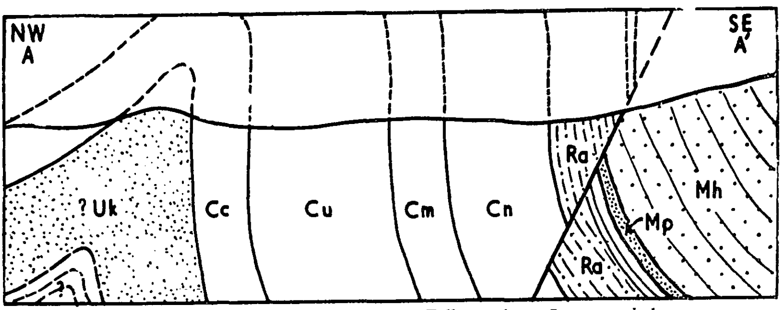

Fig. 14.—Sketch cross-section through the Motu Falls section. Stage symbols as on map. Length of section about 18,000ft. Horizontal and vertical scales are the same.

by aridity, perhaps only seasonal. In the absence of evidence for cold conditions aridity would seem to be the more likely cause, but independent evidence is required. No glacial beds are known in the New Zealand Cretaceous.

The virtual absence of limestone except in the Teurian (Danian) is a peculiar feature of the New Zealand Cretaceous. Limestones do occur, but they are either only a few inches thick and composed entirely of *Inoceramus* fragments, as in the Motuan, or so impure as to be better described as calcareous sandstone or mudstone. Limestones are known from the cold as well as from warm stages of the New Zealand Tertiary and Pleistocene, and their absence from the Cretaceous may not be due to climatic factors.

DIASTROPHISM, SEDIMENTATION, AND IGNEOUS ACTIVITY

Cretaceous Diastrophism

In 1950 the writer presented a chart showing important Cretaceous sections set out to show the evidence for dating the unconformity that was considered to separate the Cretaceous from earlier rocks. The marine and non-marine Cretaceous sections are better known than they were in 1950, and the evidence for dating unconformities within and at the base of the Cretaceous can now be reviewed with advantage. Nine sections are shown on Fig. 5. Two are from Otago, one from the west coast of the South Island, one from Canterbury, two from Marlborough, and three from Raukumara Peninsula. The sections include those shown in 1950, together with additional ones from the North Island.

The first, from Naseby, is based on Harrington's stratigraphic revision (1955). The Kyeburn beds are the important strata. The incoming of angiosperms within the apparently continuous sequence of "grey beds" suggest that they span the Coverian and range from upper Taitai to lower Clarence in age. The Kyeburn beds are separated from the overlying Hogburn Coal-measures (Arnold or Landon in age) by an angular unconformity and a period of peneplanation; and from the underlying greywacke, of possible Triassic age, by a well defined angular unconformity. Two definite unconformities are represented in this section.

The second, a composite section, is based on sections between Dunedin and Kaitangata as described by Harrington in 1955 and by Hornibrook and Harrington in 1957. The Tokomariro beds contain angiosperms and pass up into red breccia similar to that in the upper part of the Kyeburn beds. They are separated from overlying Haumurian or Piripauan coal measures by a major unconformity (Ongley, 1939) and together with the red Henley Breccia, can be correlated with the upper part of the Kyeburn beds and placed in the Clarence Series. Again there are two unconformities; the lower of the same age as that at Naseby, the upper restricted to the Raukumara series.

The third section, also composite, is based on the three important South Island west-coast sections, at Greymouth, Reefton, and the lower Buller Gorge. It is more complete than those described. The Paparoa Coal-measures, assumed to be lower Cretaceous for many years (Gage, 1952; Wellman, 1950) are now reasonably well dated (McQueen, 1956, and Couper, in Wellman, 1955: 108). They are significantly older than the sub-Haumurian coal-measures of Canterbury and Otago, somewhat younger than the Ngaterian freshwater beds of the mid-Clarence and upper Awatere Valleys, and considerably younger than the Coverian. They have been divided into seven formations (Gage, 1952) and probably represent at least two marine Cretaceous stages, and are here considered to be lower Raukumara (lower Senonian) in age. The red breccia at the base of the Paparoa coal-measures has not been dated, but as it underlies them conformably it is probably upper Clarence in age. In 1950 the writer considered that the red breccias of the west coast, being distinctive and similar, were about the same age as the Hawk's Crag breccia. It now appears (Couper, in Suggate, 1957) that the breccia at Reefton and probably the type Hawk's Crag breccia of the lower Buller Gorge are considerably older than the breccia at the base of the Paparoa Beds. The Reefton breccia is without angiosperms and is overlain by freshwater sandstone and siltstone—the Topfer Formation—that are also without angiosperms, but they contain several spores known only from Coverian (Albian) and younger beds. The Ohika Beds underlie the type Hawks Crag breccia, and from their macro- and microfloras are either basal Cretaceous or more probably upper Jurassic in age (Couper and Walkom in Wellman, 1950). The sequence from Ohika Beds to Topfer formation is evidently pre-Coverian and is considered to represent the Taitai Series and to extend down into the Jurassic. The west-coast non-marine Cretaceous sequence thus appears to extend from the top of the Jurassic well up into the Raukumara Series, with a possible break in the lower Clarence. It is separated by an angular unconformity and a period of peneplanation from the pre-Bortonian Brunner coal-measures and by a major unconformity from the probably pre-Cambrian undermass. There are two or possibly three unconformities, the upper in the Mata Series corresponds to the upper in the two sections already described, a possible middle one between the Paparoa breccia and the Topfer Formation that must be about

Clarence in age, and the lower one that represents the lower part of the Mesozoic and the whole of the Paleozoic.

The Malvern Hills section (No. 4) has not been recently studied but remains important, in spite of poor dating, because of its three unconformities. The upper separates sub-Haumurian coal measures from andesitic and rhyolitic volcanics of possibly upper Clarence age. The middle unconformity separates the volcanics from plant-bearing beds that have been considered Rhaetic by Arber (1917), but may well be Jurassic, and the lower—inferred from differences in dip and compaction—the plant beds from marine greywacke of upper Triassic age. The presence of carbonaceous layers in the basalt (Speight, 1928) gives a possibility of dating the volcanics. The upper unconformity is not well dated but corresponds with the upper ones in the previous sections and like them was terminated by a period of peneplanation.

The remaining sections contain pre-Mata marine Cretaceous beds that are dated by marine faunas. The first of these (No. 5) based on mid-Clarence (Suggate, 1958) and upper Awatere sections, is a link between the predominately non-marine and the entirely marine sequences. The upper part of the section is thin and probably interrupted by disconformities. The basalt is well dated as Ngaterian, and the conformably underlying freshwater beds are probably not significantly older. Leaf impressions were described by McQueen in 1956 and considered to be slightly older than those in the Paparoa beds.

At Seymour Stream, in the mid-Clarence Valley, the Ngaterian freshwater beds rest with angular unconformity on redeposited sediments of Motuan age, this particular angular unconformity having little time value and being absent elsewhere. In Seymour Stream and upper Awatere the Motuan rests with angular unconformity on greywacke of uncertain age, but away from the shelf region a few miles north-east in the middle Awatere and lower Clarence valleys it passes down into greywacke without obvious angular unconformity.

The Coverham Section (No. 6) in the lower Clarence Valley, has recently been described (Wellman, 1955) and needs brief mention only. It is substantially continuous down to the dark mudstone below the Wharfe Sandstone and represents all except the basal part of the Cretaceous. The significance of the "basal" conglomerate described by Thomson (1917) as marking the base of his "Notocene" will be discussed later. Meanwhile it is important to note that Fleming (1958) has described a fauna from greywacke of Gore River in the Middle Clarence Valley that is high in the Jurassic. Greywacke overlying the fossils may well be basal Cretaceous in age (Suggate, 1958) and only slightly older than the dark mudstone of the Coverham section. Although one is described as a greywacke and the other as mudstone the sediments actually differ as little in appearance as they do in age and in any other part of the sequence it would be natural to expect a gradational contact, but so far a passage has not been proved between the Jurassic and Cretaceous in New Zealand.

The Koranga Section (No. 7) is also substantially continuous, and not very different from that at Coverham. The Te Puia Section (No. 8) shows a surprising disconformity that cuts out the whole of the Clarence and Raukumara Series. The Bay of Plenty Section (No. 9) based on sections at Cape Runaway, Raukokere, and to the south-west also includes a major unconformity, but the missing stages, in the uppermost Cretaceous and Lower Tertiary, are those present at Te Puia, whereas those missing at Te Puia are mostly present at Raukokere. The lower part of the Bay of Plenty section is built up from discontinuous sequences that are lithologically similar but have not yet been found in sequence. The age of the Matakoa Basalt is uncertain, and it may be mid-Jurassic and considerably older than shown.

No widespread unconformity can be proved within the Cretaceous. The possibility of one at the base of the Cretaceous will be discussed later. The unconformities within the non-marine basins of the southern and western parts of the South Island do not extend into the Cretaceous geosynclines of Marlborough and Raukumara Peninsula. The "mid-Cretaceous" orogeny of Wellman (1950) although well enough defined in the non-marine basins as the upper unconformity in the first four sections, and the only one to be followed by a period of peneplanation, cannot be recognized in Marlborough, except perhaps as a period of slow deposition. The erosion interval at the base of the Haumurian in the Te Puia Section is probably slightly younger.

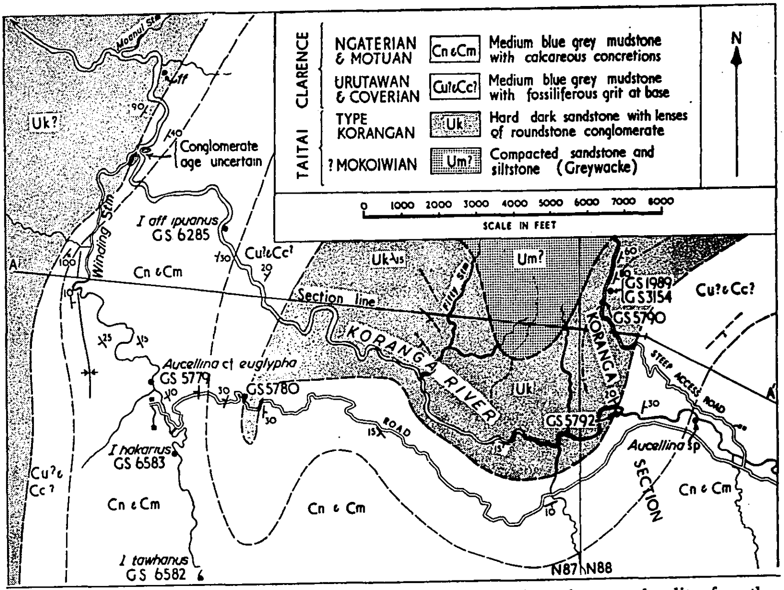

FIG. 15.—Sketch map from air photos of the Koranga section, the type locality for the Korangan Stage. Arrows are shown on strike symbols where direction of younging has been determined from outcrops, and point towards younger beds. Angles greater than 90° indicate overturned beds.

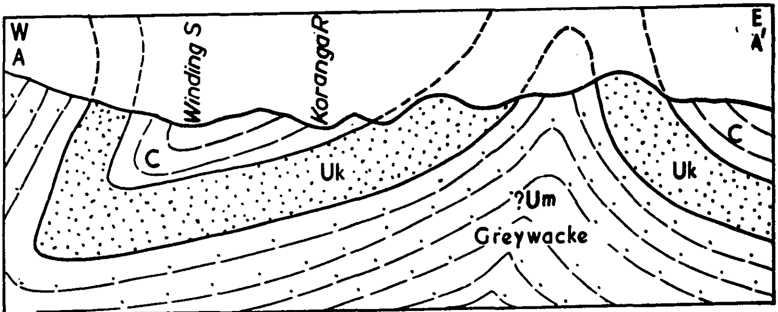

FIG. 16.—Sketch cross-section through the Koranga section. Stage symbols as on map. Length of section about 21,000ft. Horizontal and vertical scales are the same.

