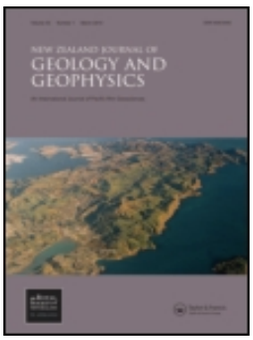

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GEOLOGY OF OKAHUKURA PENINSULA, KAIPARA HARBOUR, NEW ZEALAND

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ABSTRACT

Okahukura Peninsula, Kaipara Harbour, is underlain by rocks of the West Northland Chaos-breccia (emplaced in the upper Oligocene to lower Miocene), Waitemata Group (upper Oligocene to lower Miocene), Waitakere Group (lower Miocene), and Quaternary dune and terrace deposits. The West Northland Chaos-breccia is inferred to underlie the Waitemata Group; it consists of blocks of chert, argillaceous micrite, and glauconitic sandstone, in a matrix of bentonitic clay.

The Waitemata Group is represented by the Timber Bay Formation, thin interbedded mudstones and rippled fine sandstones, up to 1000 m thick; it rests on an irregular surface of the underlying Chaos-breccia. The Waitakere Group is divided into three formations. The new **Okahukura Formation** contains a prominent, coarse igneous conglomerate, the **Matapoura Conglomerate Member,** and a wide variety of flysch, flysch-like lithologies, mudstones, cross-bedded sands, fine igneous conglomerates, argillaceous micrite breccias, and slumped blocks. There is much lateral variation, and the Formation rests sometimes conformably but generally unconformably on the Timber Bay Formation. Some rock units described previously from the adjacent Puketotara Peninsula are here reinterpreted and transferred from the Timber Bay and Pakaurangi Formations into the new Okahukura Formation. The overlying Pakaurangi Formation is divided into two portions which are laterally equivalent: in the north the new **Oruawharo Hyaloclastite Member,** and in the centre and south mudstones and volcanic sandstones with many intraformational discordances, and fairly rich fossil faunas. The Pakaurangi Formation rests in places conformably on Okahukura Formation and in places unconformably on Okahukura and Timber Bay Formations. The topmost formation, Motuouhi Formation, is exposed only in the north. It is the southern extremity of a lens of hard, brown, fine hyaloclastite tuff which is developed more extensively on the adjacent Puketotara Peninsula.

The rocks of the Waitemata and Waitakere Groups are derived largely from contemporaneous volcanism on the Waitakere Magmatic Arc, with minor contributions from the underlying West Northland Chaos-breccia. There is an overall westerly dip, and no major faults are known.

An extensive development of late Quaternary beach ridges and dunes forms the western portion of the Peninsula, while older Quaternary quartz-rich dune sands are located at a height of *c.* 105 m a.s.l.

INTRODUCTION

Okahukura is the southernmost of three major peninsulas in the Kaipara Harbour of Northland, New Zealand (Fig. 1). It consists mostly of rocks of the upper Oligocene to lower Miocene Waitemata and Waitakere Groups (Ballance 1974; P. F. Ballance, B. W. Hayward, L. L. Wakefield, "Group

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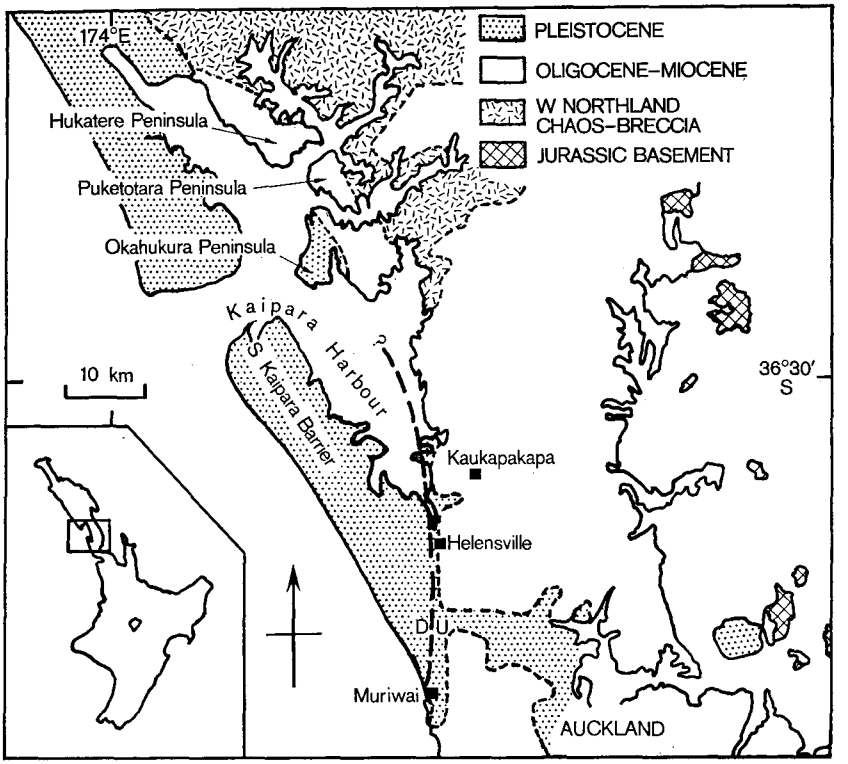

FIG. 1—Locality map, and regional setting. See text for discussion of West Northland Chaos-breccia.

nomenclature of mid-tertiary rocks of northern New Zealand", in prep.), which dip generally west and are unconformably overlain in the west by various Quaternary sediments. In the east occurs an olistostrome deposit whose stratigraphic relations to the Waitemata Group and Quaternary sediments are not clear.

The only previous description of the Peninsula and adjacent areas to the east and south was by Ferrar (1934). Puketotara Peninsula, immediately to the north, was studied recently by Carter (1967; 1969; 1971), and Hukatere Peninsula, to the north of that, by Brothers (1954a), Arlidge (1955), Ballance (1964), and Jones (1966; 1969; 1970; 1972). A basin analysis of the Waitemata and Waitakere Groups, incorporating information from Okahukura, was given by Ballance (1974).

The subject matter of this paper formed a thesis submitted for the M.Sc. degree of Auckland University by McCarthy. Ballance carried out further field work and wrote the paper.

REGIONAL SETTING

The Northland peninsula of New Zealand, although geologically complex, is characterised by a westerly dipping basement surface on a Permian to Jurassic meta-greywacke suite. Depth to basement is not known beneath Okahukura Peninsula. The base of the Waitemata Group is also not exposed, but is inferred to be unconformable on Upper Cretaceous or lower Tertiary strata, because that is the situation on Puketotara and Hukatere Peninsulas to the north (Arlidge 1955; Carter 1971). These Upper Cretaceous and lower Tertiary rocks are now assigned to the West Northland Chaos-breccia, which is discussed later in the paper.

