TRANSACTIONS

OF THE

ROYAL SOCIETY OF NEW ZEALAND

EARTH SCIENCES

VOL. 8 No. 1 14 JULY 1970

Stratigraphy, Petrography and Origin of the Te Kuiti Group in the West Piopio Area

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[Received by the Editor, 3 February 1969]

Abstract

THE Oligocene Te Kuiti Group in the west Piopio area is divided into two major units—the lower Te Anga Subgroup and the upper Castle Craig Subgroup—following the work of Barrett (1967). Within the upper subgroup, two formations are recognised and are correlated with the Orahiri and Otorohanga formations of Kear and Schofield (1959).

The Te Kuiti sediments were deposited as the sea transgressed over a broadly undulating surface of low relief that was dominated by a prominent north-trending ridge in the east. Deposition continued until this ridge was almost completely covered. The contact with the overlying Mahoenui Group is discussed and evidence presented to show that the two groups are conformable.

The various lithologies are examined in finer detail than has been the case in the past, and thin-section data is used extensively on Te Kuiti rocks for the first time. This has led to the recognition of seven members within the two formations of the Castle Craig Subgroup. A number of facies are also recognised. Isopach maps for each of the major units, stratigraphic columns for the Castle Craig Subgroup, and a detailed cross-section are presented.

The boundaries of the major units are examined in some detail. It is postulated that the Te Anga–Castle Craig boundary is approximately isochronous in the area and the change in lithology and inferred depositional environment across this boundary is the result of specific changes in the source area which supplied terrigenous sediment to the basin. The Otorohanga–Orahiri boundary is shown to be time-transgressive, and the change in depositional environment reflected in the rocks across this boundary is thought to be the result of more subtle changes in paleogeography.

Finally, the petrographic and stratigraphic data is interpreted, and a synthesis of the depositional history of the Te Kuiti Group in the area is attempted.

INTRODUCTION

THIS paper deals with the Te Kuiti Group in an area of approximately fifty square miles lying to the west of Piopio and about fourteen miles south of Te Kuiti (Fig. 1). The area covers much of the south-east corner of N.Z.M.S. 1, Sheet N82, except for a small portion south and east of New Plymouth–Te Kuiti main highway. Thirty-nine stratigraphic columns were measured in the area and

Published by the Royal Society of New Zealand, c/o Victoria University of Wellington, P.O. Box 196, Wellington.

Trans. R. Soc. N.Z., Earth Sciences, Vol. 8, No. 1, *pp. 1–26, 14 figs., 5 pls.*

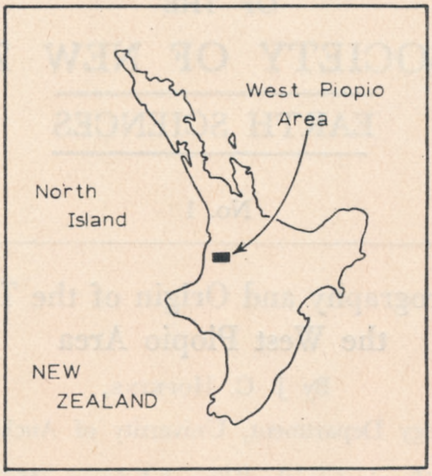


FIG. 1.—Location map of the west Piopio area.

these form the basis of the study. The columns, which are numbered "S1" to "S39" have been presented previously in detail (Hopkins, 1966). In addition, the area was mapped on a scale of four inches to one mile using N.Z.M.S. 3, area 1 mosaic maps N82/8 and N82/9. A reduced version of this map is given in Fig. 2. All grid references cited refer to the one thousand yard grid superimposed on this map.

Previous Work

The area has been mapped by Henderson and Ongley (1923), by Marwick (1946), a compilation of the efforts of several earlier workers, and by Kear (1960). None of these authors dealt specifically, or in any detail with either the Te Kuiti Group or the west Piopio area.

Kear and Schofield (1959) have defined the Te Kuiti Group and a number of formations within it on the basis of extensive work in the South Auckland district. Barrett (1962) has worked in the Waitomo–Te Anga area and later (1967) has carried out reconnaissance work in the north-west Piopio area. The discussion that follows summarises the work of these later writers as it applies to the west Piopio area.

At Worth's Quarry, Waitomo, Kear and Schofield (1959) have recognised the following formations of the Group:

Otorohanga Limestone
Waitomo Sandstone
Orahiri Limestone
Aotea Sandstone
Whaingaroa Siltsone

Barrett (1962) has attempted to trace the formations recognised at Worth's Quarry westwards to the Te Anga area and has found that the Waitomo Sandstone becomes more calcareous and eventually cannot be distinguished from the Otorohanga and Orahiri limestones. He therefore has erected the Castle Craig Limestone as a formation which he considered to be the lateral equivalent of the three topmost formations of the Te Kuiti Group at Worth's Quarry. The Whaingaroa Siltstone could not be traced west of the Waitomo area either, and the Aotea Sandstone was found to be dominantly: "A massive light, blue-grey, very calcareous siltstone." (Barrett, 1962: 9). Barrett therefore erected the Te Anga Formation to cover these rocks in this area. The formation has been defined to include all the beds below the Castle Craig Limestone in the west and the

FIG. 2.—Geological map of the west Piopio area showing the location of stratigraphic columns measured.

Orahiri Limestone in the east, the lower boundary being the post-Mesozoic erosion surface, or, where present (in the east) the Whaingaroa Siltstone. He thought that the Te Anga Formation would grade into the Aotea Sandstone to the north.

In a later paper, Barrett (1967: 1011) has elevated the Te Anga and Castle Craig formations to the status of subgroups because, in the Te Kuiti Group, " . . . two major rock units can be readily separated everywhere west of the Rangitoto Ranges between Kawhia and Piopio. The lower part of the group is mostly calcareous siltstone and sandstone, while the dominant lithology of the upper part is flaggy shell limestone".

Terminology

The following divisions of the Te Kuiti Group, instituted by previous workers, are recognised by the present writer in the west Piopio area:

Te Anga Subgroup, Barrett, 1967
Castle Craig Subgroup, Barrett, 1967
Orahiri Limestone, Kear and Schofield, 1959
Otorohanga Limestone, Kear and Schofield, 1959

In addition to these, the writer has formally defined seven members within the two formations of the Castle Craig Subgroup. A number of facies are also recognised.

"Facies" is used in an informal stratigraphic sense and rocks are grouped into a particular facies because of their stratigraphic relationships and because they possess certain characteristics which indicate deposition under similar conditions. The facies are numbered and a particular facies is referred to as, for example, Facies E3, or Facies 3 of Member E. For the Te Anga Subgroup, since formations and members are not defined, the facies are referred to as Facies TA1, etc.

The basic terminology for the limestones of the Castle Craig Subgroup is that of Folk (1959; 1962). Three terms that are used frequently and require some clarification are "mud", "calcite-mud", and "micrite". Mud is considered to be a mixture of clay and silt-sized particles in which neither end-member perdominates greatly over the other. Calcite-mud is an analagous term used where the clay and silt-sized particles are composed of calcite. Micrite is not synonymous with calcite-mud and is applied to 1–4 micron calcium carbonate with special textural properties (Folk, 1962).

General Aspects

The Te Kuiti Group in the area has a regional dip of 2° to 4° to the south-south-east. Steeper dips are usually found only near faults or along the western margin of the Tertiary cover, where uplift of the Herangi Range has imparted an average easterly dip of 15° to the Tertiary cover.

Isopach maps (Figs. 3–7) have been prepared for the major units of the group, the thicknesses being obtained from the stratigraphic columns and from additional measurements where necessary. These show that deposition took place over a broadly undulating topography of low relief cut on Mesozoic strata and dominated by a prominent north-south ridge and a subsidiary north-west trending ridge. The lower part of the group was deposited in the intervening valleys and later, when these were filled, over the ridges. Thus the Te Anga Subgroup is present only in the western part of the area for it abuts against the main north-trending ridge, whereas the Castle Craig Subgroup is widespread throughout the area. Over the southern part of the north-trending ridge the Te Kuiti Group is very thin and it is probably absent from two small areas (Fig. 3). However, no contacts between the Mesozoic basement and the Mahoenui Group (which invariably overlies the Te Kuiti Group in this area) that might confirm this, were located.

Age

Several samples were sent to Mr N. de B. Hornibrook (N.Z. Geological Survey, Wellington) for microfaunal age determination, but all but four proved too hard for foraminiferal extraction. Of these, three were taken from the base of the Te Anga Subgroup and proved to be of Whaingaroan age. The remaining sample came from the Mahoenui Group immediately overlying the Te Kuiti Group, and was dated as Waitakian.

LIMITS OF THE TE KUITI GROUP

Lower Limit

The lower limit of the Te Kuiti Group is defined by Kear and Schofield (1959: 692) as the base of "the oldest Tertiary formation at present known in the area west of the main divide of the North Island, and south of Auckland City".

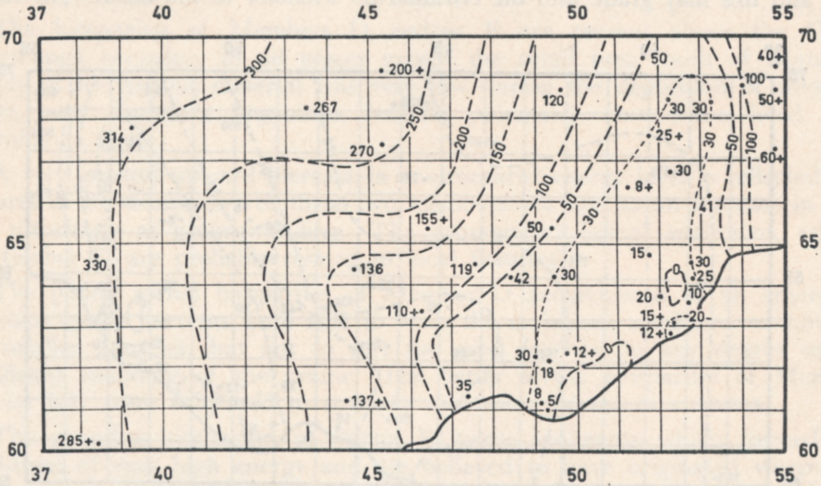


FIG. 3.—Isopach map of the Te Kuiti Group. (Thicknesses on all isopach maps are in feet.)