Nature and Rate of Deposition of Sediments

Although no New Zealand-wide unconformity can be established, a changing tempo of diastrophism is evident from the lithological variation and changing rate of deposition of the non-marine and marine sediments. The average rate of deposition is different in different districts, but in general it increases towards the north-west (Fig. 20). Within each district the rate of deposition, if it is assumed that the stage divisions are of roughly equal value, shows a gradual decrease from the lower to the upper Cretaceous. The change in the rate of deposition is paralleled by a change in the lithology of the sediments themselves. The non-marine sediments of Taitai and Clarence age are coarse and little weathered and were derived from nearby areas of high relief (Gage, 1952). The non-marine Mata sediments are highly quartzose (Suggate, 1951) and suggest that chemical weathering was playing an increasing part in the erosion cycle. The Paparoa Beds of Raukumara age are intermediate in lithology and in age and show an upward gradation from slightly quartzose to moderately quartzose sediments (Gage, 1952).

A similar lithological change is shown by the marine sediments. Taitai sediments are almost everywhere redeposited and are not very different from the older greywackes. The Clarence is largely redeposited, and the Raukumara and Mata sediments redeposited only in the areas of most rapid sedimentation. The quartzose non-marine sediments have their counterpart in the quartzose Sulphur Sands and in the finer grained Whangai Shale of the Haumurian. The bentonitic beds in the uppermost Cretaceous and Paleocene may be the products of deep chemical weathering on land at that time.

A possible temporary renewal of tectonic activity in the late Cretaceous is recorded by the Tapuwaeroa grits and conglomerates in the lower Tapuwaeroa Valley. A conglomerate at the base of the Whangai Shale at Te Rata Stream (Fig. 11) and the Black Grit of the same age at Amuri Bluff may represent the same minor orogenic phase.

With the exception of the minor diastrophic phase during the Haumurian the sediments indicate that diastrophic activity progressively decreased during the Cretaceous to reach its lowest level of activity during the period of peneplanation at the end of the Cretaceous. This gradual decrease may have been interrupted by minor bursts of activity like that recorded by the Haumurian conglomerates, but at present they cannot be established as being New Zealand-wide, and neither can it be established that the unconformities known from the South Island are recorded by conglomerates in the more continuous sequences of the North Island and Marlborough.

Relation Between Cretaceous and Jurassic Sediments

Thomson (1919: 312) described a conglomerate from a tributary of Wharfe Stream at Coverham and considered it to mark the post-Hokonui Orogeny, the major erosion interval that separates Cretaceous or post-Cretaceous rocks from pre-Cretaceous rocks in many parts of New Zealand.

Similar conglomerates occur at several places in Marlborough and at a few places in the Raukumara Peninsula, the best known being either at or somewhat below the lowest Cretaceous fossils. The two most accessible well-exposed conglomerates are at Marlborough—on the Awatere Road, half a mile east of Cam River and near the mouth of Penck River on the opposite side of Awatere River two miles downstream. The conglomerates are a poorly sorted mixture of well rounded and sub-rounded pebbles and boulders of greywacke and chert set in a silty matrix. The largest boulders are up to 10 feet through. Derived concretions are common and some are fossiliferous, the fossils being similar to those in the directly overlying beds. There is no indication of angular unconformity at the bases of the conglomerates. Similar conglomerate bands of about the same age are known from the north bank of Clarence River between Dart River and Ravine Stream and from Kekerengu River (Wellman, 1955: 110). All the conglomerates are interbedded with graded-bedded sediments which show flute casts at the base of the sandstone bands and which are almost certainly redeposited. Similar muddy conglomerates have recently been described by Crowell (1957), who considered that they were deposited either by mud flows or by turbidity currents and that they are not indicative of unconformities at the places where deposited.

It cannot be assumed that because the post-Hokonui Orogeny is well defined in some parts of New Zealand that it will extend over the whole. If Thomson's conglomerate is merely a redeposited band, other evidence has to be found to prove the orogeny at Coverham. This evidence is difficult to find, both at Coverham and in the other areas of rapid lower-Cretaceous deposition.

Many thousand feet of redeposited sandstone and siltstone that have been compacted to greywacke and argillite underlie the lowest fossiliferous Cretaceous rocks at Raukumara Peninsula, East Coast Ranges, and east Marlborough. Jurassic fossils have been found in similar greywackes and argillites in the three districts. No continuous sections are known, but the Cretaceous and Jurassic beds dip equally steeply and there is no evidence for angular unconformity between them.

The absence of obvious angular unconformity is evidence against any important orogeny. Moreover the similarity of the sediments and the rapid rate of deposition suggest that deposition may have been substantially continuous over parts of New Zealand from the Jurassic until the Cretaceous. It thus seems likely that diagnostic Neocomian fossils will yet be found in these thick greywacke sequences to fill the outstanding gap that now exists in the Mesozoic fossil sequence in New Zealand.

Cretaceous Igneous Rocks

It has generally been considered that the early Cretaceous was a period of widespread tectonic activity throughout the New Zealand region, and for lack of better evidence many poorly dated intrusives have been attributed to this period. The lack of evidence for any widespread spasm of diastrophic activity either at the beginning of the Cretaceous or within the Cretaceous has already been mentioned. From the progressive change in the lithology and rate of deposition of the sediments a gradual decrease in activity from the Triassic to the top of the Cretaceous would appear to be probable. Major intrusives that have been attributed to the early Cretaceous are the granite batholiths of the west coast of the South Island and the ultra-basic intrusives of Nelson and Otago (Cotton, 1945). The granites are probably of different ages and none are likely to be as young as Cretaceous. The ultra-basics are closely associated with upper Paleozoic lavas and are probably upper Paleozoic in age (Grindley, 1958).

Igneous rocks that may be lower Cretaceous or upper Jurassic are the andesites and rhyolites of Mt. Somers and Malvern Hills (Speight, 1928 and 1938), the syenites and associated igneous rocks of North Canterbury (Mason, 1947), the alkaline intrusives of Haast Pass (Turner, 1937) and north Westland (Smith, 1908), and the geosynclinal marine volcanics of Red Island, Matakaoa Peninsula, and Northland. The marine volcanics are all fossiliferous but the fossils are not well preserved. Mid-Jurassic is the most probable age for the Northland rocks, but the fossils from the two other areas have a possible age-range from mid-Jurassic to lower Cretaceous. The igneous rocks of more certain Cretaceous age are described below.

Taitai Series igneous rocks are known from the Tapuwaeroa Valley. Volcanics interbedded with the Mokoiwi Mudstone extend for six miles along the north side of the valley. The rocks, basalt, pillow basalt, and conspicuous red tuffs, are similar to older Mesozoic volcanics that are interbedded with greywacke, but have not been petrologically examined. The Taitai Sandstone is an unusually dark sediment and is probably tuffaceous. At most places it contains well rounded igneous pebbles, about a quarter of which are volcanic and the tuffaceous material may have been derived from older and not from contemporary volcanics.

The volcanics of the Topfer Formation of Reefton are probably of Taitai Series age also, and are represented by non-marine tuffs and agglomerates. Harris (in Suggate, 1957) has suggested that some of the tuffs were formed by pumice eruptions and has described rhyolite, obsidian, and andesite fragments from an agglomerate. Intrusions that are probably of about the same age are more basic in composition. The largest is a dolerite plug near Kirwans Hill; the others are small discontinuous north-west-striking dolerite dykes that penetrate pre-Cretaceous greywacke but do not extend into basal Tertiary coal-measures.

Clarence Series volcanics are known only from the Awatere and Clarence Valleys. Thick flows of olivine basalt with interbedded tuffs, partly marine and partly non-marine, originally covered at least 300 square miles. The largest mass preserved covers 10 square miles in the upper Awatere Valley, and is at least 3,000 feet thick, but the other areas of basalt are much smaller and thinner. The volcanics are well exposed but no detailed petrological examination has yet been made. The feeding dykes are also well exposed and penetrate greywacke and the overlying Motuan redeposited beds. The dykes are almost vertical and strike at 104° in Winterton River and at 33° in Hodder River. The basalts and fossiliferous tuffs are underlain and overlain by fossiliferous beds and are well dated as Ngaterian. The eastwards extension of the volcanics is surprisingly limited, the apparently complete Ngaterian section at Coverham, 12 miles east of the probable centre of igneous activity in the upper Awatere, being without any obvious volcanic material. A thin igneous band within the Motuan of Coverham, described as a basalt by Wellman (1955: 100), is possibly a dolerite sill of Ngaterian age. The volcanics of the mid-Clarence Valley have been severely folded and are now confined to three synclinal areas where they cover about four square miles. They probably rapidly thicken westward, the maximum thickness recorded being 1,200 feet (Suggate, 1958).

Raukumara Series volcanics are known from two places on the west coast of the South Island. Thick volcanic flows, tuffs, and agglomerates on the east side of the Greymouth coalfield thin to the west within the coal-measures of the lower part of the Paparoa Beds. Underlying rocks are hidden in the centre of volcanic activity and no feeding dykes are known. Basalt interbedded with coal measures of about the same age has been described by Hutton (in Gage and Wellman, 1944) from Koiterangi Hill, 20 miles south of Greymouth.

No definite volcanics or tuffaceous sediments are known from the marine beds of the Raukumara Series. Conspicuous red bands in the Mangaotane Mudstone may be tuffaceous, but they do not closely resemble the red tuffs commonly associated with most New Zealand Mesozoic marine basalts.

Mata Series igneous rocks are known with certainty only from the Wairarapa. The most recent description is that by Hutton (1943) of those near Ngahape. Intrusions of teschenite and dolerite and variolitic pillow basalts have a fairly high ratio of Na_2O to K_2O and a low Al_2O_3 content. The basalts and the chemically similar intrusives are probably Haumurian in age. The teschenites extend well beyond the Ngahape area and intrude Raukumara sediments ten miles south-east at Flat Point and Clarence sediments to the north near Tinui village.

In Northland poorly exposed lenses of ultra-basics and allied rocks are surrounded by uppermost Cretactous and lower Tertiary mudstones. Magnetic observations (Jones, 1940) followed by excavations for agricultural serpentine (Andrew, 1942) have shown that the lenses lie along sinuous lines that appear to follow the bedding of the mudstones. Association of basic lavas with the ultrabasics (Bartrum, 1948: 30) suggest that the full igneous suite corresponds with that of the upper Paleozoic

(Grindley, 1958), and makes it likely the igneous rocks are all of the same age as the sediments. The igneous horizon is probably uppermost Cretaceous or slightly younger.

DESCRIPTION OF CRETACEOUS STAGES

Wangaloan Stage (Danian or Paleocene)

TYPE LOCALITY. The stage is based on the Wangaloa Formation of Ongley (1939), the type locality being at Michells Point, Wangaloa, on the east coast of the South Island, 30 miles south of Dunedin (Finlay and Marwick, 1940: 86). The beds consist of about 50 feet of sandstone and conglomerate with slabby concretions and contain well preserved molluscs (Finlay and Marwick, 1937). They pass down into the Taratu Coal Measures, grade east into freshwater beds, and are directly overlain by concretionary sandstone with molluscs and Foraminifera that are probably lower Dannevirke in age (Harrington and Hornibrook, 1957: 663). A Bortonian molluscan fauna with *Monalaria concina* occurs 200 feet higher in the sequence. The structure is simple, the Wangaloan dipping south-east at 3°.

DISTRIBUTION. The distinctive Wangaloan molluscan fauna is known with reasonable certainty at only two places away from the type locality. At Boulder Hill, 30 miles north, a richly fossiliferous sandstone lens is overlain by dark glauconitic sandstone with a Heretaungan (basal Eocene) microfauna in its upper part and underlain by quartz conglomerate and Taratu Coal Measures. The other place is at Kaiwhata Stream, near Ngahape, in the East Coast Ranges of the North Island, and is represented by a single fossiliferous boulder (Hornibrook and Harrington, 1957: 664), the origin of which is uncertain. The Piripauan beds in the middle reaches of the stream are probably faulted against Tertiary marine sediments on the east, and the boulder was found near the contact.