The western margin of Tertiary rocks in southern Northland, from Muriwai north into the Kaipara Harbour (Fig. 1), is marked by what is normally assumed to be a large late-Tertiary fault, downthrown to the west (Schofield 1967). Both topographic and geologic maps suggest an extension of this fault northwards, to traverse Okahukura Peninsula near the escarpment separating late Quaternary sediments from the Waitemata and Waitakere Groups (Thompson 1961). However, recent drilling by Ministry of Works at N33/814207*, 1 km west of the escarpment, showed the Waitakere Group to underlie Quaternary sediments at a depth of less than 25 m. No marker horizons could be matched from the bores to the exposed rocks, but microfaunas from the bore (N33/f568†) indicate a stratigraphic level higher than anything presently known from the exposed rocks (see description of Pakaurangi Formation, below).

Thus the shallow depth of Waitakere Group 1 km west of the escarpment argues against a fault, while the higher stratigraphic level of the strata in the bore can be accounted for by the westerly dip. It is concluded that any extension of the Muriwai–Helensville fault on Okahukura Peninsula is more than 1 km west of the prominent escarpment separating exposed Waitemata and Waitakere Groups from extensive Quaternary sediments (Fig. 2), and is not sufficiently well established to be shown on our map, Fig. 2. The escarpment is regarded on present evidence as an erosional feature, perhaps an old cliff line.

STRATIGRAPHY

The rocks of Okahukura Peninsula are described under four lithologic groupings. In probable order of decreasing age these are: West Northland Chaos-breccia, Waitemata Group, Waitakere Group, and Quaternary sediments.

*Grid reference based on the national thousand-yard grid of the 1 : 63 360 topographical map series (NZMS 1), 1965 edition of N33.

†Fossil locality number recorded in the N.Z. Fossil Record File.

WEST NORTHLAND CHAOS-BRECCIA

Stratigraphic Position

The name West Northland Chaos-breccia is proposed by Ballance *et al.* (in prep.) for the very substantial olistostrome-cum-mélange of Upper Cretaceous and lower Tertiary rocks, which underlies the Otaua Group of Hokianga (Hornibrook *et al.* 1974) and the Waitemata and Waitakere Groups of southern Northland and Auckland (P. F. Ballance and K. B. Spörli, "West Northland Chaos-breccia", in prep.). On Okahukura there are two areas of rocks of the same lithology as the West Northland Chaos-breccia. They are tentatively referred to that formation, rather than to the lithologically identical Onerahi Chaos-breccia which overlies, and may be interbedded with, the Waitemata Group (Kear & Waterhouse 1967; "Onerahi Chaos-breccia—further thoughts", in prep.), because the regional field relations suggest that the largest outcrop underlies the Waitemata Group. This is not certain, since the contact is not exposed, and since dips in the Waitemata Group adjacent to the contact are to the east, as if dipping beneath the Chaos-breccia. However, from a consideration of the overall westerly dip of the Waitemata and Waitakere Groups throughout the northern Kaipara Harbour (Carter 1971; Arlidge 1955), and of the regional distribution of the West Northland Chaos-breccia, it seems most likely that the Chaos-breccia at the east end of Okahukura Peninsula underlies the Waitemata Group.

The stratigraphic position of the small area of Chaos-breccia on the northern coast of the peninsula is not clear (Fig. 2). It occurs near the axis of an anticline in the Timber Bay Formation (Waitemata Group), and it may underlie that Formation, or it may form a topographic high against which the Formation was banked, as is inferred at Kangaroo Point, 1·5 km to the north-west (discussed below). Alternatively, the Chaos-breccia may be interbedded with the Timber Bay Formation, or it may be a patch of Onerahi Chaos-breccia (Kear & Waterhouse 1967) emplaced on top of the Formation following earth movements and erosion.

Lithology and Thickness

The Chaos-breccia comprises a wide variety of blocks in a matrix of greenish bentonitic clay. The blocks range up to 10 m in diameter and consist of the following rock types: (a) grey, highly fractured and sheared chert; (b) grey, argillaceous, somewhat sheared micrite; (c) grey-white, unsheared, argillaceous micrite; (d) cream coloured, argillaceous, extensively sheared micrite; and (e) medium-grained, well sorted, glauconitic sandstone.

The contact with the Waitemata Group is not exposed. The topographic relief of 45 m suggests a minimum thickness for the formation. No stratification and no fossils were observed.

Age and Emplacement

No evidence of the age of the West Northland Chaos-breccia is known on Okahukura Peninsula. Ballance & Spörli (in prep.) infer emplacement by gravity glide, following a tectonic episode during the Waitakian (upper Oligocene to lower Miocene).