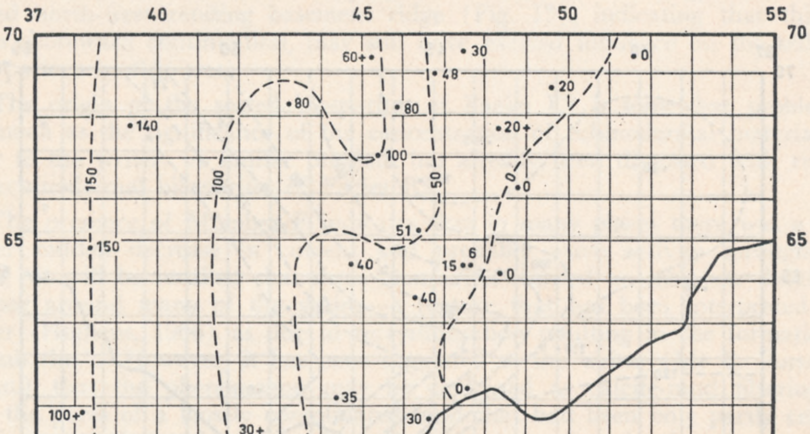


FIG. 4.—Isopach map of the Te Anga Subgroup.

This definition can be applied successfully in the west Piopio area, where a number of lithologies are present at the base of the Te Kuiti Group. In general the surface of the Mesozoic basement shows little sign of weathering before the deposition of the Tertiary sediments except where the coal measures are present, because of marine erosion immediately prior to deposition, which has resulted in local irregularities in the basement topography.

In the west, where the Te Anga Subgroup is present, the range in lithologies at the base is from coal measures to conglomerates, grits, sandy and sometimes gritty limestones, and calcareous siltstones. Similar basal lithologies and a more widespread basal limestone were noted at the base of the Te Anga by Barrett (1962) in the Te Anga area, and were included as the Awamarino Member. This division is not recognised in the west Piopio area because the basal lithologies are thinner, discontinuous, and very variable. There is some indication that an impure basal limestone becomes more continuous in the central northern part of the area, and this may grade into the Awamarino Member to the north. An excellent

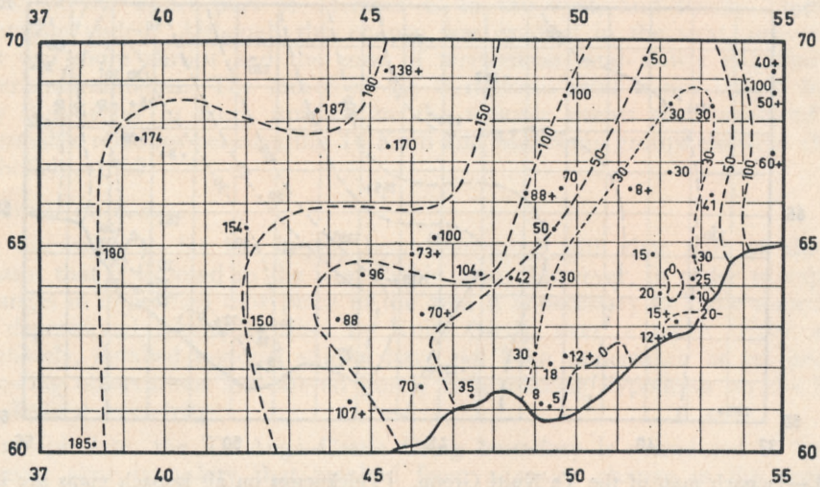


FIG. 5.—Isopach map of the Castle Craig Subgroup.

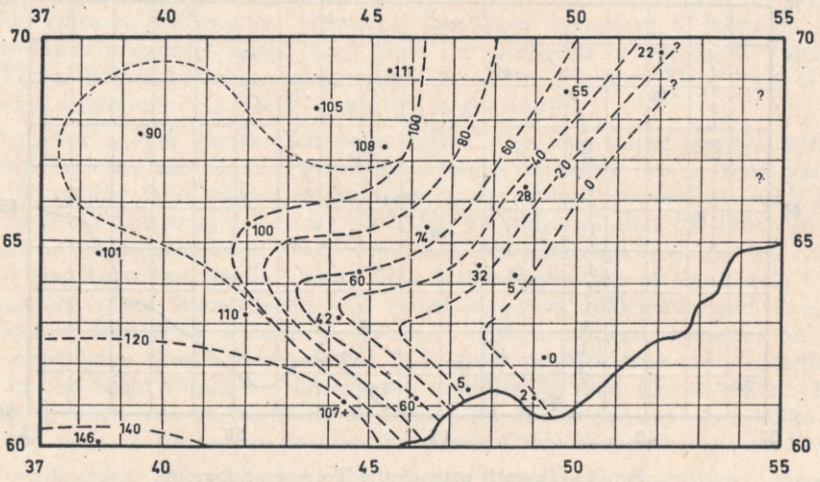


FIG. 6.—Isopach map of the Orahiri Limestone.

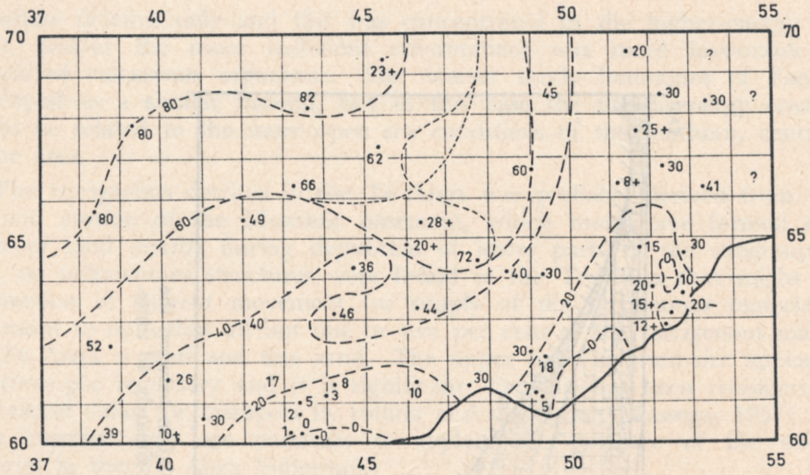


FIG. 7.—Isopach map of the Otorohanga Limestone.

exposure of the basal contact occurs in a road-cutting on the State Highway and is shown in Pl. 1, Fig. 1.

Where the Castle Craig Subgroup is in contact with the basement the basal lithologies range from conglomerates to biomicrites and biosparites.

Upper Limit

The upper limit of the Te Kuiti Group has been discussed by Kear and Schofield (1959: 692) and is defined as: " the topmost flaggy limestone (Otorohanga Limestone) in the Waitomo Valley (nine miles north of Te Kuiti township) or any equivalent offshore horizon ". As the meaning of the phrase " offshore horizon " is not clear, the upper limit may have to be redefined in the future.

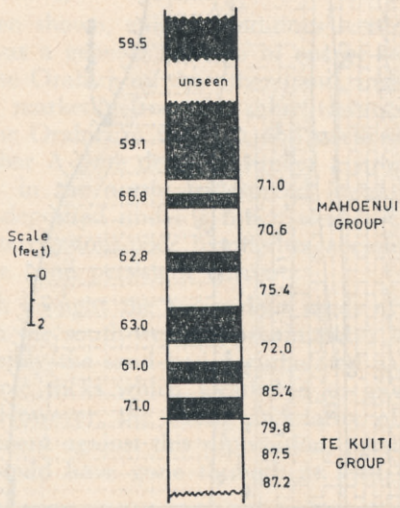


FIG. 8.—Detailed stratigraphic column for the gradational contact between the Te Kuiti and Mahoenui Groups at 390646. Figures by the column indicate per cent carbonate in samples taken from each position.

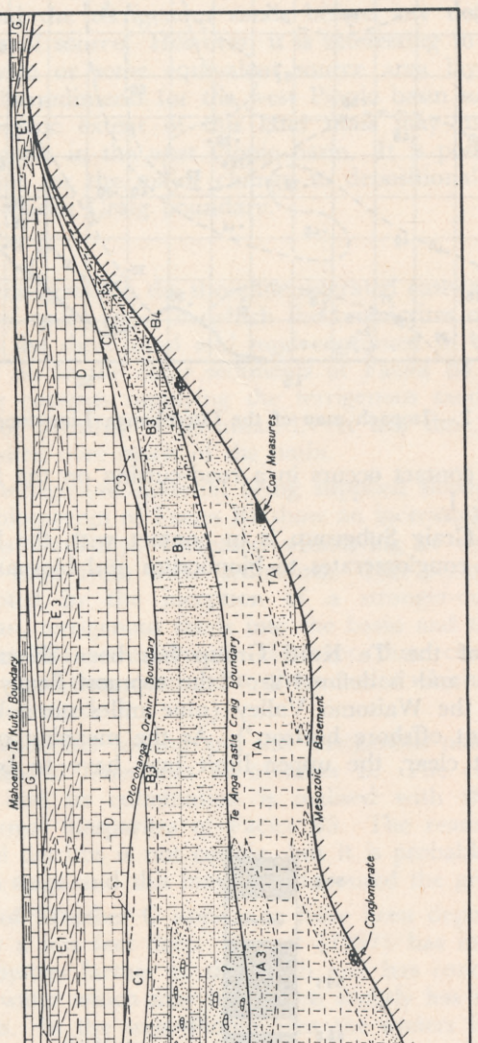


FIG. 9.—Diagrammatic cross-section of the west Piopio area showing the relation between the various units recognised in the Te Kuiti Group. Vertical exaggeration approximately 40 times.

In the west Piopio area, the contact between the Te Kuiti Group and the overlying Mahoenui Group is exposed at a number of localities, some of which are described below. At no locality could evidence be found that might indicate an unconformity, and it appears that deposition of the Te Kuiti Group was brought to a close by a change in the depositional regime. The break is both lithologic and faunal and was marked by an influx of terrigenous mud into the basin. The impending change is often heralded by the appearance of terrigenous mud and new faunal elements in the top of Member G (see later).

Along the western margin of the Tertiary cover the contact is exposed at a number of localities, the best of which is at 390646. Here alternate beds of " hard " and " soft " argillaceous limestone are found above Member G (Pl. 1, Fig. 2) and show an overall upward decrease in percentage carbonate (Fig. 8). The top of the Te Kuiti Group is taken as the base of the first " soft " bed. Bedding cannot be determined accurately in the argillaceous limestones of the Mahoenui Group immediately above the alternating sequence at any locality, but a hard limestone bed is present in the Mahoenui Group about 30ft above the top of the Te Kuiti Group in this area and has the same attitude as the beds at 390646. The contact is therefore considered to be gradational.