The Kauru Formation of Gage (1957: 25) contains poorly preserved molluscs that may be Wangaloan in age. It overlies coal measures and is disconformably overlain by Bortonian marine sandstone.

The Waipawa Black Shale was considered a correlative by Finlay and Marwick (1947: 230), but the microfauna is not significantly different from that in the underlying Teurian and the shale is now included in the type Teurian by Harrington and Hornibrook (1957, 667), as re-defined in the Waipawa Standard Section.

MACROFAUNA. The Wangaloan macrofauna has been monographed by Finlay and Marwick (1937), who described 89 species. Ammonites, belemnites, and *Inoceramus* are absent and " a great proportion of the mollusca belong to genera peculiar to the fauna, but the Cretaceous elements *Conchothyra, Struthioptera* and *Lahillia* balance a strong Tertiary element, and the age has been assessed as Danian " (Finlay and Marwick, 1948: 21). The following are some of the more important species:

Neilo (Spineilo) elongata Marshall (W, B, K)
Lahillia (Lahilleona) neozelanica Marshall (W, B, K)
Zeacolpus (Leptocolpus) semiconcavus (W, B, K)
Colposigma mesalia Finlay and Marwick (W, B)
Struthioptera osiris Finlay and Marwick (W)
Conchothyra australis (Marshall) (W, B)
Taieria allani Finlay and Marwick (B, K)
Taioma tricarinata Finlay and Marwick (B, K, N)
Pseudofax ordinarius (Marshall) (W, B, K)
Heteroterma zelandica Marshall (W, B)
Priscaphanter cingulatus (Marshall) (W, B, K)
Ongleya tholispira Finlay and Marwick (W, N)

The localities are as follows: W, Wangaloa; B, Boulder Hill; K, Kauru Formation; N, Ngahape, Kaiwhata River.

MICROFAUNA. The beds are of a shallow water facies and no microfauna is known.

STATUS AS PART OF NEW ZEALAND STANDARD STAGE SEQUENCE. From stratigraphy and paleontology it is certain that the Wangaloan lies near the boundary of the Cretaceous and Tertiary. It must correspond to part of the Waipawa Standard Section (including possible erosion intervals) between the top of the Haumurian and the base of the Heretaungan. Hornibrook and Harrington believe this part of the section to be continuous and consider the Wangaloan to be coeval with either the Teurian, Waipawan, or Mangaorapan stages. As these stages are well defined stratigraphically and more widely known than the Wangaloan, they recommend that the Wangaloan be abandoned as a stage for New Zealand-wide correlation. This recommendation is adopted in this report. Nevertheless the Wangaloan mollusca are important and distinctive, and it is unfortunate that their stratigraphic position is uncertain. They differ more from similar shallow-water Haumurian molluscs than would be expected if they were Teurian in age, and if not basal Dannevirke (Paleocene) may prove to represent a period of time marked by an unrecognized erosion interval between the Teurian and Waipawan.

Teurian Stage (Danian)

TYPE LOCALITY. The Teurian is defined by Hornibrook and Harrington (1957) as the beds at the Waipawa Section between the top of the Whangai Argillite of Haumurian age and the base of Waipawan blue-grey silty mudstone. The beds consist of 300 feet of grey silty sandstone overlain by 155 feet of black, yellow-weathering siltstone (Waipawa Black Shale) and by 10 feet of greensand. This section replaces the original type at Te Uri Stream (Finlay and Marwick, 1947: 230) which is faulted in its upper part. Correlation is by Foraminifera, which are abundant and well preserved, except in the black shale.

DISTRIBUTION. The Teurian is widely distributed in western Northland, Raukumara Peninsula, and the East Coast Ranges, and is often represented by calcareous mudstone that passes down into non-calcareous Whangai Shale. It also occurs at Waipara River, in Canterbury (Hornibrook and Harrington, 1957: 663).

MACROFOSSILS. Finlay and Marwick (1947: 230) mention small belemnites and reptile remains in South Island correlatives of the Teurian, and largely because of these macrofossils they have considered the Teurian to be Maestrichtian in age. The belemnites, at Shag Point and those below the upper Teredo Limestone south of Amuri Bluff, are associated with Haumurian microfaunas and are pre-Teurian in age (Hornibrook and Harrington, 1957: 660). The reptile remains occur in the Waipara Greensand which overlies " sulphur mudstone " with Teurian microfaunas and underlies mudstone with a basal Dannevirke microfauna (Hornibrook and Harrington, 1957: 667), and are almost certainly Teurian in age. Marine reptiles persisted longer than belemnites or ammonites in New Zealand, and strengthen the Cretaceous affinities of the Teurian.

MICROFAUNA. The following Foraminifera are given by Hornibrook (1958: 26) as being distinctive of the Teurian. They indicate a post-Maestrichtian age, and suggest correlation with the Danian.

Globigerina linaperta Finlay
Globorotalia membranacea (Ehrenberg)
Loxostomum limonense (Cushman)
Neoflabellina thalmanni (Finlay)
Bolivinoides delicatula Cushman

Haumurian Stage (Maestrichtian)

TYPE LOCALITY (Fig. 9). The type locality is the upper part of the Piripauan of Amuri Bluff as defined by Thomson in 1917. The beds below the Upper Teredo Limestone that were excluded from the Piripauan as redefined by Finlay and Marwick in 1940 can be correlated with those beds a few miles to the south that contain small belemnites and a microfauna that is pre-Teurian and typically Haumurian. They are included in the Haumurian as here defined. The following sequence, measured by the writer in July, 1954, is probably less well exposed than when examined by McKay in 1877, and the thicknesses are estimated.

AMURI BLUFF SECTION

	FEET.
ARNOLD AND DANNEVIRKE SERIES (Lower Tertiary)	
Amuri Limestone, light grey fine-grained limestone with well defined erosion interval at base	300
AGE UNCERTAIN	
Upper Teredo Limestone: very calcareous glauconitic fine sandstone, with *Teredo* tubes and echinoid spines	5
HAUMURIAN	
Glauconitic medium sandstone	70
Very calcareous grey medium sandstone with irregular concretions	5
Lower Teredo Limestone: very calcareous medium sandstone	5
Dark sulphureous siltstone with huge septarian concretions and concretions with saurian bones	400
Black Grit: very calcareous medium sandstone with scattered polished granules of black and white quartz	20
PIRIPAUAN	
Medium sandstone	40
Fine sandstone with belemnite fragments	10
Knobbly fossiliferous band	20
Medium sandstone with abundant fossils	20
Soft conglomerate with black oyster and abundant belemnites	5
Soft medium sandstone	50
Hard sandstone with scattered belemnites	10
AGE UNCERTAIN	
Calcareous sandstone and fragments of silicified wood, not well exposed and thickness uncertain	50
JURASSIC ?	
Greywacke undermass, thickness at least	500

The siltstone above the "Black Grit" is impregnated with sulphur compounds, contains a few reptile bones, and was described in early reports as "Sulphur Sands" or "Saurian Beds". The total thickness of the type Haumurian is about 500 feet.

The "Upper Teredo Limestone" is separated from the base of the Amuri Limestone by a well-defined erosion interval. The "limestone"—actually a very calcareous sandstone—is quite different from the Amuri Limestone and lithologically similar to some of the underlying Haumurian sediments, and is probably Haumurian in age. The base of the Amuri Limestone is Mangaorapan (Lower Eocene) in age (pers. comm. Mr. N. de B. Hornibrook), and the Waipawan (Paleocene) and Teurian (Danian) are probably represented by the erosion interval at the base of the limestone.

The Haumurian–Teurian contact is best defined on the East Coast of the North Island at the Waipawa standard section where the two stages are well exposed in sequence (Hornibrook and Harrington, 1957).

The Black Grit contains the two key Haumurian macrofossils *Inoceramus matotorus* n.sp. and *Ostrea lapillicola* Marwick. The knobbly band 50 feet below contains *Inoceramus australis,* one of the key Piripauan species. The Haumurian–Piripauan contact lies between, and is most conveniently placed at the base of the Black Grit.

DISTRIBUTION. The Haumurian covers a greater area than the other Cretaceous stages in all the Cretaceous regions of New Zealand. It is represented by a wide range of facies. Shallow water sediments are known with certainty only in Northland and in the South Island. In Northland they are represented by the Otamatea beds of Ferrar (1934) and contain concretions with abundant ammonites at a few places (Marshall, 1926; Mason, 1953). In the South Island they were deposited when the sea advanced from the margin of the East Marlborough geosyncline to as far west as Trelissick Basin and as far south as Brighton, near Dunedin (Fig. 1). They are mostly sulphureous sandstone with bands of siltstone and glauconitic sandstone with some beds of pure glauconite, and conformably overlie fresh-water beds at many places. *Concothyra parasitica* (Hutton) and *Ostrea* cf. *dichotoma* Bayle are the most conspicuous fossils.

Transitional beds are the most widely distributed and consist of flinty sulphureous dark siltstone. The siltstone is a distinctive formation conveniently referred to as the Whangai Shale. It is dark when fresh but has a characteristic light pinkish-brown colour in weathered outcrops. All microfaunas described by Finlay and Marwick in 1940 as Piripauan are either Haumurian or Teurian; most are from the Whangai Shale. The Whangai Shale is widely distributed in Northland, in the East Coast Ranges, and on the east side of the Raukumara Peninsula. In East Marlborough it was deposited only in the centre of the Cretaceous geosyncline, and grades south-west into the Sulphur Sand in the Clarence Valley.

The redeposited sediments are graded-bedded gritty sandstones and siltstones—the Tapuwaeroa beds of Ongley and Macpherson (1928) as now restricted. The type locality chosen is at Wairongamai Stream in Tapuwaeroa Valley, Raukumara Peninsula, and most of the typical outcrops are nearby. Tapuwaeroa beds are widely distributed in the East Coast Ranges and are well developed near Porangahau (Lillie, 1953). Haumurian beds with thick redeposited conglomerates and boulder beds occur at Ngahape in the southern part of the east coast of the North Island.

Foraminifera. At most places foraminifera are the best guide fossils. They were first described by Finlay in 1939. A revision by Mr. Hornibrook is given below:

Finlay, having failed to find Foraminifera in the type Piripauan at Amuri Bluff, considered the mid-Waipara concretionary saurian beds as a correlative (in Finlay and Marwick, 1940). The Saurian Beds are actually a correlative of the upper part of the old Piripauan—the Haumurian of the present paper. They contain abundant Foraminifera, of which the following are the most important. (F5664): *Spiroplectammina piripaua* Finlay, *Gaudryina healyi* Finlay, *Dorothia biformis* Finlay, *Dorothia elongata* Finlay, *Neoflabellina rakauroana* (Finlay), (very similar to the Maestrichtian *N. reticulata* (Reuss)), *Bulimina kickapooensis* Cole, *Buliminella sauria* Finlay, *Allomorphina whangaia* (Finlay), *Patellina piripaua* Finlay, *Anomalinoides piripaua* (Finlay), large *Gyroidina* aff. *globosa* (Hagenow), *Alabamina acutimarginata* (Finlay), *Planulina rakauroana* Finlay.

Most of the above species, with the addition of *Rzehakina epigona* (Rzehak), are common in some facies of the Whangai Formation of the North Island east coast and in the Otamatea beds of Northland. A few microfaunas of mostly pelagic forms from these beds include the typically Maestrichtian species *Gublerina* aff. *glaessneri* Bronniman and Brown, *Gumbelina* spp., *Globotruncana* aff. *intermedia* Bolli, and *Bolivinoides dorreeni* Finlay.