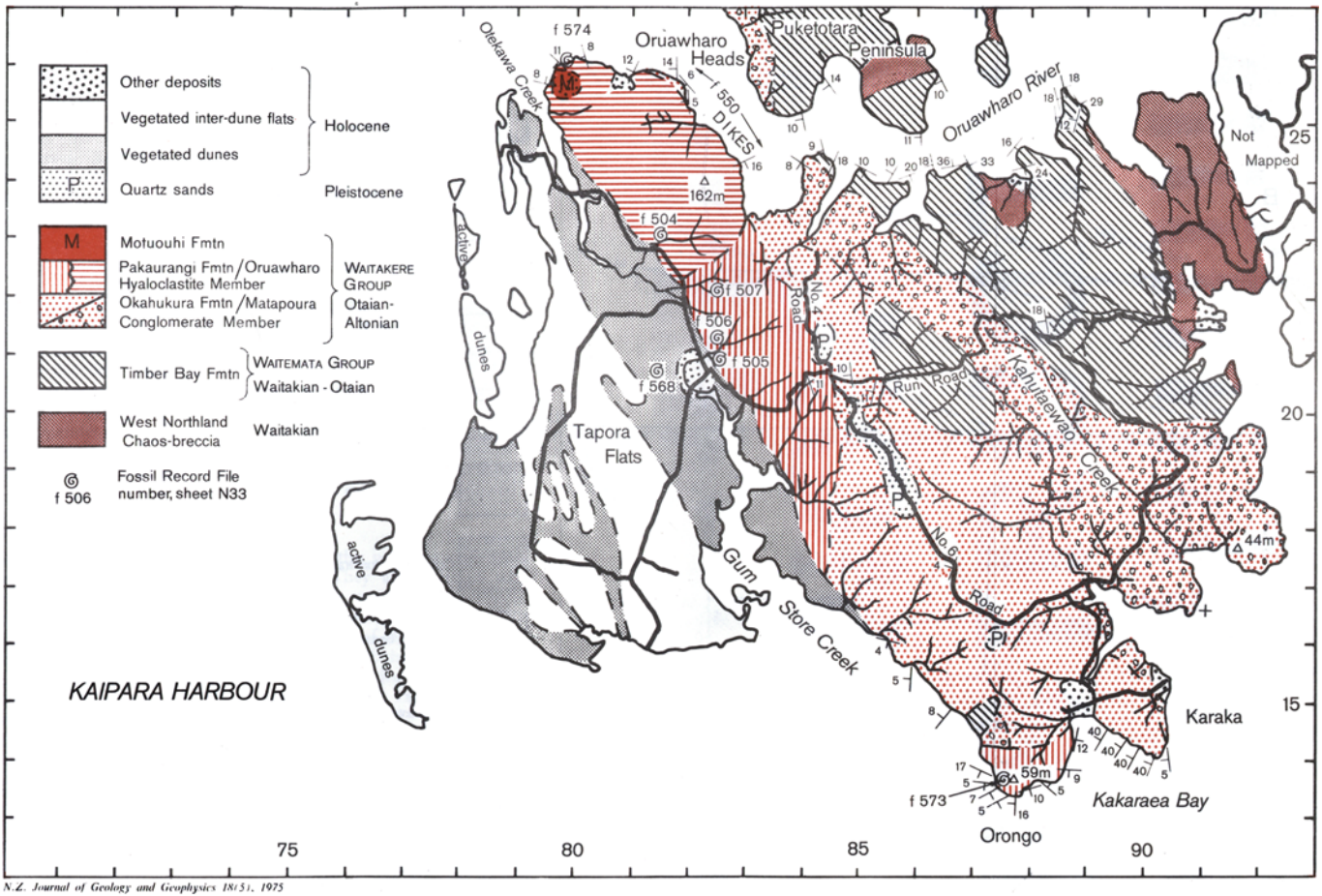

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FIG. 2 –Geological map of Okahukura Peninsula, Kaipara Harbour. The grid co-ordinates are from NZMS 1 Sheet N33, 1965 edition. N33/f568 = location of Ministry of Works bore referred to in the text.

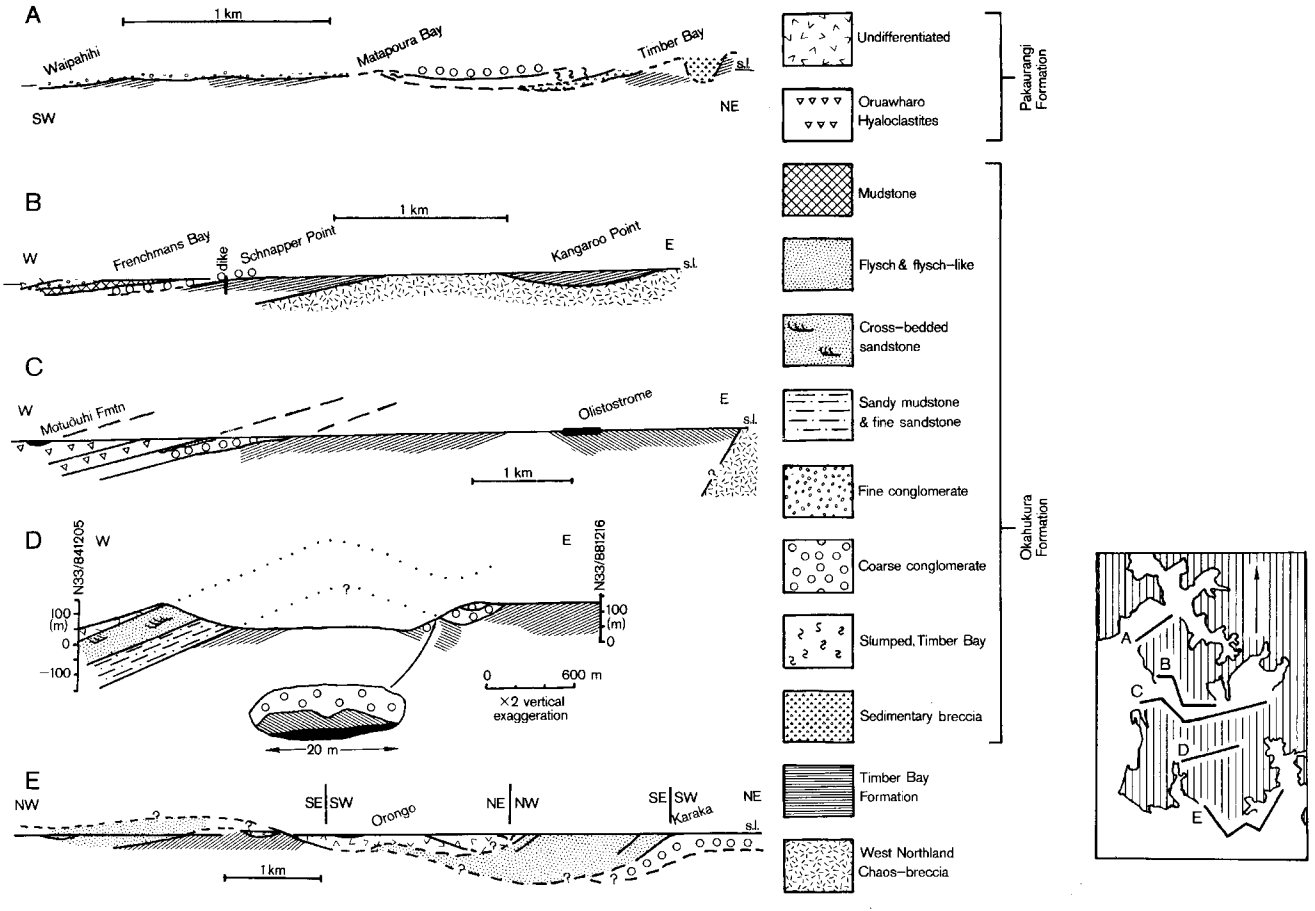

FIG. 3—Cross sections along northern and southern shores of Puketotara Peninsula (A and B) and Okahukura Peninsula (C and E). No vertical exaggeration. (D) Cross section along Run Road, Okahukura Peninsula, between N33/841205 and N33/881216. Vertical exaggeration × 2. Inset shows detail of contact between Timber Bay Formation and Matapoura Conglomerate.

Comparison with Puketotara Peninsula

Underlying the Timber Bay Formation on Puketotara Peninsula, a few kilometres to the north, Carter (1969; 1971) mapped sheared Mahurangi Limestone (Oligocene) overlain here and there by an olistostrome which he correlated with the post-Waitemata Onerahi Chaos-breccia of Kear & Waterhouse (1967). The olistostrome does not rest on Waitemata or Waitakere Groups. In view of more recent knowledge of the pre-Waitemata West Northland Chaos-breccia (Hornibrook *et al.* 1974; Ballance & Spörli in prep.), it seems likely that both the sheared Mahurangi Limestone and the olistostrome on Puketotara Peninsula are parts of the West Northland Chaos-breccia, and that both underlie the Waitemata Group.

WAITEMATA GROUP

The definition of the Waitemata Group is presently being revised to exclude the Manukau Breccias and correlatives, which are to be elevated to Group status as the Waitakere Group (P. F. Ballance "Stratigraphy and bibliography of the Waitemata Group of Auckland", in prep. a; Ballance *et al.* in prep.; Hayward 1975). The boundary separating the two groups in the central Kaipara Harbour is to be drawn at the base of the prominent igneous conglomerates, here included in the new Okahukura Formation. The Waitemata Group beneath that boundary on Okahukura consists of a single formation, the Timber Bay, established by Carter (1971) on adjacent Puketotara Peninsula.