To the east, evidence of a gradational contact becomes less obvious, however; at 437653 two " hard " and " soft " bands mark the transition from the Te Kuiti Group into the Mahoenui Group. East and south of this locality Member G becomes thinner and finally disappears, and the transition is not seen. Usually Member G, where present, is slightly argillaceous towards the top of the sequence and is overlain sharply by massive calcareous mudstones of the Mahoenui Group. Where Member G is absent the Mahoenui Group rests directly on Member F in the east and Member C in the south. In each case the contact is sharp but affords no evidence of an erosional interval. Such a contact is unusually well exposed at 486646, where 20in of dark-green glauconitic, argillaceous limestone rests directly on Member F and grades up into massive blue-grey calcareous mudstones of the Mahoenui Group.

East of the basement ridge, the upper part of Member G is, in most places, very silty and grades up into the Mahoenui Group at several localities, especially south of Piopio. Thus at 526631, two " hard " and " soft " beds above Member G mark the transition into the Mahoenui Group.

STRATIGRAPHY

Detailed stratigraphy is given only for the sequence west of the main north-trending basement ridge. This is because the lower part of the sequence east of the ridge differs markedly from that in the west.

The relation between many of the units recognised is shown in the diagrammatic cross-section (Fig. 9). This cross-section corresponds closely to what a true cross-section through the centre of the map would be like, although some changes have been made in order to emphasise the relationship between units. Thicknesses of the various units are approximately proportional to their true thickness. It should be noted that the vertical scale has been greatly exaggerated.

A description of the boundaries between the two subgroups and between the Orahiri and Otorohanga formations is given after this section.

TE ANGA SUBGROUP

The bulk of the Te Anga Subgroup in the area is composed of calcareous mudstones and fine sandy, silty limestones. Section S2 is designated as a reference section for the subgroup in the west Piopio area. At this section, 150ft of Te Anga strata was recorded—the maximum thickness seen in the area.

Description of the Reference Section

The lowest 8ft of the sequence at the reference section is occupied by coal measures which are dominantly carbonaceous mudstones. They lie on weathered basement material containing rootlet beds. Near the top of the carbonaceous sequence a 3in band of hard, carbonaceous limestone occurs and is followed by about 9in of very carbonaceous claystone which quickly grades up into non-carbonaceous, calcareous mudstone.

The next 40ft is made up of blue-grey conchoidal, calcareous mudstones which are interbedded with harder sandy, silty limestones that invariably show brown staining on surface outcrop. Above this a relatively monotonous succession of blue-grey conchoidal calcareous mudstone forms the remainder of the sequence. The upper boundary is sharply defined, and leached limestones of the Castle Craig Subgroup, with a few small pebbles at the base, are in contact with the Te Anga rocks. The upper 6in of the Te Anga has been leached to a clay pug by water percolating through the overlying porous sands.

Distribution and Variation

Rocks of the Te Anga Subgroup are widely distributed over the western part of the area, but in the central part lap against the basement ridge (Figs. 4 and 9). The various basal lithologies encountered have been mentioned in the previous section and will not be discussed further with the exception of the coal measures, which outcrop at three localities in the Kihikihi Valley. At each of these localities the Te Anga is thinner than at the reference section, showing that the coal measures do not form a continuous horizon, but were laid down in restricted pockets as the sea transgressed.

The remainder of the Subgroup is divided into three facies whose mutual relations are shown in Fig. 9. The distribution of these facies at the close of deposition of the subgroup is given in Fig. 10.

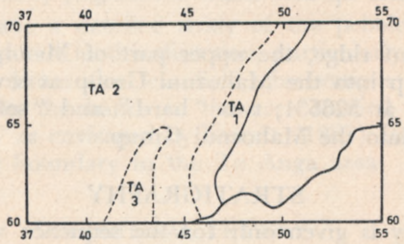


FIG. 10.—Approximate areal distribution of facies at the top of the Te Anga Subgroup.

Facies TA1: Fine sandy, silty limestones which are present near the base of the subgroup in many places comprise Facies TA1. They form a time-transgressive belt which closely followed the shore-line as the sea transgressed. Locally they may be absent, and in some places (e.g., the reference section) are interbedded with the finer calcareous mudstones of Facies TA2. Six samples of rocks of this facies were analysed and were found to contain an appreciable amount of fine terrigenous sand (10–30 per cent) and 55–60 per cent carbonate.

Facies TA2: The blue-grey conchoidal calcareous mudstones which form the upper part of the reference section, and similar rocks which are widespread throughout the area over which the Te Anga Subgroup is present, make up Facies TA2. Rocks of this facies form the dominant lithology of the subgroup. Eight samples were analysed, and the analyses showed them to be calcareous mudstones which contain approximately 45 per cent carbonate and less than three per cent fine terrigenous sand.

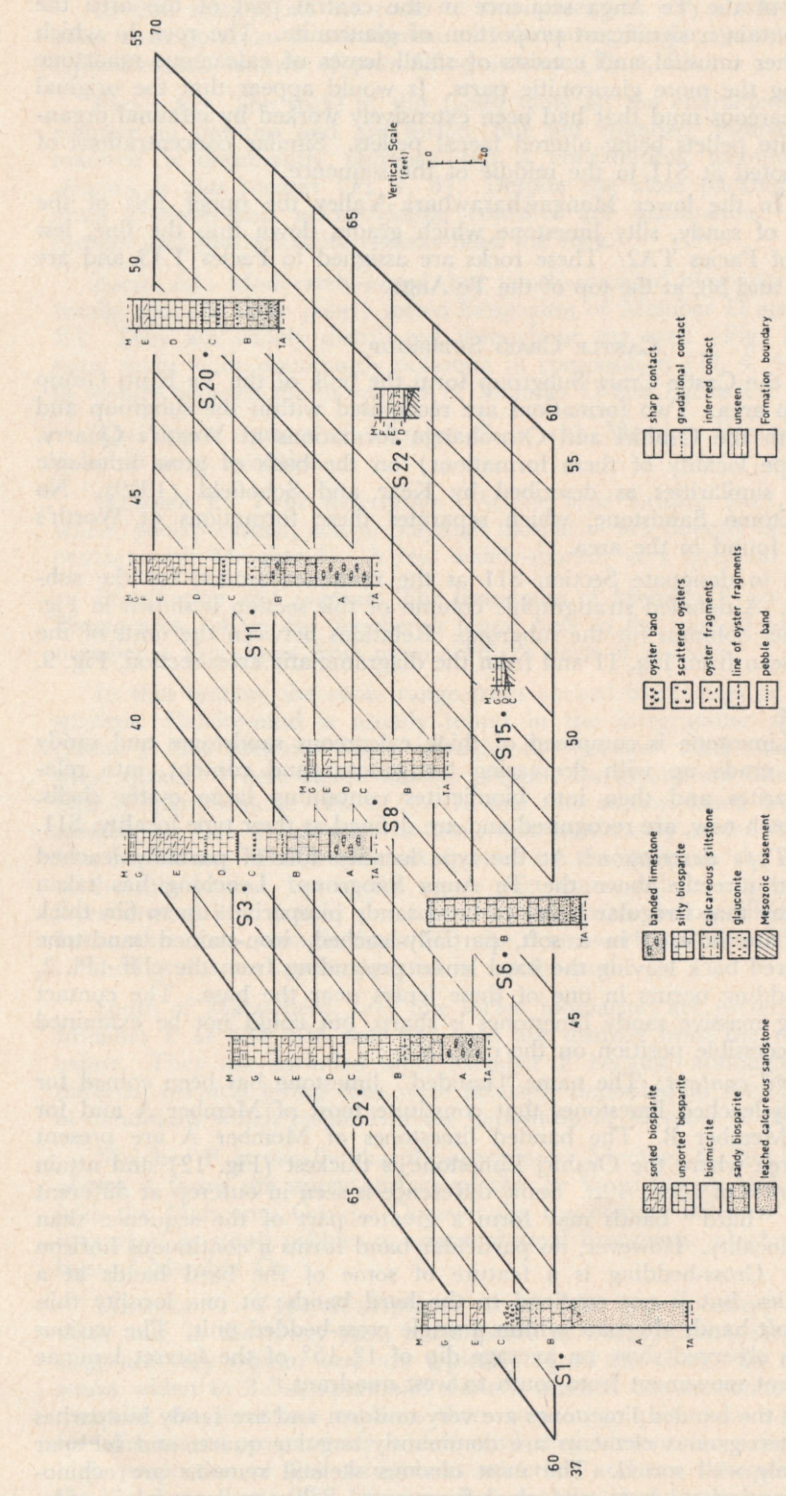


FIG. 11.—Selected stratigraphic columns of the Castle Craig Subgroup, arranged, in position, on a projection of the map grid (M = Mahoenui Group; A–G = Members A–G of the Castle Craig Subgroup; TA = Te Anga Subgroup).

Near the top of the Te Anga sequence in the central part of the area the mudstone may contain a significant proportion of glauconite. The rock in which this occurs is rather unusual and consists of small lenses of calcareous mudstone interspersed among the more glauconitic parts. It would appear that the original sediment was calcareous mud that had been extensively worked by infaunal organisms, the glauconite pellets being altered faecal pellets. Similar concentrations of glauconite were noted at S11 in the middle of the sequence.

Facies TA3: In the lower Mangawharawhara Valley the upper 15ft of the subgroup consists of sandy, silty limestone which grades down into the fine, less calcareous rocks of Facies TA2. These rocks are assigned to Facies TA3 and are also present at S7 and S8, at the top of the Te Anga.

Castle Craig Subgroup

Limestones of the Castle Craig Subgroup form the bulk of the Te Kuiti Group in the west Piopio area. Two formations are recognised within the subgroup and are correlated with the Orahiri and Otorohanga formations at Worth's Quarry, Te Kuiti (the type locality of these formations) on the basis of gross lithologic and stratigraphic similarities as described by Kear and Schofield (1959). No trace of the Waitomo Sandstone, which separates these formations at Worth's Quarry, could be found in the area.

It is proposed to designate Section S11 as the reference section for the subgroup in the area. A detailed stratigraphic column of this section is shown in Fig. 11 along with other columns for the subgroup. Relations between the units of the subgroup can be seen from Fig. 11 and from the diagrammatic cross-section, Fig. 9.

Orahiri Limestone

The Orahiri Limestone is composed of thick calcareous sandstones and sandy biosparites which grade up with decreasing terrigenous sand content, into relatively pure biosparites and then into biomicrites containing large oyster shells. Three members, each new, are recognised and are defined at their type locality, S11.