The upper Cretaceous Tapuwaeroa formation of the Dannevirke Subdivision (Lillie, 1953) has completely arenaceous microfaunas with abundant *Rzehakina epigona, Ammobaculites* sp. and at some places *Dorothia elongata* and *Gaudryina healyi* that are evidently facies variants of the larger Whangai microfaunas.

Younger Cretaceous beds with microfaunas lacking Maestrichtian species were separated by Finlay and Marwick (1947) as the Teurian Stage.

Foraminifera (S55/506, F9017) have been found recently below the upper Teredo Limestone in the bed with small belemnites (Finlay and Marwick, 1940: 85) at the mouth of Pariwhakatau Stream two miles south of Amuri Bluff. The belemnite bed contains *Spiroplectammina piripaua, Gaudryina healyi* (juveniles), *Dorothia elongata, Bulimina* aff. *kickapooensis, Buliminella sauria, Bolivina* aff. *incrassata* Reuss, *Bolivinoides dorreeni, Gyroidina* aff. *globosa,* etc., and must be correlated with the concretionary saurian beds of the mid-Waipara and with the Whangai of the North Island.

MACROFOSSILS. Small belemnites when they can be distinguished from juveniles are useful for defining the upper limit of the Haumurian, particularly for the area of the Maestrichtian transgression. They have been reported from the top of the Haumurian two miles south of the type locality, from Selwyn Rapids, from Shag Point, and from Brighton, near Dunedin (Trechmann, 1917; Finlay and Marwick, 1940: 85). They are not well preserved and more than one species may be present. The Brighton belemnites were thought by Whitehouse in 1924 probably to belong to the Albian family Dimitobelidae (Finlay and Marwick, 1940) but have recently been revised by Glaesner (1958). The Brighton Limestone overlies freshwater beds with abundant spores and pollens similar to those in the freshwater beds that conformably underlie the Maestrichtian to the north (Couper, 1953) and the belemnites are probably Maestrichtian in age.

The most widespread macrofossils are *Ostrea lapillicola* Marwick and *Inoceramus matotorus*. Both are without definite overseas correlatives. The *Ostrea* was described by Marwick in 1926 and has since been used as a key fossil in the Tapuwaeroa facies of the Haumurian (Finlay and Marwick, 1940).

It has recently been found in the Black Grit at the Haumurian type locality, and in western Northland attached to *Baculites rectus* (per com. Dr. C. A. Fleming). *Inoceramus matotorus* is found in all the Cretaceous districts but is not so abundant or as well preserved as the key Senonian species *I. australis* or *I. pacificus*. In the South Island it occurs in the Black Grit of Amuri Bluff, at Trelissick Basin, and at Mirza Stream. It is the youngest *Inoceramus* species known in New Zealand but does not seem to extend as high as do the ammonites or belemnites, for *Inoceramus* has not been reported from the Haumurian beds at Selwyn Rapids, Shag Point,* or Brighton, nor from the " Saurian Beds " of the type Haumurian.

The more important Haumurian Ammonites are listed below:

	1	*Phyllopachyceras forbesianum* (d'Orbigny)
M	1	*Pseudophyllites indra* (Forbes)
	1	*Gaudryceras (Neogaudryceras) subsacya* Marshall
M	5	*Diplomoceras* cf. *cylindraceum* (Defrance in d'Orbigny)
	1	*Ptychoceras (Phylloptychoceras) zelandicum* (Marshall)
	1	*Baculites rectus* Marshall
	2	*Maorites mckayi* (Hector)
	1	*Maorites suturalis* Marshall
M	3	*Grossouvrites gemmatus* (Huppe)
	1, 4	*Gunnarites zelandicus* Marshall
M	1	*Vertebrites murdochi* Marshall
M	1	*Desmophylites (Schluteria)* sp.

The species prefixed with " M " have lower Maestrichtian affinities. The numbers refer to the localities.

1 Northland, Marshall, 1926.
2 Collected by McKay from the Whangai Shale at Waipawa Gorge, Marwick, 1950.
3 Selwyn Rapids, Canterbury, Trechmann, 1917.
4 Collected by Dr. W. N. Benson from near Dunedin, Spath, 1953: 31.
5 Motuotaraia S.D. (N.Z. Geol. Surv. 29th Ann. Rep.: 1935).

The following lists and comments have been prepared by Dr. C. A. Fleming:—

Porifera: Undescribed fossil sponges collected by H. T. Ferrar from the ammonite beds of Kaipara Harbour are in N.Z. Geological Survey collections.

Coelenterata: The following coral species have been identified by Squires (1958) in his account of the fossil corals of the New Zealand Cretaceous and Tertiary:

Bantamia ? condocosta Squires (Tutamoa Survey District Northland)
Haimesiastraea anchistina Squires (Middle Waipara).
Dasmosmilia ? spissa Squires (Conway River mouth, possibly Dannevirke Series; Middle Waipara).

* The report of *I. multiconcentrica* at Shag Point by Park (1910: 90) is probably a mistake for *I. multiplicatus* (now *I. pacificus* Woods) from Amuri Bluff (Hector, 1877).

Deltacyathus ? complanatus Squires (Kaipara)
Wellsia cyathiformis Squires (Kaipara)

Brachiopoda: No Haumurian brachiopods have been described. Dr. P. Marshall collected terebratelloid brachiopods from Batley at Kaipara Harbour, Northland, and rhynchonellids and a parasulcate form of uncertain affinity have been recently collected by Dr. C. A. Fleming from the beds below the Upper Teredo Limestone at Pariwhakatau Stream a few miles south of Amuri Bluff.

Mollusca and Annelida: The following (other than ammonites, which are listed separately) were recorded by Woods (1917) and Wilckens (1922, 1924) from the localities here considered as Haumurian. The nomenclature is adjusted, and unpublished determinations by J. Marwick and C. A. Fleming have been added.

Pelecypoda

Solemya n.sp. (Kaipara)
Nucula 3 spp. (Kaipara)
Nuculana (*Saccella*) n.sp. (Kaipara, Whangaroa, Barron's Hill)
Nuculana (*Jupiteria*) n.sp. (Waimate, Northland)
Nuculana (*Jupiteria*) aff. *taioma* Fin. & Marw. (Barron's Hill, near Brighton)
Nuculana aff. *amuriensis* Woods (Whangaroa)
Neilo n.sp. aff. *cymbula* Woods (Kaipara)
Neilo cymbula Woods (Middle Waipara)
Neilo n.sp. A (Kaipara, Whangaroa)
Neilo n.sp. B. (Kaipara)
Pterotrigonia aff. *pseudocaudata* (Hector) (Waimate, Selwyn Rapids, Middle Waipara)
Pacitrigonia sp. A aff. *hanetiana* (d'Orb.) (Middle Waipara, Brighton)
Pacitrigonia sylvesteri Marw. (Selwyn Rapids, Acheron River)
Linotrigonia (*Oistotrigonia*) *waiparaensis* (Middle Waipara, Barron's Hill, Green Island)
Nordenskjoldia hectori (Woods) (Middle Waipara)
Nordenskjoldia woodsi Wilckens (Middle Waipara)
Glycymeris (*Glycymerita*) sp. (Waimate)
Glycymeris (*Glycymerita*) *selwynensis* (Woods) (Selwyn Rapids)
Limopsis ? sp. (Kaipara)
? *Lithophaga* sp. (Kaipara)
Pinna sp. (Selwyn Rapids)
Inoceramus matatorus n.sp. (Waimate, East Coast, Marlborough, Trelissick Basin, etc.)
Neithea grangei (Murd.) (Brighton)
Chlamys sp. (Kaipara)
Syncyclonema cf. *membranacea* (Nils) (Kaipara, Amuri Bluff Black Grit and concretionary greensands)
Camptonectes selwynensis Fin. (Amuri Bluff, Selwyn Rapids, Middle Waipara, Barron's Hill (cf.))
Limatula n.sp. (Kaipara)
Ostrea cf. *dichotoma* Bayle (Middle Waipara, Malvern Hills, Trelissick Basin)
Ostrea lapillicola Marw. (Hokianga, Kaipara, Whangaroa, Waimate, Waiapu District, Southern Hawke's Bay, Black Grit of Amuri Bluff)
Ostrea sp. (Waimate)
Anthonya elongata ? Woods (Waimate)
"*Eriphyla lenticularis*" Goldf. (Selwyn Rapids)
"*Eriphyla*" *meridiana* Woods (? Waimate)
"*Lucina*" *canterburiensis* Woods (Amuri Bluff, concretionary greensand, Selwyn Rapids, Malvern Hills)
"*Lucina*" sp. (Kaipara)
Thyasira n.sp. A (large) (Kaipara, Whangaroa, Tapuwaeroa Valley)
Thyasira sp. B (Kaipara)
"*Tellina* cf. *largillierti* (d'Orb.)" (Selwyn Rapids)
Gari ? n.sp. A (Selwyn Rapids)
Gari n.sp. B (Barron's Hill).
Ethmocardium woodsi Marw. (Middle Waipara, Selwyn Rapids)
Ethmocardium ? n.sp. (Middle Waipara)
"*Acanthocardia*" n.sp. (Middle Waipara)
N. gen. ? cf. *Ringicardium*, n.sp. (Acheron River)

Lahillia (Lahilleona) aff. *neozelanica* Marsh and Murd. (Kaipara, Middle Waipara, Shag Point, Amuri Bluff)
"*Lahillia*" n.sp. (Selwyn Rapids)
Callistina (Tikia) thomsoni Woods (Selwyn Rapids)
"*Callista*" sp. (Woods) (Selwyn Rapids, Barron's Hill)
Cyclorismina woodsi Marw. (Selwyn Rapids)
Thracia sp. (Middle Waipara)
Panopea malvernensis Woods (Selwyn Rapids)
Panopea cf. *clausa* Wilck. (Kaipara)

Gastropoda

N. gen. ? aff. *Tryblidium* (Hokianga, Black Grit of Amuri Bluff)
Trochidae (? n.gen.) (Kaipara)
"*Angaria*" sp. (*Delphinula* sp. Woods; Selwyn Rapids)
Tectarius n.sp. (Waimate)
Bittiscala inaequicostata (Wilck.) (Amuri Bluff, Saurian Beds)
Amauropsona ? sp. (Kaipara, Barron's Hill)
Lunatia selwynensis (Wilck.) (Waipara, Selwyn Rapids)
"*Scalaria*" *pacifica* Wilck. (Selwyn Rapids)
Dicroloma ? *suteri* (Trechmann) (Selwyn Rapids)
Struthioptera haastiana (Wilck.) (Waimate, Middle Waipara, Selwyn Rapids, Shag Point)
Struthioptera novo-seelandica (Wilck.) (Selwyn Rapids)
Struthioptera sp. (Barrons Hill)
Perissoptera waiparaensis (Hect.) (Kaipara, Waimate, Amuri Bluff, Black Grit and Saurian Beds, Shag Point)
Conchothyra parasitica (Hutt.) (Selwyn Rapids, Middle Waipara, ? Amuri Bluff)
Protodolium speighti (Trechmann) (Amuri Bluff, Selwyn Papids, Middle Waipara, Shag Point, Barron's Hill)
Neritopsis ? sp. (Shag Point)
Tudicla (?) (s. lat.) n.sp. (Kaipara)
"*Tudicla* ex aff. *turnida* Wilck." (Selwyn Rapids, Middle Waipara)
"*Cryptorhytis*" *vulnerata* Wilck. (Selwyn Rapids)
Aff. *Sycostoma* (Cox) n.sp. (Kaipara)
Superstes ? sp. (Kaipara)
Ringiculidae (gen. et sp. indet.) (Shag Point)
"*Eryptycha*" sp. (Kaipara)
"*Cylichna*" sp. (Kaipara)

Scaphopoda

Laevidentalium morganianum (Wilck.) (Kaipara, Selwyn Rapids, Shag Point (cf.))
Dentalium n.sp. (Kaipara, Barron's Hill)

Cephalopoda

Almost all Haumurian species are from Kaipara and Whangaroa harbours. The nomenclature of some species has been revised by Spath (1953), Wright and Matsumoto (1954), and Matsumoto (1955). Other Haumurian cephalopods are:

Aff. *Dimetobelus* n.sp. (Brighton)
Cheirobelus n.sp. aff. *lindsayi* (Hect.) (small form: Whangaroa, Kaipara, Waimate, Pariwhakatau Creek)
Belemnites (indet.) (Shag Point, Selwyn Rapids)
"*Nautilus*" sp. aff. *suciensis* Whiteaves", Marshall 1924 (Kaiwara Creek, Hurunui).