TIMBER BAY FORMATION (Carter 1971)

Extensive exposures of this formation occur on the northern coast (see Fig. 4), and poor exposures in some roadcuts. They are identical with the type exposures on Puketotara Peninsula to the north (Carter 1971), and comprise thin interbedded mudstones and rippled fine sands that are brown-grey when weathered. The chief characteristics of the formation are the predominance of mudstone, the lateral continuity of the thin beds, the absence of scour structures and large scale current bedding, and the presence of intraformational slumping and occasional load casts and clastic dykes. Some slightly thicker (0·3 m) sandstones display sharp basal contacts and are internally graded from medium to fine sand, thus suggesting turbidity currents, although they generally lack internal structures.

The rippled fine sands have undulating upper and lower margins, and occasionally display internal ripple-drift cross-lamination. Exposures that allow accurate measurements of current direction are few; at N33/852242 eight measurements gave an average flow to the ESE. Carter (1971) obtained a south-westerly current direction from these beds further north.

The base of the formation is not seen. The thickness taken from a cross section along the northern coast (Fig. 3C) is approximately 600 m on the west limb of the anticline and 1000 m on the east limb. These thicknesses assume no repetition by faulting; they contrast with a thickness of 170 m 1 km to the north on Puketotara Peninsula, as discussed below.

FIG. 4—Timber Bay Formation, northern coast of Okahukura Peninsula. Interbedded thin rippled sandstones (protruding) and mudstones (receding). Cliff is about 3 m high in the foreground.

Comparison with Puketotara Peninsula

An east–west cross section was drawn through the southern portion of Puketotara Peninsula, only 1 km north of Okahukura, using information from Carter (1967; 1971) and unpublished field observations of P. F. Ballance and B. W. Hayward (Fig. 3B). The section at Kangaroo Point suggests that Timber Bay sediment accumulated against a high of the underlying rocks with a relief of some 170 m, and the section at Schnapper Point indicates a thickness also of about 170 m. The thickness on the north coast of Puketotara is more than 249 m (Carter 1971).

Thus the Formation appears to have been deposited on an irregular surface of the underlying West Northland Chaos-breccia and to vary in thickness from 170 m to perhaps more than 1000 m.

Age and Correlation

The Timber Bay Formation on adjacent Puketotara Peninsula is Waitakian to Otaian in age (upper Oligocene to lower Miocene) (Carter 1971). No fossils other than trace fossils have been located on Okahukura, and the age is assumed to be the same as on Puketotara. The formation is assigned to the Kaipara Sub-group of the Waitemata Group by Ballance (in prep. a)

Status of Carter's (1971) Conglomerate Band

Carter (1971) described a conglomerate band within the Timber Bay Formation on Puketotara Peninsula. The same conglomerate outcrops on Okahukura Peninsula, but its stratigraphic position is here revised and

it is placed in a new formation, the Okahukura Formation. A comparison with, and reinterpretation of, the Puketotara sequence is given in the discussion of the new Okahukura Formation

WAITAKERE GROUP

This Group has been newly erected by Hayward (1975). It includes the proximal deposits of the Waitakere Magmatic Arc (P. F. Ballance, "Evolution of the Upper Cenozoic magmatic arc and plate boundary in northern New Zealand", in prep. b*) which lay to the west of the Waitemata flysch basin (Ballance 1974). The lower boundary in the Kaipara Harbour area is taken at the base of the first coarse volcanic conglomerates or breccias.

OKAHUKURA FORMATION (NEW FORMATION)

A prominent conglomerate composed largely of andesite and diorite pebbles overlies the Timber Bay Formation conformably on the north coast of the peninsula, at N33/841244, west of Oturapa Creek. It is a southerly continuation of the conglomerate mapped by Carter (1971) within the Timber Bay Formation. It can be mapped as a south-east trending belt across the peninsula, and it outcrops extensively on the southern coast. It is also well exposed in very recent road cuts on Run Road in the centre of the peninsula, where the exposures have lead to a revision of the stratigraphic interpretation of the conglomerate and associated beds, and the erection of the new **Okahukura Formation.**

Run Road Section

Extensive road cuts were made between 1971 and 1974 on Run Road, in an anticline (Fig. 3D). On the east limb of the anticline the beds consist of conglomerate with subordinate sands. At N33/871216 conglomerate rests discordantly on an eroded surface cut in Timber Bay Formation, as shown in the inset in Fig. 3D. The Timber Bay Formation is exposed only for about 20 m, and then, in the 100 m of road cuts below, conglomerate is exposed whose relationship to the Timber Bay Formation is not clear. If the Timber Bay Formation is in place, the topographically lower conglomerate may represent a higher stratigraphic level banked discordantly against Timber Bay Formation; this interpretation is suggested by the exposed contact (inset, Fig. 3D). Alternatively, the exposed Timber Bay Formation may be interbedded with the conglomerate, or may be a slumped block within it; Timber Bay lithology is not known to be interbedded with the conglomerate elsewhere, but slumped blocks of Timber Bay are known elsewhere immediately below (north shore of Puketotara Peninsula, discussed below) and above (south-west corner of Okahukura, discussed below) the conglomerate. A final alternative is that the lower conglomerate is a superficial slump from the ridge of conglomerate to the north-east; there is support for this interpretation in the slumped surface topography and the occurrence of lignite lenses in old slump hollows in

*Now in press with *Earth and Planetary Science Letters.*

the conglomerate in the road cut higher up the hill (with poorer exposure these lignites could easily be misinterpreted as being interbedded with the conglomerates).

Thus the relationship between the conglomerate and the underlying Timber Bay Formation in the Run Road exposures is not completely clear, but with the evidence of extensive discordant contacts on Puketotara Peninsula and elsewhere on Okahukura (discussed below), and of superficial slumping in the vicinity, the interpretation of the contact preferred here is that conglomerate rests unconformably on an eroded surface of Timber Bay Formation about 100 m above the bottom end of the new road cuts, at N33/871216, and that superficial slumped conglomerate is exposed in the lower 100 m of the road cut

Above the basal contact, some 100 m thickness of north-east dipping conglomerate is exposed, and at the top of the hill a further 20 m of horizontal conglomerate. The latter consists of lenses of conglomerate—some in channel-fills, others on foreset beds—interbedded with sandstone. The sandstones are in beds up to 1 m thick, and are generally fine and well-sorted. Some thin mudstones, and layers of mudstone fragments in sand, occur; there is much ripple-drift bedding, lensing, and medium-scale cross-bedding. Some conglomerate beds are graded. The constituents include large and angular blocks of white laminated mudstone and sandstone, and smaller well-rounded pebbles and cobbles of andesite and subordinate diorite.

The cross section, Fig 3D, suggests that the conglomerate body thins to the east.

Timber Bay Formation, with a superficial cover of conglomerate pebbles, is exposed in the valley bottom. On the western limb of the anticline, strata apparently equivalent to the conglomerate are exposed, but without conglomerate. Instead, between N33/847205 and N33/851205, 85+ m of sandy mudstones and very fine siltstones, with some fine sandstones, is overlain by 36+ m of coarse lithic sandstones showing medium- to large-scale, tabular cross-bedding in some beds. The cross-bedding indicates a consistent current flow to the east, and is generally in cosets from 0·2 to 1 m thick; one coset is 10 m thick, which is by far the thickest known from the Waitemata and Waitakere Groups.