Member A: *Type description*: At the type locality 40ft of partially leached limestone is found directly above the Te Anga Subgroup. Leaching has taken place in such a way that irregular lenses of hard sandy biosparite (up to 6in thick and 4–6ft long) are isolated in a soft, partially-leached, iron-stained sandstone which has weathered back leaving the hard lenses protruding from the cliff (Pl. 2, Fig. 1). Cross-bedding occurs in one of these lenses near the base. The contact with the overlying massive sandy limestones is sharp, but could not be examined because of its inaccessible position on the cliff face.

Distribution and content: The name "banded" limestone has been coined for the peculiar partly-leached limestones that constitute most of Member A and for similar rocks of Member B. The banded limestones of Member A are present throughout the area where the Orahiri Limestone is thickest (Fig. 12) and attain a maximum thickness of about 40ft. Some difference is seen in outcrop at different localities and the "hard" bands may form a greater part of the sequence than those at the type locality. However, no particular band forms a continuous horizon for any distance. Cross-bedding is a feature of some of the hard bands at a number of localities, but is not confined to the hard bands; at one locality thin ($\frac{1}{8}$in) hard and soft bands alternate within a single cross-bedded unit. The various cross-bedded units observed show an average dip of 12–15° of the foreset laminae and indicate current movement from south to west quadrant.

In thin section the banded limestones are very uniform and are sandy biosparites (Pl. 3, 1). The terrigenous elements are dominantly angular quartz and feldspar and are moderately well sorted. The most obvious skeletal remains are echinodermal plates, foraminiferal tests, and algal fragments. Polyzoan material is widespread but less obvious. Only a few molluscan grains are present, and no brachiopod material was positively identified. Identification of the smaller grains is difficult and pressure-solution effects have often considerably modified the original grain shape. Sparry calcite cement fills the intergranular and skeletal cavities, but rarely shows a mosaic texture in the former. Rim cementation of echinodermal fragments is common and in a number of cases has resulted in poikilitic enclosure of terrigenous grains.

The material between the hard bands has a similar framework to that of the hard bands, but is much more poorly cemented. Subaerial leaching has probably removed some of the cement, but there is little evidence that this material was ever completely cemented. Generally only echinodermal rim cement and a little sparry calcite cement around the grains are present and bind them loosely together.

Member A is not solely composed of banded limestones, and in the region of the Mangaotaki and Kihikihi streams junction alternating poorly-sorted, sandy-silty limestone and calcareous siltstone are present beneath the banded limestones. There is no regular distribution of these beds, which have developed only locally.

MEMBER B: *Type description*: At the type locality Member B is 50ft thick and is composed of sandy biosparites and minor calcareous sandstones which show an overall upwards percentage decrease in terrigenous material and a corresponding increase in the carbonate content. Near the base of the member the limestone contains an appreciable amount of terrigenous mud and some glauconite pellets.

The interval between 24ft and 30ft is occupied by coarse banded limestone which interrupts the general trend. Banding is not developed to the extent seen in the banded limestones of Member A, but consists of hard bands (3–4in wide) separated by thin, discontinuous softer bands that have weathered back into the outcrop.

Near the top of the member, a 15in bed of large oysters is seen in slightly sandy biosparite. Three feet above this another oyster bed is present, but is associated with biomicrites. The base of this bed is taken as the top of the member.

Distribution and content: Member B is widespread throughout the area west of the main north-trending basement ridge and the rocks are recognised as belonging to four different facies (Fig. 9).

Facies B1: Calcareous sandstones and sandy biosparites which grade up into purer biosparites at many localities are included as Facies B1. In the lower parts of the sequence, these rocks may contain appreciable amounts of terrigenous mud, and freshly broken slabs show evidence of infaunal activity. Usually they are massive in outcrop, but some of the more carbonate-rich rocks show incipient development of stylolitic seams.

In thin section (Pl. 3, 2), the rocks are poorly to moderately sorted, sorting increasing vertically. The terrigenous grains are usually angular to sub-angular and are dominantly quartz with a lesser amount of feldspar. Vertically, the quartz-feldspar ratio becomes greater and near the top of the sequence large sub-rounded quartz grains appear. Polished and abraded glauconite pellets are present in the lower parts of the sequence. The skeletal fragments are well comminuted and are dominantly echinodermal, polyzoan, and foraminiferal. Algal grains are conspicuous but small in quantity, while molluscan material is always rare. In the more carbonate-rich rocks the grains are generally coarser and echinoderm plates more prevalent. Pressure solution has considerably modified the margins of many of the grains. Sparry calcite and echinoderm rim cement are widespread. Micrite is typically absent from the intergranular cavities although it does occur in some skeletal cavities. The proportion of micrite (if any) in the more muddy rocks could not be determined.

Facies B2: The banded limestones of Member B are included as Facies B2 and form a tongue into the rocks of Facies B1 (Fig. 9). They outcrop over approximately the same area as the banded limestones of Member A but do not appear at section S3 in the north-west. As at the type locality, banding takes the form of hard cemented sandy biosparite separated by thinner, irregular lenses of poorly-cemented calcareous sandstone.

In thin section, these rocks are very similar to the banded limestones of Member A but on the whole are a little more poorly sorted, some larger terrigenous grains being present.

Facies B3: Near the top of Member B at many localities, slightly sandy to almost pure biosparites occur. They represent a culmination of the vertical trend towards a reduction in terrigenous sand that was observed in Member B at several sections. In outcrop, regular seams are usually present.

In thin section, well-sorted terrigenous sand (dominantly subangular quartz) is present, but forms less than 20 per cent of the rock (Pl. 3, 3). The skeletal elements are dominated by numerous echinoderm plates which are rim-cemented. Sparry calcite binds the remaining grains.

Facies B4: In the east, where the Orahiri Limestone is thin, glauconitic biomicrites that are somewhat different from the other rocks of Member B are present. They are characteristically poor in terrigenous sand, the few grains present being quartz and minor feldspar (Pl. 3, 4). Glauconite is common as large green and brown pellets and also fills some skeletal chambers. In one sample (from the bottom few feet of S6) glauconite pellets form about 50 per cent of the rock. The skeletal grains are very poorly sorted and are dominantly polyzoan, though foraminiferal tests and large molluscan fragments are common. Echinodermal and algal grains are less frequent. Sparry calcite fills some skeletal cavities but the intergranular material is calcite-mud or, more rarely, micrite.

Member B is overlain by Member C at many localities. Only in the area around S7 and S13 is this not the case and here Member B is overlain sharply by the Otorohanga Limestone. The contact with Member C is rarely defined sharply in outcrop. In some cases, one or more lines of flat oyster fragments or, rarely, a thin bed of oysters is present near the top of Member B. Member C is encountered immediately above, or within a few feet of these beds.

Member C: *Type description*: At the type locality, Member C is 18ft thick and contains two beds of concentrated and apparently unorientated oysters. The lower bed is found at the base of the member and is 9in thick, while the upper one is 12in thick and occurs 16ft above the base. The rock between the oysters is dark-brown to grey biomicrite, which fractures conchoidally. Seams are present, but are very irregular and are spaced widely apart. In the interval between 8ft and 12ft an interval of biosparite with more regular seams interrupts the biomicrite sequence. The upper contact is with the Otorohanga Limestone and is sharp.

Distribution and content: Member C is present throughout most of the area over which the Orahiri Limestone outcrops and is absent only from S7 and S13. The large oysters which are prominent in rocks of this member have been discussed by Barrett (1967). No attempt to classify these fossils has been made in this work and hence a taxonomic name is not used. Three facies are recognised within the member.

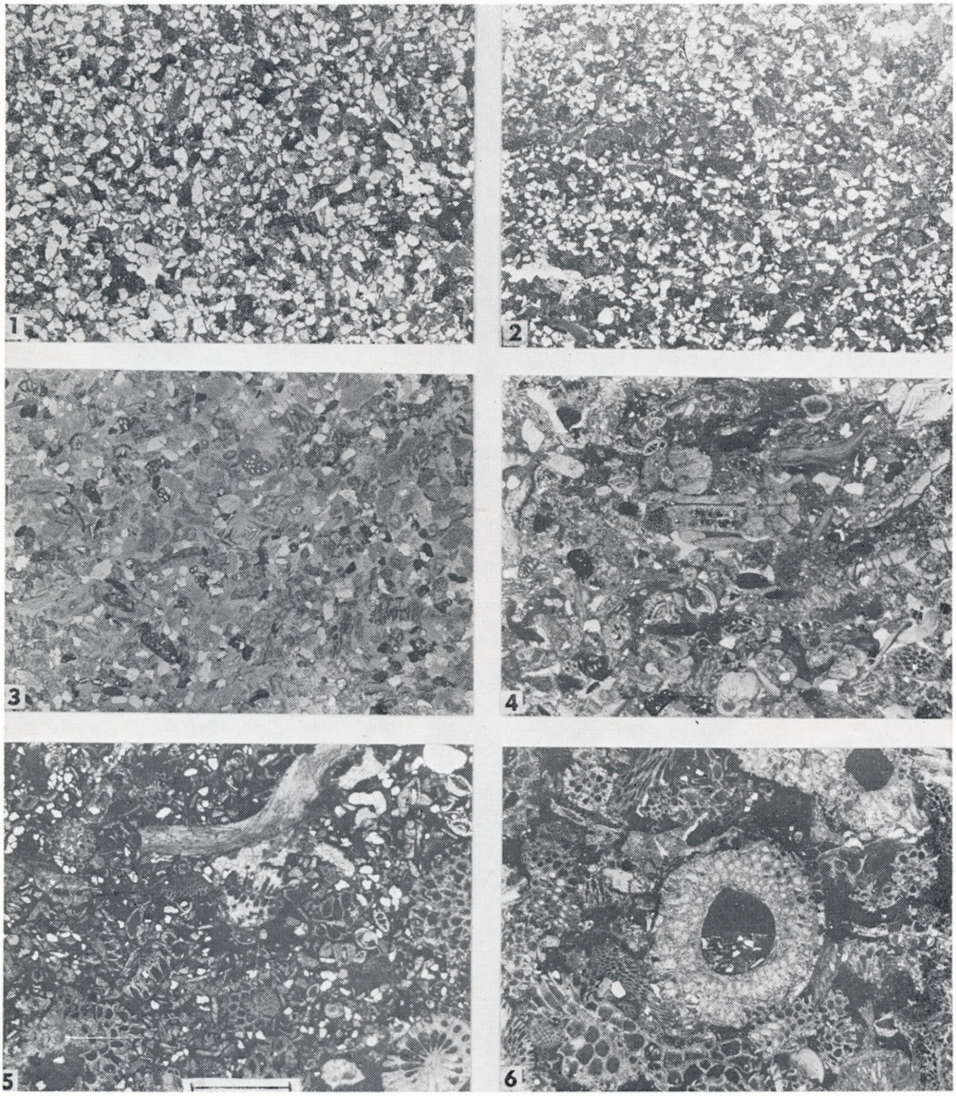
Facies C1: Biomicrites with associated oyster beds constitute Facies C1, the rocks of which are widespread and form the bulk of the member. The oyster-beds range from several inches to several feet in thickness and cannot be traced as a continuous horizon for any distance. Neither are they confined to any particular position within the member and at a number of localities are not present at all. The shells are often whole with both valves together, although disarticulated shells

FIG. 1.—The Mesozoic–Tertiary contact at 468608. A lensing conglomerate fills irregularities in the Mesozoic basement surface.