Annelida

Rotularia ornata (Wilckens) (Amuri Bluff, Black Grit)
Rotularia cf. *discoideum* (Stol.) (Shag Point)

Crustacea: Undetermined fossil crustacea, mainly fragmentary, are known from the Haumurian of Whangaroa, Waimate, and the Tapuwaeroa Formation of Raukumara Peninsula. Wilckens listed *Hoploparia* ? from the Malvern Hills *Ostrea* bed. A rolled stalk of the barnacle *Euscalpellum zelandicum* Withers from a conglomerate in Tapuwaeroa Valley that also includes small belemnites and *Thyasira* n.sp. A (coll. M. Pick, 1956) is either Haumurian or Teurian.

Echinoderma: The following have been identified by Dr. H. B. Fell (1952 and 1956):

Ophryaster novaezelandiae Fell (Omihi, Canterbury)
Hippasteria antiqua Fell (Omihi, Canterbury)
"*Cidaris*" (? *Cyathocidaris*) *pistillum* Quenstedt (Pariwhakatau Creek mouth)

Vertebrata: The following Elasmobranchii were recorded by Chapman (1918) from fish teeth collected from the Black Grit of Amuri Bluff:

Synechodus sulcatus (Davis)
Scapanorhynchus subulatus (Agass.) (also Middle Waipara)
Lamna crassa (Agass.)
Callorhynchus hectori Newton
Ischyodus thurmanni Pict. & Camp.

The classification of New Zealand Cretaceous reptiles by Owen, Hector and Hutton needs revision. The following list is compiled from early published determinations, with some modification based on Romer (1950). Most of the Amuri Bluff specimens are from the Saurian Beds, but bones also occur in the Black Grit, and some may be from the underlying Piripauan Stage.

? *Myopterygius* sp. (listed by Romer)
Elasmosaurus sp. (listed by Romer)
Mauisaurus haasti Hect. (Amuri, Waipara)
Mauisaurus latibrachialis (Amuri)
Cimoliosaurus australis (Owen) (Amuri, Waipara)
Cimoliosaurus caudalis Hutton (Waipara)
Cimoliosaurus holmesii (Hect.) (Amuri, Waipara)
Cimoliosaurus hoodii (Owen) (Amuri, Waipara)
Cimoliosaurus mackayii (Hect.) (Amuri)
Cimoliosaurus tenuis (Hect.) (Amuri)
Tylosaurus haumuriensis (Hect.) (Amuri, Waipara)
Taniwhasaurus oweni (Hect.) (Amuri)
Crocodilus sp. (Amuri)

Piripauan Stage (Upper Campanian)

Type Locality (Fig. 9): The Piripauan Stage is defined by the beds with *Inoceramus australis* and *I. pacificus* that form the lower and more fossiliferous part of the Piripauan of Thomson. The beds consist of calcareous sandstone with concretionary bands—the grey sandstone and calcareous conglomerate of McKay (1877)—and are about 200 feet thick. Details are given in a text section under Haumurian.

The type Piripauan directly underlies the type Haumurian, the top of the Piripauan being at the base of the Black Grit. The base of the Piripauan is not exposed at the type locality, the lowest Piripauan bed being separated from the top of the probably Jurassic greywacke by a poorly exposed 50ft interval. Silicified wood and carbonaceous shale fragments indicate that the Piripauan probably passes down into fresh-water beds that rest unconformably on the greywacke. At Mikonui Stream, described as the east limb of the Amuri Bluff Section by McKay but actually separated from the main section on the coast by an anticlinal greywacke core, McKay collected *Inoceramus nukeus*. This fossil, which has not been recollected, is one of the key species of the Teratan Stage, and beds of this age probably underlie the Piripauan at Mikonui Stream. Freshwater beds with silicified wood, like that at Amuri Bluff, and bentonite (Fyfe, 1934) unconformably overlie the greywacke, but the contact with the overlying Cretaceous marine beds is not well exposed.

The base of the Piripauan is well exposed 40 miles north of Amuri Bluff at Burnt Saddle on the track from Remuera Homestead to Coverham, where sandstone with *I. pacificus* and *I. australis* rests conformably on dark mudstone of Teratan age with *Inoceramus nukeus*, described as *I.* sp A by Wellman (1955: 98).

Distribution. Piripauan beds are known from several places in Raukumara Peninsula, East Coast Ranges, and East Marlborough, and occur at the type locality and at Conway River mouth in Canterbury, and at two places in Western Northland.

MACROFOSSILS. The two *Inoceramus* species *pacificus* and *australis* are by far the most important and most widely distributed fossils and have been found at about 60 localities. Other macrofossils have been found at a few places only and appear to be restricted to a particular facies of shelf sediments. The type locality at Amuri Bluff is the most important. Mikonui Stream and Conway River mouth are only a few miles distant from Amuri Bluff. New macrofossil localities, with fossils similar to those at Amuri Bluff, have recently been discovered in the North Island near Lake Waikaremoana. The best is in the headwaters of Ruatahuna Stream, about 7 miles upstream from the Waikaremoana-Rotorua road.

The following list has been compiled by Dr. C. A. Fleming from the species recorded from the "calcareous conglomerate" at Amuri Bluff and Mikonui Stream by Woods (1917), Wilckens (1922), and others. Collection GS13 represents all horizons from the Piripauan calcareous conglomerate to the Haumurian greensands, and species that are found in this collection only may be Haumurian in age and are marked with an asterisk (*). Species marked with a dagger (†) also occur in the Conway River railway cutting.

BRACHIOPODA

Discina sp. (Wilckens, 1922: 33)

MOLLUSCA

PELECYPODA

Nuculana (*Jupiteria*) *amuriensis* Woods
Nuculana (*Saccella* s. lat.) sp. (Woods, 1917: 18)
Barbatia mackayi Woods
Cucullaea sp. (Woods, 1917: 20)
Cucullaea (*Cucullastis*) *zealandica* Woods
**Glycymeris* (*Glycymerita*) sp. (Woods, 1917: 20)
†*Trigonia* (*Pterotrigonia*) *pseudocaudata* (Hect.)
Trigonia (*Pacitrigonia*) aff. *hanetiana* (d'Orb.)
†*Linotrigonia* (*Oistotrigonia*) *waiparensis* (Woods)
Modiolus cf. *typicus* Forbes
Modiolus cf. *flagellifer* (Forbes)
Dreissensia cf. *lanceolata* (Sow.)
Modiolus cf. *typicus* Forbes
Modiolus cf. *flagellifer* (Forbes)
Dreissensia cf. *lanceolata* (Sow.)
†*Inoceramus australis* Woods
Inoceramus pacificus Woods
**Pinna* sp. (Woods, 1917: 28)
†*Camptonectes selwynensis* Fin.
Mixtipecten amuriensis (Woods)
Syncyclonema membranacea (Nilsson)
Limatula woodsi (Suter)
Ostrea sp. (Woods, 1917: 25)
†*Exogyra* sp. (Conway River only)
Eriphyla meridiana (Woods)
Anthonya elongata Woods
Lucina canterburiensis Woods
Cultellus cretaceus Woods
Callistina (*Tikia*) *wilckensi* Woods
**Acanthocardia* (?) aff. *acuticostatum* (d'Orb.)
Panopea clausa Wilckens
Eximiothracia (?) *haasti* (Woods)

GASTROPODA

Pleurotomaria (*Perotrochus*) *maoriensis* Wilckens
Pleurotomaria (*Chelotia*) *woodsi* Wilckens
**Angaria* ? sp. (Wilckens, 1922, pl. 1, fig. 5)
"*Calliostoma*" *decapitata* Wilckens
*"*Patella*" *amuritica* Wilckens

Procancellaria parkiana Wilckens
**Conchothyra parasitica* Hutton
†*Struthioptera novo-seelandica* (Wilckens)
**Maoricrypta hochstetteriana* (Wilckens)
**Protodolium speightii* (Trechmann)
*"*Scalaria*" *pacifica* Wilckens
Tudiclana ? alta (Wilckens)
Eriptycha punamutica Wilckens
"*Cylichna*" *thomsoniana* Wilckens

SCAPHOPODA

Dentalium morganianum Wilckens

CEPHALOPODA

**Eutrephoceras* sp. (from beach pebble)
Kossmaticeras (s. str.) *haumuriensis* (Hector)
Gaudryceras aff. *jukesi* (Whiteaves)
Anisoceras ? sp.
Baculites cf. *vagina* Forbes
Pachydiscidae, gen. et sp. indet.
†*Cheirobelus lindsayi* (Hector)

ANNELIDA

Rotularia ornata (Wilckens)

VERTEBRATA

ELASMOBRANCHI

Hexanchus dentatus (Woodward)
Synechodus validus Chapman
Scaphanorhynchus rhaphiodon (Agass.)
Scapanorhynchus subulatus (Agass.)
**Carcharias incurva* (Davis)
**Isurus apiculatus* (Agass.)
**Isurus appendiculatus* (Agass.)
**Isurus crassus* (Agass.)

TELEOSTEI

Thrissopater ? sp.

FORAMINIFERA (by N. de B. Hornibrook): At most places, including the type locality, the Piripauan is composed of well sorted medium sandstone that is devoid of useful microfossils. A microfauna has recently been collected from George Stream, a tributary of Mangaotane River, in the Raukumara Peninsula, with *Inoceramus pacificus* (GS6275). It contains the following species: *Bathysiphon* sp., *Rhabdammina* sp., *Proteonina,* 2 spp., *Ammodiscus glabratus* Cushman and Jarvis, *Glomospira corona* Cushman and Jarvis, *Gaudryinella* sp., *Marssonella* aff. *oxycona* (Reuss), *Haplophragmoides* 2 spp., *Lagenidae, Gyroidina* aff. *nitida* (Reuss), G. aff. *globosa* (Hagenow), *Cibicides* sp., *Globigerina* aff. *cretacea* d'Orb., abundant, and *Globigerinella* aff. *aspera* (Ehrenberg).

The *Cibicides* sp. and *Gaudryinella* sp. occur in the Puketoro and Mangaotane mudstones—part of the Raukumara Series of Wellman (1955)—but are not known in the Haumurian. *Globigerina* aff. *cretacea* is usually abundant in the Clarence and Raukumara series but is not known in the Haumurian or Teurian stages. The Piripauan microfaunas thus more closely resemble those of the Raukumara Series than they do those of the Haumurian Stage.

Teratan Stage (lower Campanian)

TYPE LOCALITY (Fig. 11). The Teratan is the uppermost stage of the Raukumara Series. It is defined as the beds with *Inoceramus nukeus* and *I. opetius* at the Mangaotane Valley section. The name is taken from Te Rata Stream, a tributary of Mangaotane River. The beds consist of massive blue-grey siltstone and are about 1,000ft thick. They conformably underlie Piripauan sandstone and siltstone with *I.* aff. *pacificus* and *I. australis* and conformably overlie the type Mangaotanean.

DISTRIBUTION. Teratan beds are known from all Cretaceous areas north of Amuri Bluff. At Northland they consist of siltstone similar to that at the type locality. At Raukumara Peninsula they range from thin shelf sandstone at the southern and western margin of the region, through siltstone at the type locality and adjoining areas, to very thick siltstone and redeposited sandstone at the north end of the region. At the East Coast Ranges they range from siltstone on the west to siltstone and redeposited sandstone at the coast. In East Marlborough they consist entirely of shelf sandstone and are only about 100ft thick, except at Burnt Saddle, where they consist of thick dark mudstone. The stratigraphic position of the stage is defined by many sections and is well established, Teratan fossils having been collected from about 70 localities.