Thus the Run Road section appears to show the conglomerate as a lenticular body in east–west section, and a similar interpretation of the conglomerate on the north shore of Puketotara Peninsula will be described later. The conglomerate at Run Road is apparently replaced to the west by sandy mudstones overlain by coarse, cross-bedded sandstones.

Section on North Shore of Okahukura

The conglomerate overlies the Timber Bay Formation conformably, as already described, at N33/841244. A small thickness of conglomerate is exposed before exposure ceases in a wide, mangrove-filled bay. West of the bay, 10 m of thick-bedded volcanic sandstones with minor mudstones are exposed beneath the overlying hyaloclastite member of the Pakaurangi Formation (see below).

Section on South-East Shore of Okahukura

The outcrop of conglomerate widens greatly towards the south-east. It is exposed extensively on No. 6 Road, and on the coast, where it forms the three unnamed headlands north of Karaka (N33/920197; N33/920172; N33/910167). Dips are here horizontal or very low.

Conglomerate at Karaka Point is overlain along the eastern shore of Kakaraea Bay by a distinctive north-west dipping sequence, approximately 800 m thick. The predominant lithology in this sequence is mudstone, with discontinuous layers of sandstone, up to 0·6 m long and 50 mm thick. There are thicker sandstones, which are generally coarse and poorly sorted, perhaps pebbly, with a predominance of lithic grains, both sedimentary and volcanic. They range up to 1 m in thickness and sometimes show current bedding, graded bedding, and mudstone inclusions.

These beds are either overlain by, or faulted against, the Pakaurangi Formation exposed on the west side of Kakaraea Bay. The contact is not exposed, but the fact that the two formations dip towards each other makes the structural situation complex (Fig. 3E).

Section on South-West Shore of Okahukura

Conglomerate is again exposed 1 km north of Orongo Point at N33/871142. It is lenticular in form and overlies Timber Bay Formation discordantly (Fig. 5). The conglomerate is internally lensed and channelled, and towards the top contains layers of lensing and cross-bedded sand with thin mudstone interbeds. It is overlain by a unit consisting of slumped blocks of Timber Bay Formation in a matrix of conglomerate. The overlying Pakaurangi Formation rests unconformably on all three units.

The Timber Bay Formation underlying the lens of conglomerate is folded by slump folds, but dips generally north-west. It is overlain to the north-west, at N33/869148, by yet another unit of the Okahukura Formation, consisting of a coarse-grained flysch lithology. The graded sandstones are strongly laminated. They contain clasts of grey mudstone and white pumice, up to 20 mm diameter in the thickest beds. Load casts, flame structures, and other soft-sediment deformation structures are common. The thickest graded bed varies in thickness from 3 m in the cliff to 2 m in the shore platform, and contains clasts of locally derived sediment up to 0·5 m long; the underlying beds are in places torn up and disrupted.

The flysch unit is approximately 60 m thick, and is overlain, apparently conformably since the contact is obscured but the strikes are similar, by thick-bedded, poorly sorted medium sandstones with thin mudstone interbeds up to 20 mm thick. These beds are folded into a gentle, south-west plunging syncline. At N33/853159 they consist of medium-grained, moderately to poorly sorted, quartz-lithic sandstones, which in places are carbonaceous and cross-bedded (0.1 up to 1 m). The sandstone unit is only a few metres thick, and the top is not exposed.

Summary of the Okahukura Formation on Okahukura Peninsula

The mappable unit distinguished here as the Okahukura Formation is thus a heterogeneous assortment of unfossiliferous lithologies, in which there is much lateral variation. It is sandwiched between the distinctive

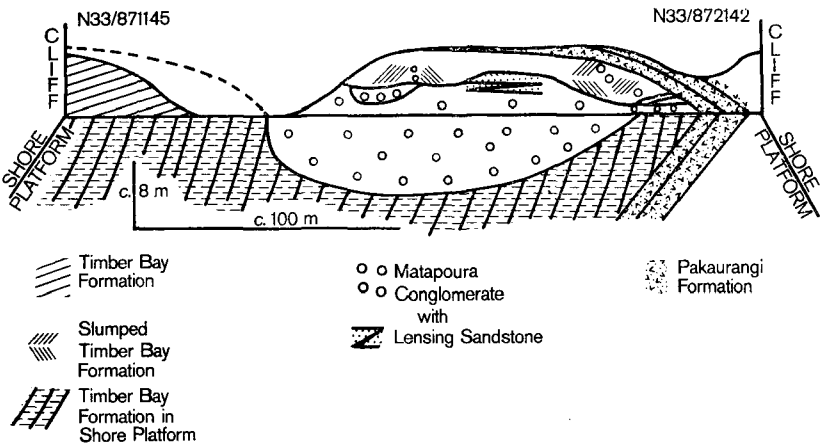

FIG. 5—Diagrammatic view of cliff and shore platform 1 km north of Orongo Point, to show relationship between Timber Bay, Okahukura (Matapoura Conglomerate Member), and Pakaurangi Formations. Location of section is the north-western segment of cross section E, Fig. 3.

Timber Bay and Pakaurangi Formations. It varies in thickness from a little over 100 m to over 800 m, and it overlies the Timber Bay Formation sometimes conformably and sometimes unconformably. The dominating characteristic is a prominent NW–SE belt of coarse andesite/diorite conglomerate which is apparently lenticular in NE–SW section. It appears to be replaced laterally to the west by current-bedded sandstones in the centre of the peninsula, and by flysch in the south-west, and is overlain by a flysch-like unit in the south.

The age of the Formation is not known directly. Lying between the Timber Bay Formation (Waitakian–Otaian, upper Oligocene–lower Miocene) and the Pakaurangi Formation (Upper Otaian–Altonian, lower Miocene) it is presumably Otaian (lower Miocene).

It must be considered whether the various constituent units should be made formal members of the formation. Apart from the conglomerate, however, the greatest distance that any one unit can be traced is 2 km, and for most units precise stratigraphic relations are unknown. It has therefore been decided to distinguish only the conglomerate as a member.

Matapoura Conglomerate Member (New Member)

The name **Matapoura Conglomerate** was used in an unpublished manuscript by Carter (1967), and referred to by Ballance (1974), but has not previously been defined. The name is derived from the bay west of Timber Bay, on the north shore of Puketotara Peninsula (N28/805326); it is not named on the Lands and Survey NZMS 1 map, but is known locally as Matapoura Bay. The outcrop of the conglomerate lies between Matapoura Bay and Timber Bay (N28/813335 to 810329), which is the type section

of the Member. Carter (1967; 1971) mapped it across Puketotara Peninsula, and we have mapped it across Okahukura Peninsula. On Okahukura it appears to be confined largely to a well-defined NW–SE belt, as discussed above, and there is evidence that this may also be true on Puketotara, as discussed below. Similar conglomerate is exposed at Mataia, 10 km south-east of Okahukura (Fig. 1).