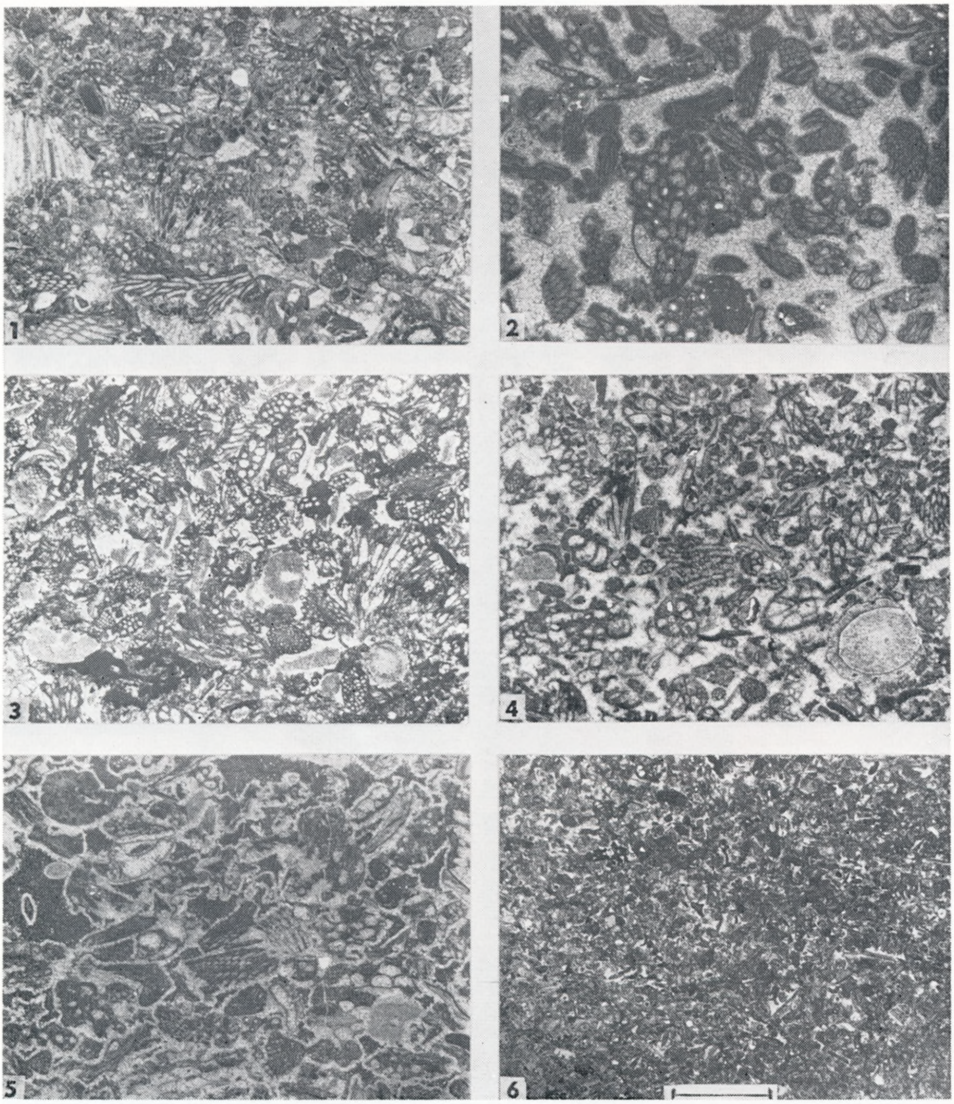
FIG. 2.—The Te Kuiti–Mahoenui contact at 390646. Two "hard" beds are seen in contact with two "soft" beds above Member G of the Otorohanga Limestone.

FIG. 1.—The "banded" limestone of Member A at the type locality S11.

FIG. 2.—Member E at 423638, showing the irregularly cavernous weathering and regularly spaced seams.



Photomicrographs of thin sections of the Orahiri Limestone. The scale line on No. 5 corresponds to approximately two milimetres in each thin section. (1) Moderately sorted, sandy (45 per cent), mixed polyzoan-algal-echinodermal biosparite. Member A, Section S11. Sample taken from one of the hard bands of the banded limestone at this locality. (2) Moderately sorted, sandy (25 per cent), polyzoan-echinodermal biosparite. Facies B1, Section S11. (3) Sorted, slightly sandy (< 10 per cent), echinodermal-polyzoan biosparite. Facies B3, Section S4. Although the overall appearance is not one of good sorting, each species of grain tends to be rather well sorted. (4) Glauconitic, mixed polyzoan-foraminiferal-algal-molluscan packed biomicrite. Facies B4, Section S18. The matrix of this rock is calcite-mud. (5) Slightly sandy (< 10 per cent), fragmental polyzoan packed biomicrite. Facies C1, Section S11. One large molluscan fragment is present (top centre). (6) Coarse-polyzoan packed biomicrite. Facies C3, Section S11. Note the preservation of the larger, more delicate polyzoan structures as compared with No. 5.



Photomicrographs of thin sections of the Otorohanga Limestone. The scale line on No. 6 corresponds to approximately two millimetres in each thin section. (1) Poorly-sorted polyzoan biosparite. Member D, Section S11. The skeletal fragments are tightly packed, but grain rupture due to compaction is minimal. (2) Well sorted, rounded polyzoan biosparite. Facies E1, Section S28. Despite the apparently loose packing, the grains are in three-dimensional grain-support. Sparry calcite cement fills all the intergranular spaces. (3) Moderately sorted polyzoan-echinodermal biosparite. Facies E2, Section S24. (4) Moderately sorted polyzoan biosparite. Facies E3, Section S36. (5) Polyzoan, spar-rimmed biomicrite. Member F, Section S11. Sparry calcite occurs as a rim around each allochem and fills most of the smaller intergranular spaces. Calcite-mud is present in the larger spar-rimmed cavities. (6) Slightly argillaceous (< 10 per cent), glauconitic mixed foraminiferal-polyzoan-echinodermal biosparite. Member G, Section S11. Sample from the top few inches of the Te Kuiti Group. Note the abundant small globular Foraminifer tests.

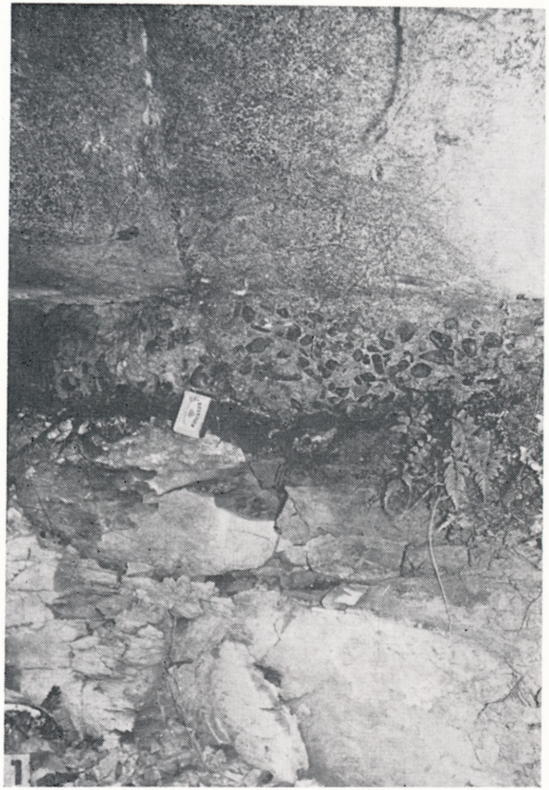


FIG. 1.—The pebble band at the base of the Orahiri Limestone at S6. Glauconitic, calcareous sandstones (Facies B4) occur above the pebble band; calcareous mudstones (Facies TA2) below.

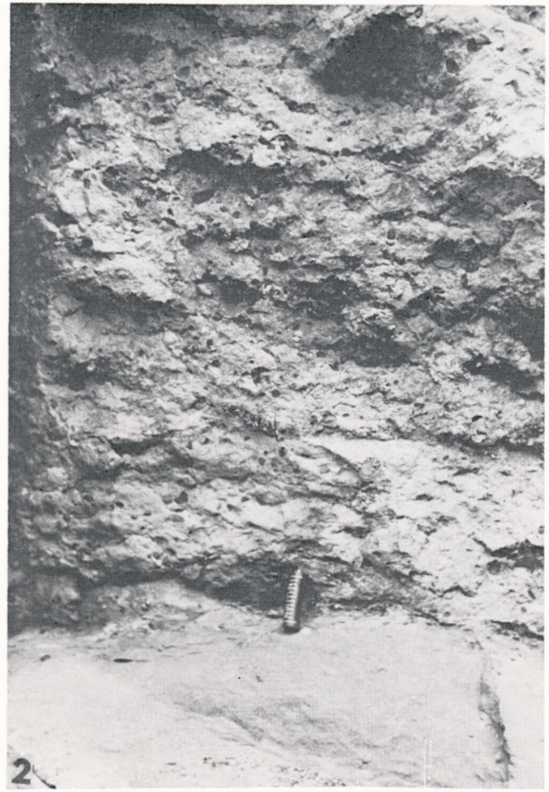


FIG. 2.—The pebble band at the base of the Otorohanga Limestone at S13. Note the wide spacing of the pebbles, which do not form a grain-supported framework. The object in the centre of the photograph is 2in high and rests on the top of the Orahiri Limestone (Member E).

are not uncommon and in some beds they are broken into coarse fragments. Many of the oysters have been drilled by shell-boring organisms and no preferred orientation of the shells in the thick beds was obvious from a casual examination.