MACROFOSSILS. The two key species are *Inoceramus nukeus* and *I. opetius, Inoceramus nukeus* regularly overlying *I. opetius* in all sections in which both are found. The only other fossils are ammonites and a single poorly preserved gastropod; an undescribed ammonite species being reported with *Inoceramus opetius* from western Northland, and *Gaudryceras* sp. and the gastropod with *Inoceramus nukeus* from a boulder in the middle reaches of Cover Stream, Marlborough.

MICROFAUNA. Two microfaunas (Table I) have been described by Mr. Hornibrook, "A" from Teratan beds at Coverham and " B " from Puketoro Stream (in Wellman, 1955).

TABLE I

	A	B
Ammobaculites sp.	x	x
Lagenidae, moderately large	x	
Glomospira charoides (Jones and Parker)	x	x
Ramulina sp.	x	x
Gyroidina aff. *globosa* (Hagenow)	x	
"*Anomalina*" sp.	x	x
Globigerina cretacea d'Orb.		x
Gaudryinella cf. *delrioensis* Plummer		x

Similar Teratan faunas occur in Northland and in the Dannevirke Subdivision.

Mangaotanean Stage (Coniacian to Santonian)

TYPE LOCALITY (Fig. 11). The Mangaotanean is the middle stage of the Raukumara Series. It is defined by the beds at the Mangaotane Valley Section with *Inoceramus bicorrugatus* Marwick. They consist of massive blue-grey siltstones and are about 500ft thick.

The type Mangaotanean conformably underlies the type Teratan and conformably overlies the type Arowhanan. The name is from Mangaotane Stream, a tributary of Motu River.

DISTRIBUTION. The Mangaotanean is represented in the four northern Cretaceous areas; by shelf sediments in Western Northland and Eastern Marlborough, by transitional and redeposited sediments in the East Coast Ranges, and by shelf, transitional, and redeposited sediments at Raukumara Peninsula.

FOSSILS. *Inoceramus bicorrugatus* Marwick is the only widely distributed macrofossil. It has been found at about 40 localities. A small, poorly preserved, and undescribed molluscan fauna (GS2566, and GS8385) occurs with *I. bicorrugatus* on the East Coast of the North Island near Waimarama in redeposited gritty sandstone. The Waimarama fauna contains Lucinidae (n.gen.), *Opalia* n.sp., aff. *Cerithioderma* (?) n.sp., Cymatiidae (n.gen.), aff. *Perissoptera* n.gen., *Tudicla* n.sp., *Neritopsis* ? sp., none of which are closely related to known New Zealand Cretaceous species. Ammonite fragments are reported to be associated with *I.* aff. *bicorrugatus* (identified by Fleming and Marwick in Lillie, 1953: 28, as *Inoceramus* cf. *labiatus subhercynicus*

Seitz) near Porangahau. The fossils (GS2030) probably come from a lower Tertiary conglomerate, and the ammonite fragments may not be of the same age as the *Inoceramus*.

The microfaunas are similar to those in the Teratan.

Arowhanan Stage (Coniacian)

TYPE LOCALITY (Fig. 11). The Arowhanan is the lowest stage of the Raukumara Series. It is defined by the beds with *Inoceramus rangatira* in the Mangaotane Valley Section. The beds consist of siltstones with bands of redeposited sandstone and are about 500ft thick. The stage conformably underlies the type Mangaotanean and conformably overlies Ngaterian beds with the key fossil, *Inoceramus fyfei*. The name is from Arowhana Survey District.

DISTRIBUTION. The Arowhanan Stage is represented in the four northern Cretaceous areas. Only a single locality, near Whangape Harbour, is known from western Northland. In Raukumara Peninsula the stage is represented by mudstone overlain by shelf sandstone near Tahora at the southern part of the area, by siltstone at Puketoro Stream, and by siltstone with bands of redeposited sandstone in the northern part of the area. In the East Coast Ranges it is represented by siltstone near Tinui and by redeposited sandstone and siltstone at Waimarama and near Flat Point, but is not known elsewhere. In East Marlborough it is represented by shelf sediments at Sawpit Gully, at Seymour River, at Long Creek, a tributary of Hapuka River, and in boulders at Marfells Beach. About twenty fossiliferous Arowhanan localities are known. The Arowhanan beds of Sawpit Gully were included with the Bicorrugatus Zone of Wellman (1955: 105) pending the introduction of the Arowhanan stage.

FOSSILS. *Inoceramus rangatira* is the only widely distributed macrofossil. *Belemnites* (*Dimitobelus*) *superstes* Woods occurs at Sawpit Gully and is abundant at Long Creek, a tributary of Hapuka River. The Arowhanan is richly fossiliferous only near Seymour River, in the mid-Clarence Valley. The fossils were originally collected by McKay, and were described by Woods. The following list prepared by Dr. C. A. Fleming includes later collections. The species listed are from: GS6188 (Bluff River); 570, 5825, 5826 (Seymour River); 5827 (The Fell). The key Arowhanan fossil *Inoceramus rangatira* occurs in 5825 only, and the remaining collections may be Ngaterian in age.

Modiolus kaikourensis (Woods) (570, 5827, 6188)
Inoceramus rangatira (5825)
Ostrea sp. (5827)
Megatrigonia (*Iotrigonia*) *glyptica* (Woods) (570, 5825, ?5826, 5827)
Esalaevitrigonia meridiana (Woods) (570, 5825, 5826, 5827)
"*Astarte*" sp. (5825)
Lucinidae n.sp. (5825)
Pleurotomaria (*Perotrochus*) n.sp. (5826)
Struthioptera sp. (570)
Dimetobelus aff. *superstes* (Hector) (570, 5825)

Wilckens (1922: 35) described *Turritella solitaria* n.sp. from Hapuka River (GS293), but the type is lost and its generic position is uncertain. *Megatrigonia glyptica* (Woods) is known from the North Island at Waiotahi River (N78 GS6287), and Kaiwhata River (N161 GS5200) and from the South Island, in addition to the mid-Clarence Valley localities already mentioned, from near the Towy River (S48 GS2278) where it occurs with *Nototrigonia* n.sp., *Modiolus kaikourensis*, and *Struthioptera* sp. The absence of diagnostic *Inoceramus* from these collections makes the age somewhat uncertain, and it is possible that *M. glyptica* extends down into the Ngaterian.

Ngaterian Stage (Upper Turonian)

TYPE LOCALITY (Fig. 13). The Ngaterian is the uppermost of the four Clarence stages. It is defined by the beds in the Motu Falls section with *Inoceramus fyfei*, *Inoceramus tawhanus,* and *Inoceramus hakarius*. The beds are at least 1,500 feet thick and consist of dark siltstone with bands of redeposited sandstone. The name is taken from Ngateretere Survey District. The stage is conformably overlain by Arowhanan beds with the key fossil *Inoceramus rangatira,* and is conformably underlain by the type Motuan.

DISTRIBUTION. The Ngaterian Stage is represented in western Northland by siltstone with bands of redeposited sandstone that contain *Inoceramus tawhanus* at two localities. It is represented by a wide variety of sediments in Raukumara Peninsula: by shelf or transitional sediments at Waiotahi River and at Winding Stream, and as boulders composed of shrlf sediments in Haumurian beds at " Port " Awanui; and by redeposited beds at the Motu Falls Section and near Ruatoria at Wairongamai and Waingakia streams.

In the East Coast Ranges the Ngaterian Stage is known definitely only by massive mudstone which appears to disconformably underlie Haumurian beds at Tangaruhe Stream near Porangahau and by redeposited beds near Flat Point. In East Marlborough it is represented by two very different kinds of deposits: at Coverham by massive mudstone (Sawpit Mudstone and the upper part of the Cover Mudstone, Wellman, 1955), and in the middle Clarence and Awatere Rivers by basalts and fossiliferous tuffs. *Inoceramus ? fyfei* occurs in alternating sandstones and mudstones in beds mapped by Suggate (1958) as Split Rock formation (Motuan). The beds are possibly overturned and part of his Gridiron Formation (Ngaterian) and not unconformably below it as described.

MACROFOSSILS. The shelf sediments contain a variety of fossils, only some of which have been described. Fossils collected from the tuffs in the Middle Awatere River by McKay (GS741) were described by Woods. The following list has been revised by Dr. C. A. Fleming:

Barbatia cf. *marullensis* (d'Orb.)
Modiolus cf. *kaikourensis* (Woods)
Ostrea sp.
Esalaevitrigonia meridiana (Woods)
Nototrigonia n.sp.
Spondylus cf. *striatus* Sow.
Camptonectes sp.
Syncyclonema cf. *orbicularis* (Sow.)
" *Lima* " *marlburiensis* (Woods)
Inoceramus tawhanus (Wellman)
Panopea awaterensis Woods

McKay's collection (GS615) from the mid-Clarence probably includes some Arowhanan species. It is listed by Fleming in Suggate 1958: 404.

Ammonites are the most important fossils for dating this stage as Turonian. *Otoscaphites awanuienses* Wright was found in a boulder at Port Awanui with *Inoceramus tawhanus* and other mollusca, and *Hyphantoceras* cf. *reussianum* with *Inoceramus* aff. *costellatus* in a boulder at Wharfe Stream junction near Coverham, that probably comes from upper Ngaterian beds. The two ammonites are closely related to European upper Turonian forms (Wright, 1957). Mr. A. Russell, of the British Petroleum Company, recently collected *Mariella* cf. *lewisensis* (pers. comm. Mr. C. W. Wright) from dark mudstone 200 feet below *Inoceramus hakarius* and *I. fyfei* half a mile south of Matawai.

FORAMINIFERA (N. de B. Hornibrook). Distinctive microfaunas consisting mostly of calcareous species occur in the Sawpit and Cover mudstones of Coverham and in the mudstone at Tangaruhe Stream. They contain the following species, but have not been fully studied:

Lagenidae, small and distinctive
Anomalinidae, small and distinctive
Gyroidina, tiny and like *G. nitida* Reuss
" *Bulimina* ", tiny

Globigerina cretacea d'Orb.
Globigerinella aspera (Ehrenberg)
Karrerulina clarentia Finlay

Motuan Stage (Upper Cenomanian to Lower Turonian)

TYPE LOCALITY (Fig. 13). The Motuan is the upper of the two middle stages of the Clarence Series. It is defined by beds in the Motu Falls section that are divisible into an upper part with *Inoceramus ipuanus* and *Aucellina* sp. and a lower part with *Inoceramus urius* and *Aucellina euglypha*. The beds consist of dark siltstone with bands of redeposited sandstone and have a total thickness of about 1,200 feet. The name is taken from Motu River. The type Motuan conformably underlies the type Ngaterian and conformably overlies the type Urutawan.

DISTRIBUTION. At many places the Motuan is underlain by unfossiliferous greywacke, and is the lowest widespread fossiliferous Cretaceous stage. It is represented in Northland by conglomerate between Tupo and Motu Kahakaha bays (N7, GS4658). At Raukumara Peninsula it is represented by siltstone and redeposited sandstone at Mangaotane Valley and at the type locality, and by transitional mudstone in the Koranga district. A boulder of limestone probably derived from Haumurian conglomerate and composed entirely of *Aucellina euglypha* was collected by McKay from "Port" Awanui on the east side of the Raukumara Peninsula. It probably represents the shelf facies from the east side of the region. *Inoceramus ipuanus* has been found in a boulder of well sorted sandstone from the same locality. The Motuan is represented in the East Coast Ranges by thick siltstone and redeposited sandstone at Bushgrove, Gentle Annie, and Makarika streams, near Tinui. Ammonites are fairly abundant in concretions at the two first streams.