The conglomerate consists generally of well-rounded pebbles, randomly orientated in a poorly sorted sandstone matrix. Packing varies; the pebbles are sometimes in grain support, and sometimes matrix supported. The rock types, in order of decreasing abundance, are: (a) andesite, both augite andesite and hypersthene andesite, occuring either as well-rounded, porphyritic pebbles and cobbles (average diameter = 100 mm), or as larger (average diameter = 0·5 m) subrounded boulders of vesicular lava; (b) hornblende microdiorite, internally somewhat deformed, occuring as small (10–50 mm) well-rounded and polished pebbles; (c) argillaceous, glauconitic biomicrite; (d) grey-black chert, in small well-rounded and polished pebbles; and (e) biotite dacite, also in small, well-rounded, polished pebbles.

The sedimentary structures present are crude and irregular bedding, occasional grading, channel-fill, and cross-bedding. The sandstone matrix consists largely of smaller grains of the larger lithic components, with crystalline fragments of plagioclase, quartz, biotite, and chlorite.

The assemblage of rock types compares closely with that typical of the Albany Conglomerate (Bartrum 1920; 1924; Bunting 1970) which occurs in the flysch facies of the Waitemata Group 25 km to the south-east. It is inferred that the two conglomerates are correlative (Ballance 1974).

The maximum thickness of the Matapoura Conglomerate Member is not known; it is at least 120 m. Its age is not known directly, but is inferred, like the Okahukura Formation to be Otaian (lower Miocene).

Comparison with Puketotara Peninsula

On Puketotara Peninsula, to the north of Okahukura, Carter (1967; 1971) interpreted the Matapoura Conglomerate as being interbedded with the upper levels of the Timber Bay Formation, whereas on Okahukura we place it above the latter. A re-examination of Puketotara was therefore made by Ballance and B. W. Hayward, with the object of checking Carter's interpretation. We now believe that a revised interpretation of the Puketotara sequence, bringing it into line with the Okahukura sequence, is consistent with the evidence.

The crux of the matter is the stratigraphic position of exposures of the Timber Bay Formation in Matapoura Bay (N28/805326), west of the outcrop of the Conglomerate. On the basis of the overall westerly dip, Carter believed these exposures to lie stratigraphically above the Conglomerate. The finer-grained conglomerates exposed to the west of Matapoura Bay, above the Timber Bay Formation in the Bay, were therefore regarded as a separate formation, equated with the Hollands Member of the Pakaurangi Formation.

However, we believe that the Matapoura Conglomerate discordantly overlies the Timber Bay Formation in the shore platform on the east side of

Matapoura Bay. The finer conglomerates west of Matapoura Bay, which also discordantly overlie the Timber Bay Formation, are thus lateral equivalents of the Matapoura Conglomerate. They are therefore members of the Okahukura Formation. rather than belonging to the overlying Pakaurangi Formation. The discordant contact between conglomerate and the underlying Timber Bay Formation is traceable in the shore platform and at the base of the cliff for over a kilometre south-west of Matapoura Bay. We therefore propose to include Carter's (1971) Hollands Member in our Okahukura Formation. The name Hollands Member can then no longer be used on Puketotara Peninsula, because the name was coined by Jones (1969) for a member of the Pakaurangi Formation.

The incompletely exposed sequence on the south side of Puketotara is more easily accommodated to our interpretation than to Carter's. Matapoura Conglomerate overlies Timber Bay Formation discordantly on the west side of Schnapper Point at N33/834251, the contact is visible for about 150 m, and the dip in the Conglomerate is low. From there north-westwards round the shores of Frenchmans Bay, intermittent exposures of conglomerate occur for some 2·5 km. At N33/818279 conglomerate is overlain abruptly by thin-bedded, muddy, very fine sandstones, which are lithologically not the same as Timber Bay Formation. These beds dip gently north-west, and at N33/814280 are overlain discordantly by a finer-grained conglomerate of andesite and diorite, with much sandstone, which displays channelling and lensing. These conglomerates then dip west beneath Pakaurangi Formation. We propose to include the two conglomerates and the intervening muddy, very fine sandstones in the Okahukura Formation.

A further consequence of our examination of the north shore of Puketotara concerns the stratigraphic position of the prominent channel-fill breccia on the east side of Timber Bay (N28/821336). This is cut into Timber Bay Formation and was included by Carter (1971) in that Formation. On the west side of Timber Bay, 2 m of Timber Bay Formation, dipping west, and containing layers of fine breccia, is overlain conformably by about 20 m of a complexly bedded breccia which is lithologically identical to the breccia in the channel-fill; that is it consists mostly of argillaceous limestone, with rare igneous clasts. The breccia is overlain by a unit consisting of large slumped blocks of Timber Bay Formation, some of them containing occasional thin interbeds of breccia like that beneath; there are also occasional blocks of Puriri Formation (Ballance 1964). The slumped unit is overlain by very coarse Matapoura Conglomerate. In our interpretation the channel-fill, the bedded breccia, and the slumped unit all overlie the Timber Bay Formation and are included in our Okahukura Formation.

Our interpretations of the northern and southern coastal sections of Puketotara Peninsula are summarised in Fig. 3A and 3B.

PAKAURANGI FORMATION (Jones 1969)

The Pakaurangi Formation was erected by Jones (1969) for the well-known fossiliferous beds of Pakaurangi Point, Hukatere Peninsula. He mapped six Members. Carter (1971) recognised three of the six members on adjacent Puketotara Peninsula, but, as discussed above, his Hollands Member is regarded by us as belonging to the new Okahukura Formation. The

Pakaurangi Formation on Puketotara unconformably overlies the Okahukura Formation (Carter's Hollands Member), and is unconformably overlain in turn by the distinctive Motuouhi Formation.

In the equivalent stratigraphic position on Okahukura Peninsula there are two lithological units: in the north, prominent glassy volcaniclastic rocks (hyaloclastites), and, along-strike in the centre and south, a variable unit of fossiliferous mudstones and volcanic sandstones. The former is distinguished as the new **Oruawharo Hyaloclastite Member**, and the latter is mapped as undifferentiated Pakaurangi Formation. The contact between the hyaloclastites and the underlying Okahukura Formation is conformable in places and unconformable in others. The contact between the Pakaurangi and Okahukura Formations in the centre of the Peninsula, on the Run Road section (Fig. 3D), appears to be conformable, whereas in the south the Pakaurangi Formation is strongly unconformable on both the Okahukura and Timber Bay Formations (Fig. 5).

Oruawharo Hyaloclastite Member (New Member)

The type section and name-bearer of the member is Oruawharo Heads, the northern extremity of Okahukura Peninsula (Fig. 2). Exposures are more or less continuous from the mouth of Otekawa Creek at N33/796259 eastwards to N33/829242. The exposed thickness is estimated at some 225 m. The basal contact on the Okahukura Formation is in some places conformable and gradational, and in others discordant. The Member is overlain conformably by the Motuouhi Formation. The hyaloclastites therefore occupy the same stratigraphic position as the Pakaurangi Formation to the north and south. Since there are glassy lavas interbedded within the Pakaurangi Formation at Motukumara Point on adjacent Puketotara Peninsula (Carter 1971), which appear to be a lateral continuation of the Oruawharo rocks, the Member is regarded as a large lens of hyaloclastites within, and at Oruawharo Heads entirely replacing, the undifferentiated Pakaurangi Formation.