The biomicrites are poor in terrigenous material, which rarely forms more than 10 per cent of the rock and is almost entirely angular to subangular, medium to fine sand-sized quartz and minor feldspar. The skeletal material is dominantly polyzoan and is very poorly sorted (Pl. 3, 5). Foraminiferal, echinodermal and algal fragments are usually present but in most cases contribute little to the bulk. Molluscan material is not at all common as sand-sized fragments, even in samples taken from between oyster shells. Micrite is widespread and many of the grains, especially the smaller ones, are mud-supported (Dunham, 1962). Sparry calcite occurs chiefly as a mosaic cement filling skeletal chambers and cavities, both primary and secondary. The latter cavities have been formed by solution of unstable skeletal material—presumably once aragonite.

Facies C2: In the vicinity of the Mangaotaki and Kihikihi streams junction, a tongue of biosparite interrupts the biomicrites of Facies C1, as noted at the type locality. At S10 the facies is repeated vertically. The biosparites are poor in terrigenous detritus, that which is present being almost entirely medium-sand-sized, subrounded or rounded quartz. The skeletal fragments are well sorted but there is considerable variation in the proportions of each of the three major types of skeletal grain present (foraminiferal, echinodermal, and polyzoan) from one outcrop to the next.

In outcrop, regular seams are present, usually 3–5in apart, in contrast to the irregular seams of the biomicrites of Member C.

Facies C3: In the southern and western parts of the area coarse, dark, packed biomicrite is present at the top of Member C. These biomicrites are poor in terrigenous material and contain delicate polyzoan skeletal structures which are not as finely comminuted as are the polyzoan fragments in the biomicrites of Facies C1 (Pl. 3, 6). Sparry calcite cement is almost completely confined to skeletal cavities.

The top of Member C, in all cases, is sharply defined and is in contact with the Otorohanga Limestone except in a small area south of Matawhero where Member C terminates abruptly beneath the Mahoenui Group.

Otorohanga Limestone

The Otorohanga Limestone is the most widespread Tertiary formation in the west Piopio area and is composed dominantly of polyzoan biosparites which are poor in terrigenous material. Near the top of the formation biomicrites are present in places, and at the very top, terrigenous mud may form a significant proportion of the rock. The formation is divided into four members, each new, the lowest of which is defined at the reference section S11, while the upper three are defined at S1 where they are exposed more typically.

MEMBER D: *Type description*: Member D at the type locality consists of 35ft of hard, crystalline, flaggy, poorly-sorted, polyzoan biosparite. Occasional small sandy lenses are present in places. The flags, which have been formed by differential weathering along seams, are rather uniform and are characteristically 3–4in thick. The upper contact is with Member E and is gradational over a short distance.

Distribution and content: Member D is widely represented throughout much of the area over which the Otorohanga Limestone is present and is absent only from some of the more southern parts of the area. It is easily recognised in field outcrop because of the uniform crystalline nature of the biosparites and the regular flags. The origin of the seams which weather to produce the flags has been discussed by Barrett (1964).

Poorly-sorted biosparites make up the great bulk of the member, although locally, near the base, moderately-sorted biosparites may be present and in one case a poorly-washed biosparite was noted. Occasional small sandy lenses similar to those noted at the type locality are present elsewhere and are usually associated with slightly better-sorted material. Seams which dip more steeply than other seams at a particular locality give the appearance of following cross-bedding, but confirmation of their cross-bedded nature is difficult to obtain.

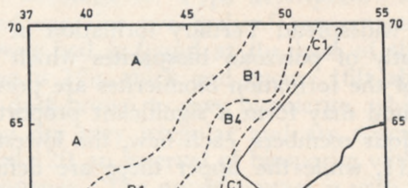
In thin section, terrigenous detritus is rare and that which is present is almost entirely subrounded, medium-sand-sized quartz. The skeletal constituents are dominantly polyzoan, but minor amounts of echinodermal, foraminiferal, and algal fragments are usually present (Pl. 4, 1). These grains are very closely packed and exhibit microstylolitic contacts in a number of cases. Sparry calcite cement is common in all types of cavity, while micrite is usually confined to a few skeletal chambers.

Member D is overlain by Member E over much of the area. The contact is sharp at some localities but more often is gradational over an interval of 2–3ft. In the latter case sorting increases vertically, the number of grain contacts decreases (because of looser packing), and a correspondingly larger amount of intergranular cement is found.

Member E: *Type description*: At the type locality, Member E is represented by 10ft of white, sorted, polyzoan biosparite which weathers in outcrop in an irregularly cavernous fashion. Cross-bedding is present and is shown by the angular discordance between seams.

The contact with Member F is sharp.

Distribution and content: Member E is composed of moderately-sorted to well-sorted polyzoan biosparites which are poor in terrigenous material. In field outcrop they are defined by their light colour and irregular weathering (Pl. 2, Fig. 2). This form of weathering appears to be related to the ease with which sparry calcite cement can be leached from the rock, leaving behind a weak framework of grain-supported skeletal fragments. At some outcrops it is evident that there are patches or lenses that have never been completely filled with cement and these, no doubt, contribute to the irregularity of the weathered surface. Seams are invariably present and are regularly spaced though irregular weathering may conceal them from the casual glance.



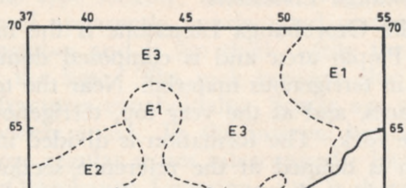


Fig. 12.—Approximate areal distribution of facies at the base of the Orahiri Limestone.

Fig. 13.—Approximate areal distribution of the facies of Member E.

Three facies are recognised and their areal distribution is shown in Fig. 13.

Facies E1: The loosely packed, well sorted, rounded biosparites that were observed at the type locality are found at a number of other localities and are grouped as Facies E1. As at the type locality, these biosparites occasionally show cross-bedding, but no preferred current direction could be determined. At two localities cross-bedded units showed opposing dips.

In thin section, all the rocks of this facies are very similar. Skeletal detritus other than polyzoan is uncommon and the intergranular sparry calcite exhibits the typical mosaic texture of pore-filling cement (Pl. 4, 2).

Facies E2: The rocks of this facies show all the characteristic features of the member in outcrop and are sorted, but not rounded, biosparites. The skeletal material is dominantly polyzoan but a considerable amount of echinodermal detritus is also present (Pl. 4, 3). Despite the close packing of the allochems, grain rupture and microstylolitic contacts are uncommon. Echinodermal rim cement and sparry calcite cement bind the rock.

Facies E3: Moderately-sorted, but poorly-rounded biosparites which grade texturally into the more poorly sorted biosparites of Member D are grouped as Facies E3. They are widely distributed throughout the area (Fig. 13). Thin sections show them to be dominantly polyzoan in composition (Pl. 4, 4) and intermediate in texture between the biosparites of Member D and Facies E1.

The upper contact of Member E is with Member F or Member G and is sharp at most localities.

MEMBER F: *Type description*: At the type locality (S1), two feet of grey-white, poorly-washed, coarse polyzoan biosparite lies directly beneath and in sharp contact with Member G. A few widely-spaced, very irregular seams are present.

Distribution and content: The limestones of Member F are unique in the west Piopio area, where the member is found only to the west of basement ridge. The member is also absent from more northern parts of the area.

In thin section, the rocks range from packed biomicrites to poorly-washed biosparites. Calcite-mud is usually found in the integranular spaces where sparry calcite is not present. More infrequently, micrite rather than calcite-mud fills these spaces. Where calcite-mud is present, the grains are often surrounded by a film of sparry calcite (Pl. 4, 5). In one thin section taken from the base of the member at S14 a transition is seen, and moderately sorted biosparite passes up into biomicrite. The framework formed by the grains is the same in both parts of the thin section, but in the upper part sparry calcite is present only as a thin layer around the grains, the intergranular spaces being filled with calcite-mud. In another case (sample from S2) the framework has been disrupted and spar-rimmed grains are mud-supported in calcite-mud.

South of Matawhero, very fine sorted biosparites are present in the position of Member F at S35, S36 and S37, and are distinct from the rocks of Member E below. They are included with Member F because although they belong to a different textural group they were probably deposited in response to the same set of conditions which resulted in the deposition of Member F elsewhere (see later).

Member F is usually sharply overlain by Member G, but where the latter is absent it forms the upper surface of the Te Kuiti Group and is in sharp contact with the Mahoenui Group. Occasionally the contact between Members F and G is marked by small pebbles or coarse skeletal fragments, which are confined to the base of Member G.

MEMBER G: *Type description*: At S1 (the type locality) Member G is 27ft thick and, in the lower part, is composed of flaggy, poorly-sorted biosparite. The flags are very regular and are typically 1½ to 2in thick. In the upper part, the seams widen to 2–3in apart and show a marked concentration of fine terrigenous material, the limestone between them remaining quite pure. In the topmost few feet the seams progressively widen until they become irregular beds containing a high proportion of fine terrigenous material, and are subequal in thickness with the limestone flags. The limestone between the terrigenous concentrations becomes increasingly contaminated with terrigenous material towards the top. The contact with the Mahoenui Group appears to be wholly gradational.

Distribution and content: Member G is the uppermost member of the Otorohanga Limestone and outcrops conspicuously in many places. It is absent from three areas only; that bounded by S11 in the west, S20 in the east, and S18 in the south; between S17 and S22; and south of S6. It reaches a maximum thickness of 30ft at S2 and thins more or less regularly towards those places from which it is absent.

In field outcrop, the rocks are defined by their narrow, regular seams as noted at the type locality. The appearance of mud in the seams and in the limestone itself, towards the top of the member, is also characteristic but is not seen at every locality where the member outcrops. At some, the limestone is relatively pure over the whole of the member, while at others, especially in the eastern parts of the area, the member may be very muddy from the base upwards.

The lower mud-free rocks are poorly sorted biosparites in which the grains are very tightly packed. It is this feature and the somewhat smaller grain-size that distinguishes these biosparites from those of Member D in thin section. The few terrigenous grains present are sub-angular quartz. The skeletal grains are dominantly polyzoan but some algal and echinodermal debris is invariably present, as are foraminiferal tests. The latter are multicellular and are of a type not seen elsewhere in the Castle Craig limestones in the area. Sparry calcite cement binds the grains, micrite being confined to a few skeletal chambers.