The Motuan is represented in the Coverham district by the lower part of the "Porrectus Zone" of Wellman, 1955, and consists largely of siltstone and redeposited sandstone that extend up the Clarence Valley to Seymour River, to form Suggate's (1958) Split Rock Formation with *I. ipuanus*. It also occurs in the middle Awatere Valley. At Coverham a thin lens of basalt is interbedded near the top of the Motuan Stage (Wellman 1955: 100) but the more extensive and thicker basalt flows at middle Awatere and Clarence Valleys are probably slightly younger and entirely Ngaterian in age. The Motuan in the Awatere Valley contains thick layers of redeposited conglomerate with numerous concretions, some of which contain Motuan fossils. It is represented to the east at Dunsandel Stream (tributary of Ure River) by concretionary soft greywacke with *Aucellina euglypha*, and to the south at Wharekiri Stream by conglomerate and redeposited beds similar to those at Awatere Valley.

FOSSILS. The geosynclinal Motuan beds in the upper Waioeka Valley contain scattered fossils which are not yet described, including pelecypods, gastropods, brachiopods and echinoids (GS6278, 6283). *Arca* sp., *Aucellina* sp., *Variamussium* sp., *Syncyclonema* sp., and *Nuculana* sp. occur in the Motuan beds of the Mid. Clarence (Suggate, 1958: 400).

Wright (1957) has described five species of ammonites from Motuan beds—*Puzosia* sp., *Phyllopachyceras* sp., *Anagaudryceras* sp., and *Wellmanites zelandicus* from near Tinui, Wairarapa, and *Pachydesmoceras* from near Coverham, Clarence Valley. Saurian remains occur with the ammonites near Tinui.

The fossils that occur at the type locality—*Inoceramus ipuanus* and *Aucellina* sp. in the upper part, and *Inoceramus urius* and *Aucellina euglypha* in the lower part—are by far the most widespread. *Aucellina* cf. *gryphaeoides* occurs with *A. euglypha* at several places. Only poor microfaunas are known from definite Motuan beds (Suggate, 1958: 400) but it is probable that the Motuan microfaunas do not differ significantly from those of the Ngaterian.

Urutawan Stage (Cenomanian)

TYPE LOCALITY (Fig. 13). The Urutawan is the lower of the two middle stages of the Clarence Series. It is defined as the beds with *Inoceramus kapuus* in the Motu Falls Section. The beds consist of dark siltstone with bands of redeposited sandstone and a few thin bands of *Inoceramus* limestone. They are about 3,000 feet thick. The name is taken from Urutawa Survey District. The Urutawan is conformably overlain by the type Motuan. It is conformably underlain by 500 feet of compacted dark siltstone and redeposited sandstone which conformably overlies massive sandstone similar to and probably the same age as the type Korangan 20 miles to the south-west.

DISTRIBUTION. The Urutawan occurs at a few places in the Motu and Matawai districts, but is not known elsewhere with certainty. At many places it is doubtless represented by the unfossiliferous greywacke that conformably underlies the Motuan. At Coverham it is probably represented by the " barren zone " between the Porrectus Zone and the Concentricus Zone.

FOSSILS. The only definite Urutawan fossils are *Inoceramus kapuus, Pseudolimea* sp. and *Pinna* sp. *Inoceramus kapuus* occurs at three horizons at the type locality, *Pseudolimea* and *Pinna* occur at single horizons only.

Coverian Stage (Albian—Lower Cenomanian)

TYPE LOCALITY (Wellman, 1955; Figs. 1 and 6): The Coverian is defined as that part of the Cover Mudstone with *Inoceramus concentricus* and *Inoceramus* sp. Z in the Coverham Section. The Concentricus Zone consists of medium blue-grey mudstone with concretionary bands and is about 1,000 feet thick.

The Concentricus Zone is overlain by about 1,000 feet of similar mudstone without diagnostic fossils—the Barren Zone of Wellman, 1955, and this is overlain by the Porrectus Zone. The Coverian is underlain by the Wharfe Sandstone. The name is taken from Cover Stream.

DISTRIBUTION. The Coverian is not known with certainty away from the type locality. At Motu Falls Section the beds between the base of the Urutawan and the top of the massive sandstone are possibly Coverian in age. The only fossil is a coral *Oculina ? nephrens* (Squires) that extends up into the Ngaterian. A highly fossiliferous band of gritty sandstone at the Korangan Section (GS5792) is probably Coverian in age. It is immediately above the sandstone with the type Korangan fossils and about 1,000 feet below Motuan mudstone with ***Aucellina* aff. *euglypha.*** The fossils are listed below. Unfortunately they contain no species in common with the type Coverian. In other sections pre-Motuan beds are probably unfossiliferous.

FLORA. From the marine beds at the type section the following Spores and Pollens have been recorded by Couper (in Wellman, 1955: 108):

Osmundacidites wellmanii Couper
Podocarpidites major Couper
Cyathidites australis Couper
Podocarpidites cf. *ellipticus* Cookson
Microcachryidites antarcticus Cookson
Cyathidites minor Couper
Araucariacites cf. *australis* Cookson
Trilites verrucatus Couper
Hymenophyllum sp.
Lycopodium fastigioides Couper
Tricolpites ? sp. Cookson ex Couper

These fossils are important, for in conjunction with those collected from the Ngaterian coal-measures in the Seymour River district they enable the Cretaceous fresh-water beds of the West Coast to be dated. The only angiosperm pollen in the above list is *Tricolpites* sp. It is extremely rare, being represented by a single pollen grain in a preparation of about 500 spores and pollens.

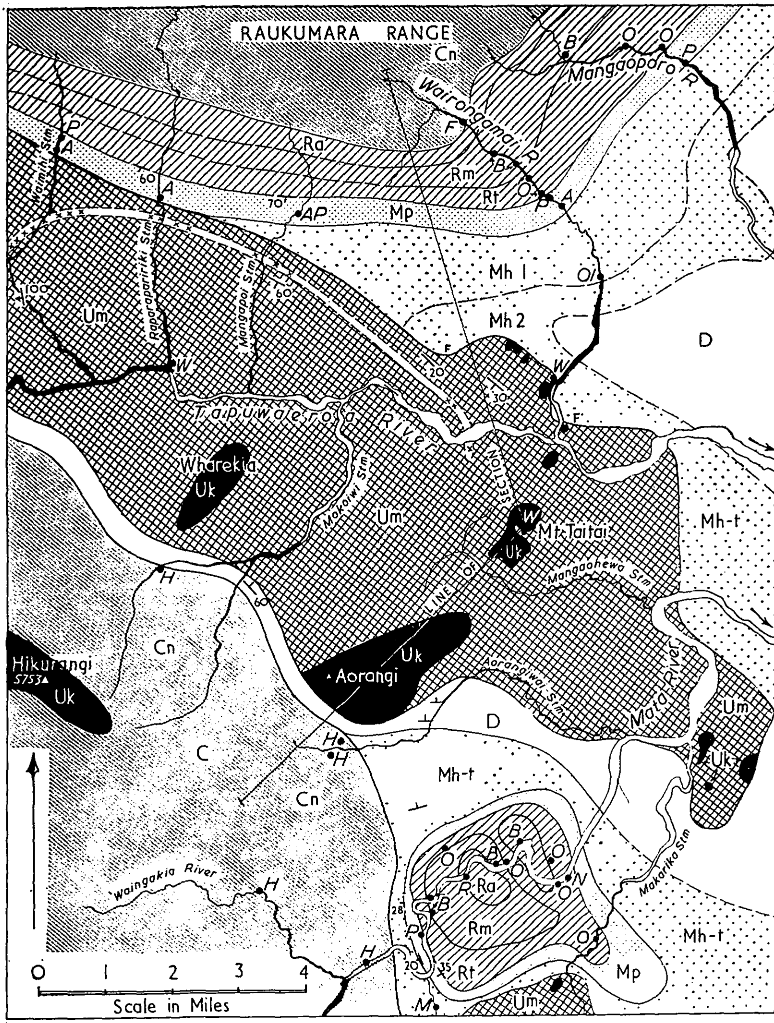

FIG. 17.—Sketch map of the lower Tapuwaeroa and Mata Valleys. Mokoiwi Stream is the type locality for the Mokoiwian Stage. A standard section for the Raukumara Series is in the lower Mata Valley.

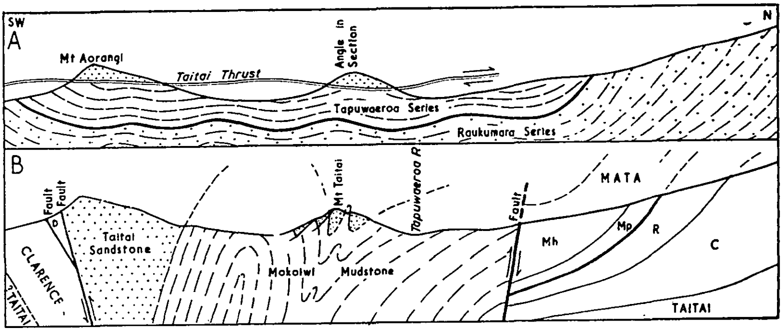

FIG. 18.—Sketch cross-sections across Tapuwaeroa Valley showing different tectonic and stratigraphic interpretations. Length of sections about 12 miles. Horizontal and vertical scales are the same. A: Interpretation according to Macpherson (1946) with Taitai thrust separating Taitai Sandstone from Tapuwaeroa Beds. B: Interpretation favoured by writer, with Mokoiwian Mudstone in sedimentary contact with Taitai Sandstone and in fault contact with upper Cretaceous beds.

TERT.	DAN.		D	Mottled bentonitic mudstone and black shale	
UPPER CRETACEOUS	MATA	TEURIAN	Mt	not definitely determined. Calcareous mudstone	
		UPPER HAUMURIAN	Mh2	Concretionary sandstone greensand bent. mudstone	
		LOWER HAUMURIAN	Mh l	Sandstone, grit, and dark mudstone	OL *Ostrea lapillicola*
		PIRIPAUAN	Mp	Carbonaceous sandstone and mudstone	A *Inoceramus australis* P *I. pacificus*
	RAUKUMARA	TERATAN	Rt	Green grey siltstone with red bands	O *I. opetius*
		MANGAOTANEAN	Rm	Siltstone with bands of redeposited sandstone	B *I. bicorrugatus*
		AROWHANAN	Ra	Dark siltstone with bands of redeposited sandstone	R *I. rangatira*
	CLAR.	NGATERIAN	Cn	Strongly compacted siltstone redeposited sandstone bands	H *I. hakarius*
LOWER CRET.	TAITAI	KORANGAN	Uk	Dark massive sandstone well rounded igneous pebbles	no fossils
		MOKOIWIAN	Um	Dark crushed mudstone and redeposited sandstones	W *I. warakius*
		MOKOIWIAN volcanic band	Umv	Basalt pillow basalt and red mudstone	

FIG. 19.—Legend for Figs. 17 and 18. Undifferentiated Clarence beds shown on map "C" are not included in legend.

The cycad *Zamites* cf. *takuraensis* Walkom was collected from about 100 feet lower in the sequence (McQueen, 1956).

FAUNA. The following occur at the type section:

PISCES

Diplomystus coverhamensis Chapman

MOLLUSCA

Turrilites circumtauriatus (Kossmat)
(*Mariella* or *Pseudhelioceras* according to Spath, 1953: 46)
Inoceramus concentricus Parkinson
Inoceramus sp. Z

CORALS

Haimesiastrea anchistina Squires

Dr. C. A. Fleming has listed the following from the fossil band at Koranga (GS792):

Nucula sp.
Nuculana sp.
Cucullaea ? aff. *hendersoni* Eth.
Aucellina aff. *gryphaeoides* (Sow.)
? *Chlamys* sp.
Parvamussium sp.
Pseudolimea n.sp. aff. *echinata* (Eth.)
Puzosiinae (gen. indet.)
Rotularia sp.
Undetermined rhynchonellid and terebratulid brachiopods.
Isurus sp.