The Member consists of hyaloclastite breccias, common hyaloclastites, and stratified hyaloclastites (Parson's 1969 classification), cut in places by numerous dikes. The breccias are massive and unsorted, while the finer-grained varieties range from massive and poorly sorted, to finely stratified and well-sorted. A channel-fill is exposed at N33/811259.

The glass is largely replaced by palagonite, and there is an extensive development of zeolites.

Undifferentiated Pakaurangi Formation

The presumed lateral transition from the Oruawharo Hyaloclastite Member to the undifferentiated Pakaurangi Formation is not exposed. To the south the first exposures of fine-grained, fossiliferous rocks are on No. 4 Road at N33/841215, where thick-bedded muddy sandstones, with scattered, fragmentary fossils, are exposed. Alternating fine, muddy and coarse pumiceous sandstones, containing a fauna of bivalves and solitary corals, are exposed nearby on Run Road at N33/842207. Similar muddy lithologies with fossils were penetrated in the Ministry of Works bore 1 km west of the escarpment separating Waitakere Group rocks from Quaternary sediments (N33/814207,

N33/f568). Microfaunas from N33/f568 include *Globigerinoides trilobus trilobus* and *Globorotalia praescitula,* indicating an Altonian (Pl) age (lower Miocene) (B. W. Hayward pers. comm.).

The thickness of the Pakaurangi Formation in the Run Road area is estimated at 330+ m, assuming the rocks penetrated by the MOW bore to be in stratigraphic continuity with the exposed rocks. The top is not seen.

To the south there is a gap in outcrops of some 6 km, before Pakaurangi Formation is seen again at Orongo. Here the basal contact exposed in the cliff at N33/872140 is strongly unconformable on the Okahukura and Timber Bay Formations (Fig. 5). The beds here consist generally of coarse to very coarse, poorly sorted volcanic-rich sandstones, in beds up to a metre thick. Most display small- to medium-scale current bedding, and some are graded. Occasional fine sandstones and mudstones are present. There are many intraformational discordances (e.g., Fig. 6).

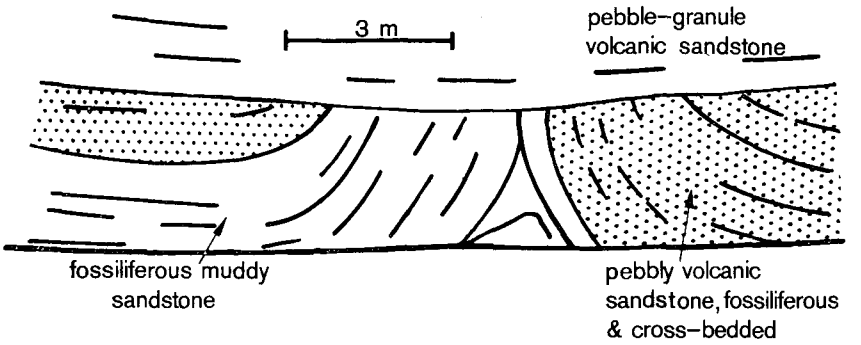

FIG. 6—Undeformed strata overlying a diapiric anticline; an intraformational disconformity within the Pakaurangi Formation. Cliff exposure, Orongo, N33/874137. Fossil locality N33/f573 is situated in the coarse sandstone shown on the lower right, a few metres to the right of the sketch.

In places the beds are calcareous and fossiliferous, particularly the 3 m of very coarse, poorly sorted sandstone exposed at N33/874137, from which the following fauna was collected:

N33/f573 MACROFAUNA (Identified by J. A. Grant-Mackie).

COELENTERATA

Lophelia parvisepta Tension-Woods 1880.
cf. *Lophelia parvisepta* Tension-Woods 1880
Oculina virgosa Squires
Notocyathus orientalis Duncan 1876
Caryophyllia japonica Marenzeller 1888
?Dendrophyllia boschmai van der Horst 1926
Flabellum sp.
Scleractinian
Hydrocoral sp.

GASTROPODA

Falsicolus kaiparaensis Suter 1917
cf. *Echinophoria* sp.
cf. *Maurea gracilis* Marshall
Vaginella torpedo
Turridae
Gastropoda spp.

BIVALVIA

Mesopeplum subconvexus
Venericardia sp.
Notocorbula illecta Laws 1941
Jupiteria parleachi Laws 1939

?DENTALIIDAE

N33/f573 MICROFAUNA (Identified by G. W. Gibson)

FORAMINIFERA

Lenticulina sp.
Vaginulina sp.
Quinqueloculina sp.
Biloculina sp.
Bulimina pupula Stache
Sphaeroidina bulloides d'Orbigny
Elphidium sp.
Cribrononion sp.
Globigerina woodi woodi
G. bulloides d'Orbigny
G. spp.
Globoquadrina dehiscens Chapman *et al.*
Planulina cf. *renzi*
Cibicides 3 spp.
C. temporatus
C. notocenicus Dorreen
Nonion dorreeni Hornibrook
Pullenia quinquelobus Reuss
Gyroidinoides zelandica Finlay
Osangularia bengalensis
Oridorsalis prominula
Cerobertina bartrumi Finlay

OSTRACODA

Ostracoda sp.

GASTROPODA

Protoconch of Gastropoda

The thickness at Orongo is 48+ m; the top of the formation is no longer present.

The relationship to the underlying Okahukura Formation in Kakaraea Bay is, as mentioned before, complex, since the two formations dip towards each other and the contact is not seen. The simplest interpretation of the relationship is thought to be that presented in the cross section (Fig. 3E); in view of the numerous discordances and variations in thickness and facies within the Waitakere Group, it is assumed that the Pakaurangi Formation is banked against a localised thick lens of Okahukura Formation. Similarly, to the north of Orongo the Okahukura Formation beneath the Pakaurangi Formation thickens from zero to about 200 m (Figs 3E, 5).

Age and Correlation

The Pakaurangi Formation on Puketotara and Hukatere Peninsulas, to the north, is assigned to the upper Otaian and Hutchinsonian (new Altonian of Scott 1972) Stages (lower Miocene) by Scott (*in* Jones 1969, and Carter 1971). Of the fossil records on Okahukura (see Fig. 2) only two faunas give a well-based age. N33/f568, from the MOW bore, indicates an Altonian age (Pl of Scott 1972, lower Miocene) (B. W. Hayward pers. comm.). This is the youngest age known for the Waitakere Group on Okahukura. On the other hand, N33/f573, from the Pakaurangi Formation at Orongo, indicates a Waitakian age (Upper Oligocene to lower Miocene) on the basis of the abundance of *Globigerina woodi woodi* and the absence of *G. woodi connecta* (G. W. Gibson pers. comm.). However, it is most improbable that this is the correct age, since the underlying Timber Bay Formation is Waitakian–Otaian, and since only the basal strata of the Waitemata Group in the north of the basin are of Waitakian age (Ballance in prep. a). It is assumed, therefore, that the Pakaurangi Formation has the same age as on Puketotara and Hukatere Peninsulas, viz Otaian–Altonian (lower Miocene), and that the absence of *G. woodi connecta* from N33/f573 is coincidental.

The Formation is assigned to the Hukatere Sub-group of the Waitakere Group by Hayward (1975).