In the more muddy rocks, the overall grain-size decreases and the skeletal elements reflect a changing fauna of which small globular Foraminifera are an important element (Pl. 4, 6). The terrigenous mud forms an irresolvable groundmass and masks any micrite or calcite-mud that may be present. Sparry calcite fills some skeletal chambers and is very occasionally present as a cement between the grains. Where terrigenous mud does not form an important part of the rock towards the top of the member and where Member G is thin, glauconite may be a significant constituent. It occurs either as small round green pellets (probably faecal pellets) or fills skeletal chambers, particularly Foraminifer tests.

Member G is invariably overlain by the Mahoenui Group and this contact has been discussed earlier.

Interformational Boundaries

Te Anga–Castle Craig boundary

The Te Anga–Castle Craig boundary was observed at a number of localities and is relatively well defined. No evidence, however, was found that might indicate an erosional break between the two Subgroups. At several localities there is strong evidence to suggest that deposition was continuous across the boundary, but the type of sediment changed markedly. A description of the contact at some of the localities observed follows.

Along the western margin of the Tertiary cover, where the Te Kuiti Group is thickest, leached brown sands of Member A sharply overlie calcareous mudstones of Facies TA2. A few small pebbles are present in the base of Member A in places but they are never numerous and do not form a thick pebble band.

In the vicinity of the Mangaotaki and Kihikihi streams junction, the sequence at the base of Member A is variable (see earlier). Where the banded limestones of Member A are present at the contact, a few small pebbles are sometimes evident. Elsewhere, where sandy and silty beds are present in the base of Member A, a well-defined pebble band may occur, as at 448673. The pebbles in the band are numerous, closely-packed, well-rounded and up to 1½in in diameter.

In the lower Maungawharawhara Valley there is a complete gradation over an interval of about three feet from the fine sandy argillaceous limestone of Facies TA3 into the sandy-silty biosparite of Member B.

At S18, S13, and S7 Member B is in sharp contact with the Te Anga and in each case small pebbles are present in the base of Member B. Finally, at S6, a pebble band 6in thick separates very glauconitic, calcareous sandstones (Member B) from calcareous mudstones (Te Anga). The pebble band contains numerous well-rounded pebbles of all sizes up to 1½in (Pl. 5, Fig. 1) and resembles the dense pebble bands in the Kihikihi Valley and the pebble band which Barrett (1962) found at the Te Anga–Castle Craig boundary near Castle Craig. The matrix between the pebbles appears to be somewhat different, however, and consists of polyzoan fragments (some of which are large and only partly broken) set in micrite. A few foraminiferal tests are also present.

Otorohanga–Orahiri boundary

The Otorohanga–Orahiri boundary is of special interest because it would appear that it is time-transgressive and becomes younger towards the south. At all the localities examined the contact is sharp, and in many cases pebbles are present in the limestones near the contact.

Scattered pebbles are present in the base of the Otorohanga Limestone at S12, S15, S17, S18, S20, and S21, but do not form a concentrated pebble band. In the two areas around S2, S3, S23, and S7, S13, S28 the pebbles are more numerous and it is likely that a well-developed pebble band is present in these areas. At S4 and 401644 the pebbles are again common and are found in the top of the Orahiri Limestone as well as in the base of the Otorohanga Limestone. In contrast with the more closely packed pebble bands seen at the Te Anga–Castle Craig boundary, the pebbles at this boundary are not in grain-support with each other (Pl. 5, Fig. 2) and are typically 3–4in apart. They are well rounded and are up to 1½in in diameter, but are usually smaller than this. They tend to be very well sorted, so that only one size is common at any particular locality.

At S1 there is evidence of interformational disturbance at the contact and chunks of the underlying Member C are incorporated in the rounded biosparites at the base of Member E. However, there is no evidence of a widespread erosion interval, a full sequence of the Orahiri Limestone being present.

The stratigraphic relations between the two formations can be seen from the two isopach maps (Figs. 6 and 7) and from the detailed stratigraphic columns, Fig. 11. The more significant features are as follows:

Along the western margin of the Tertiary cover the three stratigraphic columns S1, S2, and S3 (Fig. 11) show that although the Castle Craig Subgroup is approximately of the same thickness at each locality, the Orahiri Limestone thickens markedly to the south at the expense of the Otorohanga Limestone. A similar situation is seen at S8, where the Otorohanga Limestone is much thinner and the Orahiri Limestone much thicker than at S7 to the south. Farther east, at S13, the Orahiri Limestone is still thinner, whereas the Otorohanga is well-developed.

The small area south of Matawhero, where the Otorohanga Limestone becomes very thin and finally disappears, is of particular interest in evaluating this boundary. Exposures of the upper part of the Te Kuiti sequence are particularly good in this area, which has been studied in some detail. A number of stratigraphic columns have been measured and are shown in Fig. 14. They show how the Otorohanga Limestone thins rapidly to the south, the various members progressively disappearing, leaving the Orahiri Limestone in contact with the Mahoenui Group.

From these observations it is believed that the only reasonable interpretation is that the boundary between the two formations is time-transgressive.

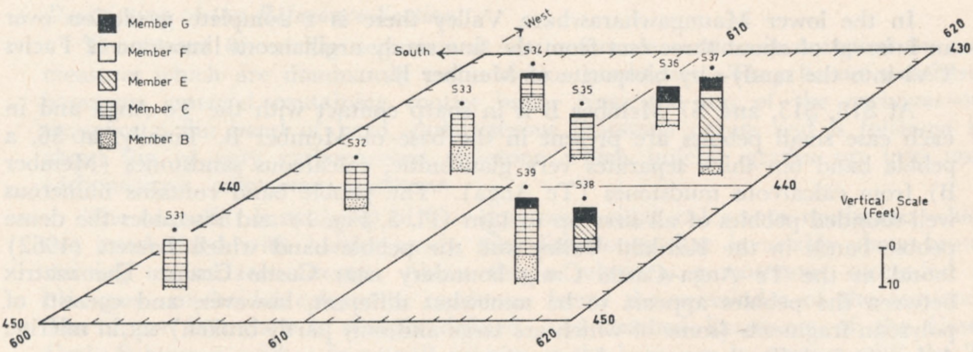


Fig. 14.—Stratigraphic sections S31–S39 arranged on a projection of the map grid. The contact with the Mahoenui Group was observed at all sections except S37.

Pebble bands

The majority of the pebbles in the Castle Craig Subgroup are located at the formational boundaries, as described above. Pebbles are also present at other horizons but do not form striking or widespread bands. In every case except one, these pebbles are associated with a change in lithology. The only exception recorded is at S18 where a few small pebbles occur at two closely-spaced horizons in the biosparites of Member D. In addition to these pebble concentrations occasional isolated pebbles are found in the purer limestones and are not confined to any particular horizon.

A wide variety of rock types is represented by the pebbles which include volcanic, plutonic, and indurated sedimentary types. They are thus similar in composition to the pebbles studied by Barrett (1967) in the Te Anga area.

The writer has not made a detailed study of the pebbles in the west Piopio area and more work is required in this direction, particularly with respect to their origin and emplacement. From the few field observations made he believes it unlikely that the pebbles in the bands in the area studied were emplaced by a high density "gravel flow" as envisaged by Barrett (1967) for the pebble bands at the Te Anga–Castle Craig boundary in the Te Anga area.

Depositional History

This section is an attempt to relate all the observed data and to infer something as to the nature of the deposition of the Te Kuiti Group in the area. Much of the interpretation of the petrographic data is based on Folk's "textural-maturity" schemes (Folk, 1951; 1962). The terms "onshore" and "offshore" are used occasionally and refer to the shoreline formed along the western margin of the north-trending basement ridge as the sea transgressed over it.

Te Anga Subgroup

The various lithologies found at the base of the Te Anga Subgroup developed in response to the local conditions prevailing as the sea transgressed over the basement. As the water deepened over a particular locality progressively more off-shore conditions prevailed and the fine terrigenous material which dominates the rocks of the subgroup was deposited. Near the shore, where presumably wave action was stronger, the sediment was subjected to a slightly higher-energy environment and the fines were winnowed away. Hence the rocks of Facies TA1 are coarser than those of Facies TA2. The higher percentage of carbonate in the rocks of Facies TA1 may be explained by the fact that organisms supplied coarse carbonate detritus only and this was concentrated in the higher-energy environment, and/or the more turbulent environment was more favourable to the growth of calcareous organisms. The coarser sandy limestones of Facies TA3 developed in a similar fashion, but in this case the higher-energy environment would be related to the more open sea conditions of the southern, central parts of the area.

The terrigenous detritus in the Te Anga was probably derived from weathering and erosion of the Mesozoic basement, which must have formed extensive tracts of land nearby during deposition of lower parts of the subgroup. However, no sedimentary structures were found in the Te Anga that might indicate a direction of current movement for supply of the terrigenous material. It is important to note that all but one or two per cent of the terrigenous material in the Te Anga is mud and fine sand. The upper limit in grain-size appears to be the three-phi boundary and it is significant that this has been considered to be the critical value for transport by rolling and suspension (Passega, 1957). Hence, weak currents only are necessary to explain the presence of the terrigenous material in the Te Anga Subgroup.

The basal coal measures appear to have been deposited near the shore under swampy conditions and their repeated occurrence at successively higher levels up the basement ridge suggests that the Te Anga basin was relatively shallow. The uniform nature of the sediments indicates a fairly constant rate of transgression and in a few cases only is any evidence of a break in deposition seen. Thus the glauconite-rich bands occasionally encountered in the stratigraphic sections may mark periods of low sedimentation at a particular locality.

Castle Craig Subgroup

The change which led to the deposition of the Castle Craig sediments was abrupt, and it appears that the Te Anga–Castle Craig boundary in the west Piopio area is approximately isochronous. Although it is not certain what caused the change, the effect was a general rapid cessation in deposition of fine terrigenous material and an influx of terrigenous sand into the basin. It was accompanied by a complete reversal in the distribution of the environmental energy conditions from the top of the Te Anga to the base of the Castle Craig.

As has already been shown, energy conditions were low for deposition of the Te Anga and there was a general increase in energy towards the shoreline. The facies at the base of the Orahiri, on the other hand, indicate that the environment energy level increased markedly from the shore towards the centre of the basin. Thus at the base of the Orahiri in the west and north submature to mature cross-bedded sands of Member A were deposited under a strong-current regime. Nearer the shore, and locally in the north, widespread immature sands and, in places, pockets of mud were deposited under a much weaker current regime. Along the shoreline glauconitic, terrigenous-poor biomicrites accumulated in an environment that was relatively free from persistent currents.