In Fifty Stream, gritty conglomerate (GS1401) contains *Aucellina* aff. *gryphaeoides*, *Syncyclonema* (?) sp. *Exogyra* cf. *conica* (Sow.), *Rotularia*, and a brachiopod, *Kingena* (?) sp.

No foraminifera have been found in the Coverian.

Korangan Stage (Aptian)

TYPE LOCALITY (Fig. 15). The Korangan Stage replaces the Taitai Series of Finlay and Marwick (1940: 102). No type locality was given, but Finlay and Marwick mentioned that the fossils on which the Taitai Series was based came from the Koranga district and that the name was taken from the Taitai Sandstone at Tapuwaeroa Valley, 40 miles north-east. The Taitai Sandstone is unfossiliferous and may not be the same age as the fossiliferous beds. The fossils represent a relatively short time interval, certainly not of series rank. It thus seems best to redefine the fossiliferous beds as a stage, for which the name Korangan—taken from the Koranga River district—is the only one available. The name Koranga "Series" was used by Ongley (1930: 8) in the sense of a formation name for a group of beds that were considered to underlie the Korangan but which actually overlie and are now included in the Raukumara "Series" of Ongley and Macpherson (1928) and considered to be Coverian to Ngaterian age. The confusion is due to overturning in Winding Stream (Fig. 15) not seen by Ongley.

The relation of the Korangan to the overlying sediments is illustrated in Fig. 8. The stratigraphy is given below:

KORANGA SECTION

	Feet.
Motuan Stage	
Mudstone with *Aucellina* cf. *euglypha*	20+
Urutawan and Coverian stages?	
Mudstone, no fossils found	500
Grit bands with abundant fossils (GS5792)	5
Korangan Stage	
Hard dark sandstone with ill-defined conglomerate bands	500
Feldspathic medium sandstone with rare fossils (GS3154)	20
Conglomerate and dark sandstone with rare fossils (GS5790)	10
Possibly Mokoiwian	
Dark sandstone and siltstone (greywacke) with rare conglomerate bands	500+

No fossils have been found in the lower part of the sequence, and the base of the Korangan Stage is not well defined. The Korangan fossils come from two thin gritty sandstone bands that grade laterally into unfossiliferous sandstone similar to that above the fossils. The sandstone contains conglomerate bands with well rounded igneous pebbles and is fairly distinctive, and the top of the sandstone is here regarded as the top of the Korangan stage. It is overlain—possibly disconformably—by the fossiliferous grit that has already been described under Coverian.

DISTRIBUTION. The Korangan Stage is probably represented in the Raukumara Peninsula and the East Coast Ranges by the upper part of the Taitai Sandstone, but the sandstone is unfossiliferous and its exact age is uncertain. The only fossiliferous correlative is a bed with concretionary bands and pebbles of concretions half a mile east of the mouth of Hawai River on the coast east of Opotiki. The fossiliferous bed is part of a thick greywacke sequence that extends over most of the west side of the Raukumara Peninsula and which contains lower Jurassic fossils at Waimana River (Fleming, 1953) and upper Jurassic or lower Cretaceous fossils at Waiotahi River.*

FOSSILS. The fossils at the type locality were discovered by Mr. M. Ongley during his survey of the Wairoa Subdivision. They were mistakenly considered Jurassic by Marwick in 1934 but identified by him as Aptian in 1939. Several re-collections have been made since, and the complete list, given in Table II, and the discussion that follows has been prepared by Dr. C. A. Fleming.

TABLE II.

	1403	1989	2084	3154	5790
Nuculana sp.				x	
Cucullaea sp. A				x	
Cucullaea sp. B	x				
Cucullaea sp. (fragment)					x
Dicranodonta sp.		x			
Aucellina n.sp. aff. *pavlowi* Sok.	x	x	x	x	x
Maccoyella magnata Marw.		x			
Pteria sp.				x	
? *Pseudopteria* sp. (large)				x	
Inoceramus sp. (cast of prismatic shell)	x		x		
? *Neithea* sp.				x	
Camptonectes sp.				x	
Spondylus sp.				x	
"*Lima*" n.sp.				x	
? *Ctenoides* sp.				x	
Ostrea sp.				x	
"*Lucina*" aff. *tenera* (Sow.)				x	
Astarte (s. lat.) sp.				x	
Trigonia (*Trigonia*) n.sp. aff. *tenuis* Kitchin		x			
? *Buchotrigonia* sp.				x	
? *Protocardia* sp.				x	
"*Martesia*" n.sp.				x	
Panopea sp.				x	
Pleuromya n.sp.				x	
Belemnite fragment		x			
"*Serpula*" sp.				x	x
Rotularia (= *Tubulostium*) sp.				x	
Dentalium (s.l.) sp.					x

Five collections are registered at the Geological Survey, but all are from near the saddle through which a recently constructed access road passes (Fig. 8), and are in similar rusty conglomeratic sandstone—the Taitai Series of Ongley (1930) and Marwick (1939):

* GS6292, Kahunui Stream, north end of Kaihikatea Settlement: *Maccoyella* sp., and *Pleuromya milleformis* Marw.

GS1403, Motu (SW) S.D. Ridge at head of Elmar and Harding streams (M. Ongley, 1930).

GS1989, Moanui (SE) S.D. Track, 50 chains north of Koranga River, 5 miles 10 chains at 315° from Maungatapere Trig Station (M. Ongley, 1929).

GS2084, Motu (SW) S.D. Ridge leading up westward from head of Harding Stream (M. Ongley, 1929).

GS3154, Koranga S.D. Conglomerate, ridge one mile NW from Williams Road (M. Ongley and Tichener, 1941; re-collected by H. W. Wellman, 1955).

GS5790, N88/518. Quarry at saddle on access road north from Williams Homestead (H. W. Wellman, 1952).

Dr. J. Marwick (1937: 463) reported *Maccoyella* from GS1989 and *Aucellina* from 1403, 1989, and 2084. His manuscript notes have been used in compiling Table II. Most of the fossils are fragments and moulds.

Marwick (1939) concluded that the Korangan fossils are probably Upper Aptian (Gargasian) from *Aucellina* which ranges from upper Aptian to upper Cenomanian in Western Europe and from *Maccoyella magnata* which has advanced sculptures like the Aptian species from the upper part of the Roma Series of Queensland. His subsequent recognition of *Dicranodonta* (Upper Jurassic to Aptian) and the resemblance of the Taitai *Aucellina* to the Aptian species *A. pavlowi* reinforces the evidence for the Aptian age.

The only other important Koranga collection is GS5773/N70/501; coast half a mile NE Hawai R., 16 miles E of Opotiki (H. W. Wellman, 1953).

Aucellina n.sp. aff. *pavlowi* Sokolov
Aucellina cf. *aptiensis* (d'Orb.)
Inoceramus sp. (prismatic fragments)

Aucellina is represented by four fragments of undistorted left valves in concretions and by several crushed and indeterminable specimens. Three of the undistorted left valves are high and inflated with fine radial striae and with very stout beaks suggesting comparison with two Russian species: the upper Aptian to Albian *A. nassibianzie* Sokolov, and the Aptian *A. pavlowi* Sok. that have been distinguished by their stout beaks from other members of the genus (Gillet, 1924: 36). They cannot be distinguished from, and are probably not very different in age from the *Aucellina* aff. *pavlowi* from Koranga.

The other left valve has a low narrow beak similar to the upper Aptian *A. aptiensis* (d'Orb.), as figures by Pomeckj (1901, pl. 16, f. 5). The diagnostic hinge characters of *Aucellina* cannot be fully demonstrated and the shell may be a *Buchia* but is certainly distinct from the New Zealand upper Jurassic species of *Buchia* of the Kawhia and Oteke series.

No foraminifera have been obtained from the type locality or from the beds below the Urutawan in the Motu Falls Section.

Mokoiwian Stage (Upper Neocomian to Lower Aptian)

TYPE LOCALITY (Fig. 17). The Mokoiwian is the lowest stage at present recognised in the Taitai Series. It is defined as the beds with *Inoceramus warakius* in the Tapuwaeroa Valley. The beds are several thousand feet thick, but their base is not defined and their total thickness is uncertain. In the lower part of the valley they consist of crushed dark mudstone that is soft and easily eroded. Ongley and Macpherson (1928) confused this mudstone with the much younger Tapuwaeroa Formation. In the upper part of the valley the Mokoiwian contains many thin bands of redeposited sandstone and is stronger, less crushed, and very like other New Zealand greywackes. An interbedded band of pillow lava and agglomerate about a hundred feet thick has been traced for several miles along the north side of Tapuwaeroa Valley. In the headwaters of Tapuwaeroa River, the Mokoiwian contains interbedded bands of massive sandstone somewhat similar to the sandstone of Taitai Hill and darker in colour than the thin redeposited bands already mentioned.

The name is based on the Mokoiwi Formation of Mr. C. St. J. Bremner, of the Vacuum Oil Company, who used it in an unpublished report dated April, 1934, for " black shales and grey sandstone in Mokoiwi Stream, in the lower three miles of the Raparapaririki Stream, and in the Tapuwaeroa River for ten miles upstream from the mouth of the Wairongamai Stream ". Mr. Bremner was the first to distinguish these rocks from the much younger Tapuwaeroa Formation (Haumurian).

The Mokoiwian is overlain by the Taitai Sandstone—a hard sandstone with conglomerate bands that forms the upper parts of the mountains within the Tapuwaeroa Valley. The sandstone is a fairly distinctive formation that closely resembles the fossiliferous sandstone at Koranga on which the Korangan Stage is based. The name Taitai Series was originally applied to the present Korangan Stage because of this resemblance.

DISTRIBUTION. The Mokoiwian is known at several localities, everywhere represented by dark crushed mudstone with *I. warakius.* It covers about 40 square miles in Tapuwaeroa Valley, and about 12 square miles to the south-east in the centres of the Makarika and Te Puia domes. To the south in the East Coast Ranges, *Inoceramus warakius* occurs in dark mudstone at the mouth and headwaters of Pahau River, and in the Owahanga River.

FOSSILS. The only fossil known in addition to the *Inoceramus* is a *Globigerina* from Tapuwaeroa River (F3182) mentioned by Finlay in an unpublished report. No overseas correlatives are known for the *Inoceramus.*

REVIEW OF RESULTS AND ACKNOWLEDGMENTS

Relative Stratigraphic Importance of Fossil Groups.

Foraminifera are of the greatest importance in the uppermost Cretaceous and define the contact between the Cretaceous and Tertiary, which at most places in New Zealand is gradational and not easily defined by macrofossils. Foraminifera become progressively less useful in the lower stages, in part because of the higher degree of compaction of the strata, and are less reliable than molluscs for stratigraphic division in the Raukumara and pre-Raukumara stages.

Ammonites have been less useful than might be expected. They are extremely rare at most places and of little use for internal correlation. Several have proved to be reliable for overseas correlation, but some have provided misleading ages, or have suggested internal correlations that have been given undue weight. Belemnites are abundant and well preserved only in the Piripauan and Arowhanan shelf sediments at a few places. They appear to have little stratigraphic importance, but have not been studied closely.

Inoceramus and *Aucellina* are by far the most useful fossils. Distinct species of *Inoceramus* are known from all stages except the Teurian and Korangan, and division is based largely on this genus. At present *Aucellina* is known only in the Motuan and Korangan, but it is a facies tolerant genus and useful new species will probably be found in pre-Ngaterian beds.

The usefulness of the other molluscs is limited by their virtual restriction to a small range of shelf sediments. Several small faunas remain to be studied, but it is unlikely that many large well preserved faunas remain undiscovered.

The rapid increase in the abundance and number of species of angiosperms from the Albian to Senonian represents a floral revolution as important as the faunal revolution at the end of the Cretaceous. Within the critical Albian to Senonian age-range pollens may prove to be the most diagnostic fossils. Microfloras have been studied from a few of the marine stages, but further work is required for close correlation of the non-marine beds of the southern and western parts of the South Island.