The currents which brought the terrigenous sands of Member A to the site of deposition flowed from the south-west (approximately) but provide little information as to source. Possibly the sand had accumulated as a lag deposit, being concentrated from Mesozoic rocks which weathered to give the fine detritus of the Te Anga Subgroup. However, the strong angularity of many of the terrigenous sand-grains is an argument against this supposition, particularly when it is realised that such sediments would have gone through at least two cycles of weathering, erosion, and transport.

From observations in the Te Anga–Castle Craig area, particularly with respect to the composition of pebbles in the pebble bands, Barrett (1967) was able to suggest that the Mesozoic Moeatoa Conglomerate (which today outcrops on the coast to the south-west of Te Anga) may have been exposed to active erosion at the time and would be a likely source for the pebbles.

In the west Piopio area more detailed work is required on the composition of both the pebbles and the terrigenous sands before any definite answer can be given to the problem of source. However, it is interesting to speculate that if the Moeatoa Conglomerate or some equivalent source area lay to the west at the time and provided the sediments for the west Piopio basin sudden changes in the relief or paleogeographic extent of this land mass may have caused profound changes in sedimentation in the west Piopio basin. It is possible that these influences were responsible for the major change in depositional regime that is seen across the Te Anga–Castle Craig boundary.

Orahiri Limestone

With continued transgression the shoreline migrated eastwards and was followed closely by the zone of quiet water in which the biomicrites of Facies B4 accumulated. Farther from the shore sand and mud continued to be deposited by weak currents and lapped on to the older sediments of Facies B4. Still farther out in the basin the strong currents supplying the terrigenous sand suddenly weakened and the deposition of Member A terminated. At this time, sediments of Facies B1 were being deposited over much of the basin.

The amount of terrigenous material being supplied slowly lessened with time, and thus the sandy biosparites of Facies B1 show an increasing tendency to become richer in shell debris vertically. Increased winnowing or decrease in supply led to the exclusion of mud from these sediments. This period of deposition was temporarily interrupted by the inception of a stronger-current regime which brought coarser, clean, terrigenous sands into the basin and the banded limestones of Member B (Facies B2) were formed. However, these currents did not persist, and after some time conditions returned to those under which the sandy biosparites of Facies B1 were deposited.

The trend towards better sorting and less terrigenous material continued after deposition of the banded limestones of Member B. The change becomes more apparent vertically and its culmination is realised with the deposition of the ubiquitous echinodermal biosparites of Facies B3. The reason for the concentration of echinodermal detritus is not certain, but it is probable that the water was fairly shallow at this stage and this may have favoured the growth of echinoderms.

The biomicrites of Member C appear to have been deposited in very shallow water—perhaps only a few feet deep. Barrett (1967) has investigated the significance of the large oysters farther to the north and has concluded that they preferred very shallow water which may have been slightly less saline than in normal marine environments. In the west Piopio area the oysters lived on banks which were not continuous for any great distance. Only a small thickness of oysters accumulated at any one location, indicating that conditions were continually changing. Thus most of the oyster beds are *in situ* accumulations but some of the thinner beds, especially those in which fragmented and disarticulated shells are common, may have accumulated by transport from the larger banks.

The micritic matrix of the oyster beds and biomicrites between these beds, together with the relative absence of finely broken molluscan material, suggests that the environment was generally one of low energy. The relatively fragile polyzoans could easily be broken with a minimum of wave action. In the south, where sandy biosparites were being deposited contemporaneously with and not far from the oyster banks, some terrigenous sand was carried into areas where biomicrites and oysters of Facies C1 were being deposited. The currents carrying these sands were not persistent and did not interfere with the deposition and entrapment of the micrite. In this respect it is likely that the oyster banks themselves would rapidly disperse such currents and inhibit the removal of the finer sediments.

The presence of the biosparites of Facies C2 to the north suggests that a more persistent period of higher energy interrupted deposition of the biomicrites and produced conditions that were unfavourable to the growth of oysters.

Deposition of Member C terminated at a number of localities, especially in the south, after a period of very low energy had prevailed. This is suggested by the non-comminuted nature of many of the polyzoan fragments in the biomicrites of Facies C3.

The time-transgressive nature of the Orahiri–Otorohanga has been established earlier, and this complicates the depositional pattern, for the various members are not only vertically related but are in part laterally equivalent. The factors controlling this relationship are discussed at the end of this section.

Otorohanga Limestone

The biosparites of Members D and/or E are present above the Orahiri–Otorohanga boundary in all places except the small area south of Matawhero. Supply of terrigenous material was very low during the deposition of these limestones, and abundant organisms (chiefly polyzoan) must have lived in the Otorohanga seas.

A very general upward increase in environment energy level is reflected in the textures of the biosparites of these two members—at first as an increase in sorting and ultimately as grain-rounding. The pronounced lateral variations, especially in Member E, are probably related to local features.

The poorly sorted biosparites of Member D accumulated in an environment in which gentle currents were able to wash the carbonate sand and winnow away the smaller particles, but not to sort the sand fraction to any degree or effect significant rounding of the grains. The better sorted biosparites of Member E (Facies E3) were subjected to stronger and more persistent currents.

The rounded biosparites of Facies E1 were sediments which formed under conditions of very high energy and are believed to have originated where strong local currents persisted or else in shallow water where wave action could exert much influence on the particles. The latter may have been the case where the rounded biosparites of Facies E1 protrude into the lower-energy facies over the buried north-west-trending basement ridge (Fig. 13), indicating that this ridge, or its shoreward continuation, may still have exerted influence on the sedimentation pattern in this area.

The origin of the sorted biosparites of Facies E2 is somewhat problematical inasmuch as the significance of the concentration of echinodermal material is not clear to the writer. A similar problem has already been discussed with regard to the echinodermal biosparites of Facies B3.

The presence of Member F indicates that in many places there was a general rather sudden decrease in current and probably wave activity throughout the basin. It will be recalled that these biomicrites showed an incipient development of spar around many of the grains—a feature that has been interpreted by the writer (Hopkins, 1966) as due to recrystallisation resulting in the formation of a "comb rim". However, it has been suggested to the writer (Mr B. Purser, pers. comm.) that the phenomenon may be explained as calcite-mud filtering down into the pores of a loosely consolidated sand that had been only partly cemented. If the latter solution is correct then the supposition that the drop in energy level was rapid is further borne out.

The decrease in energy that led to the accumulation of the biomicrites of Member F was probably synchronous over much of the basin where the member is present. Member F is thus considered to be the first record of the changing conditions which brought Te Kuiti sedimentation to a close in the area. South of Matawhero, where Member F consists of very fine, sorted biosparites, special conditions are envisaged. The higher turbulence which did not allow calcite-mud to accumulate in these rocks was probably due to the shallowing of seas near the retreating oyster banks to the south.

The biosparites at the base of Member G in the west show that a period of slightly higher energy followed the deposition of the biomicrites of Member F in this region. However, continuing change is obvious, and the polyzoan detritus at the base of the member is slowly replaced by small foraminifer tests as the dominant skeletal element. It is likely that this change was accompanied by an increase in the depth of water at the site of deposition. Nearer the shore sedimentation continued at a very slow rate and in the north the biomicrites of Member F continued to be deposited under conditions of very low energy.

Terrigenous mud was supplied to the basin in increasing quantities during deposition of the upper part of Member G in the west, and finally Te Kuiti sedimentation ended. Although this change was gradual in the west, nearer the shore it was more abrupt and the zone of terrigenous mud slowly engulfed the shallower environments. The source of the terrigenous mud is not known but it is likely that it lay in lands uplifted by the tectonic events that produced the unconformable relations between the Te Kuiti and Mahoenui groups elsewere (Kear and Schofield, 1959).

Extra-basinal influences

The discussion so far has largely been concerned with that part of the Te Kuiti basin that is exposed in the west Piopio area. However, in order to explain why changes in deposition took place in the area it is necessary to know something of the depositional history of the Te Kuiti Group over a much wider area. Unfortunately, detailed regional studies have not been undertaken as yet and so the following observations are offered purely as a working hypothesis on the basis of very limited knowledge.

To recapitulate, the Te Anga–Castle Craig boundary is considered to be an approximate time boundary that resulted from a major change in the type of terrigenous material supplied and in environment energy. The banded limestones of Members A and B developed in response to a particular set of conditions that were initiated and terminated abruptly. These changes were probably related to specific extra-basinal events. However, the upper boundary of Member B is obviously time-transgressive, and thus, while the sediments of Facies B3 (and, in places, Facies B1) were being deposited in the south, Member D at least of the Otorohanga Limestone was being deposited in the north.

The answer to the question of what caused the time-transgressional relation to develop between the various members involved probably lies in the distribution of the nearby land masses at the time of deposition. Barrett's isopach map of the Te Anga Subgroup (Barrett, 1967, fig. 8) indicates that for much of the deposition of the subgroup the west Piopio area was separated from the Te Anga–Waitomo area by a low saddle. Some time before deposition of the Castle Craig sediments took place transgression had raised sea level sufficiently and the two basins became linked by a narrow sea-way. With continued transgression this sea-way must have slowly widened and it is quite possible that the depositional pattern in one basin would be significantly modified by that in the other. This, in essence, is what may be proposed to explain the facies changes observed in the middle and most of the upper part of the Castle Craig sequence west of Piopio.

The explanation offered is that the zone of terrigenous deposition (Member B) moved southwards with time owing to the initiation of a new depositional regime which moved southwards from the north. Member C was deposited in the zone between them. Continued transgression and consequent enlargement of the sea-way between the two basins caused the southern basin to come under increasingly greater influence from the northern one, and thus the northern depositional regime moved south more rapidly with time. The effect would be more or less what is seen in the rocks today—a steepening of the time-trangressive Orahiri–Otorohanga boundary to the south and an increasingly greater contrast between the energy level of the environments on each side of this boundary.

ACKNOWLEDGMENTS

The writer wishes to thank Mr J. A. Grant-Mackie of the Geology Department, University of Auckland, for his generous advice and guidance during the course of this study, which was originally presented as part of a thesis submitted at the University of Auckland for the degree Master of Science. Mr Grant-Mackie also read and made a number of useful comments on the manuscript of this paper. Mr P. J. Barrett kindly supplied an advance copy of the manuscript of his recent publication on the Te Kuiti Group.

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