Further Work

There is good potential for further work on the faunas of the Pakaurangi Formation. Fossils occur also in the Oruawharo Hyaloclastite Member; *?Lophelia parvisepta* and *Venericardia* have been found at N33/799260, N33/f574.

MOTUOUHI FORMATION (Carter 1971)

This formation was erected by Carter (1971) on adjacent Puketotara Peninsula, where it unconformably overlies the Pakaurangi Formation. On Okahukura it is exposed in a small synclinal outcrop at Oruawharo Heads between N33/795254 and N33/794256, where it conformably overlies the Oruawharo Hyaloclastite Member of the Pakaurangi Formation.

The formation consists of hard, fine-grained, brown hyaloclastite tuff, closely resembling argillite in hand specimen. A maximum of 8 m is exposed.

The Motuouhi Formation is only known from these two peninsulas, and is regarded as a lens within the Hukatere Sub-group of the Waitakere Group (Ballance 1974, fig. 14; Hayward 1975).

Age and Correlation

No fossils were seen on Okahukura, but Carter (1971) reported foraminifera, shell fragments, and wood on Puketotara. On the basis of a microfauna and its stratigraphic position, Carter deduced a Southland age (Scott's 1972 Altonian Stage, lower Miocene).

Quaternary Deposits

Older Dune Deposits

Old dune deposits are preserved, at heights ranging from 90 to 150 m above sea level, on the ridge of Waitakere Group rocks closest to the Kaipara Harbour, but are not preserved further inland (Fig. 2). They consist of well-sorted, white quartz sand, and are the northern-most of a series of such small deposits which occur close to the eastern shore of the Kaipara Harbour to as far south as Helensville (Fig. 1). These deposits were mapped by Ferrar (1934) as part of his Kaihu Formation (now Kaihu Group) of older Pleistocene deposits. Some of them to the south of Okahukura have been, or are being worked for industrial use. On Okahukura the sands mantle an irregular topographic surface, and the thickness seems to be only a few metres.

Such highly quartzose sands are unusual in Northland, which is dominated by intermediate to basic igneous rocks and sediments derived from them. It is thought that they are the greatly condensed lateral equivalent of the much more voluminous Kaihu Group on the west side of the Kaipara Harbour, where it makes up the northern and southern outer peninsulas of the Harbour (Ferrar 1934) (Fig. 1). There the sands are strongly lithic, feldspathic, and ferromagnesian, with only rare quartz (Brothers 1948), and it seems likely that the quartzose sands of the eastern Kaipara Harbour were winnowed by prolonged weathering and transportation. This presumably took place during glacial periods, when the lowered sea level would have drained the Kaipara Harbour, but as yet there is no independent evidence of the age of the deposits. The fact that they often form eroded hill-top remnants suggests an older Pleistocene age. However, they occur at all heights down to present sea level, which suggests that at least some of them accumulated during the last glaciation.

Younger Dune and Beach Deposits

The western half of Okahukura Peninsula comprises the Tapora Flats, an extensive area of Recent sand accumulation, Two parallel belts of fixed dunes are recognised (Fig. 2), while a third parallel belt of active dunes forms offshore islands separated from the Peninsula by hard sand which is uncovered at low tide. The two belts of fixed dunes are separated by an older beach flat that lies between 1·5 and 4·5 m above present high water. The fixed dunes rise to 15 m above sea level, and in the outer of the two belts small flat areas can be recognised corresponding to beach flats and interdune lakes. From the low elevation above sea level of the Tapora Flats, and the freshness of the land forms, it is thought that the accumulation belongs entirely to the post-glacial period. Thompson (1961) assigned the three dune belts to the Holocene and distinguished them as Younger Foredunes 3 (oldest), 2, and 1 (youngest).

Such an extensive area of sand is unique in the Kaipara Harbour, the edges of which are generally muddy. Its presence appears to be due to the exposed position of Okahukura Peninsula directly opposite the Harbour entrance.

Low Terrace Levels

A large number of small coastal terraces at heights of between 0·6 and 4·5 m above high water are ascribed to the apparent peak of the Flandrian transgression, the effects of which are widely preserved in northern New Zealand (Ballance 1968).

Near the mouth of Gum Store Creek small terraces occur at heights of 4·5, 9, and 12 m above high water. Terraces at similar heights elsewhere in northern New Zealand (Kear & Waterhouse 1961; Brothers 1954b; Chappell 1970) are thought to have been cut during the last interglacial period. In the Okahukura Peninsula area such an age would conflict with the post-glacial origin inferred for the entire Tapora Flats (above); there is no independent evidence with which to resolve this apparent conflict.

PETROGRAPHY OF THE WAITEMATA AND WAITAKERE GROUPS

Sandstones

The sandstones are strongly lithic, and the predominant lithic grains are volcanic (Table 1). The volcanic fragments consist of plagioclase microlites set in a glassy mesostasis, but they are generally weathered to limonitic or chloritic material; the lava type is presumed to be andesite. The most abundant detrital mineral is plagioclase (andesine–labradorite) in angular to subrounded grains up to 0·2 mm in diameter, and generally fresh in appearance. Quartz rarely forms more than 10% of the rock and occurs as angular to subangular, fresh, inclusion-free grains up to 0·2 mm in diameter.

Lesser constituents include sedimentary rock fragments (mudstone and micrite) and glauconite. The heavy mineral suite is dominated by opaque ore minerals, with common green and brown pleochroic hornblende and pyroxenes, and rare zircon. A matrix of clay is in some samples partially or completely replaced by authigenic zeolite of the clinoptilolite–heulandite type (P. M. Black pers. comm.).

Using the classification of Folk *et al.* (1970), the sandstones are nearly all poorly to moderately sorted, fine, medium or coarse sandstone: plagioclase volcanic litharenites.

In the coarse and very coarse sandstones lithic grains form up to 90% of the rock. In some (e.g., 19992—University of Auckland Rock Catalogue Number), colourless grains of isotropic chabazite occur (P. M. Black pers. comm.). Some of these show a peripheral zone of labradorite.

The mudstones are sandy and essentially similar to the sandstones, but have a much larger proportion of clay, chiefly montmorillonite.

Oruawharo Hyaloclastite Member (Pakaurangi Formation)

Both the fine-grained and coarse-grained varieties of hyaloclastite now consist largely of palagonite, in which weakly birefringent acicular fragments occur in two sets at right angles. Vesicles are filled either with palagonite or with zeolites. The latter consist either solely of radiating fibrous natrolite,

TABLE 1—Modal composition of sandstones of Waitemata and Waitakere Groups (in %).

	TIMBER BAY FORMATION					PAKAURANGI FORMATION				
SAMPLE*:	19909	19913	19979	19989	19992	19941	19864	19942	19978	19982
Quartz	11·5	11·6	5·6	3·4	rare†	4·4	2·6	9·8	1·8	rare
Feldspar	17·7	7·6	12·2	9·8	5·8	10·4	2·4	13·0	14·8	4·6
Volcanic fragments	45·5	59·0	45·4	41·4	39·4	25·2	14·6	49·2	16·8	34·8
Sedimentary fragments	4·1	4·6	10·0	4·8	28·0	14·0	11·2	3·4	4·6	22·8
Indeterminate lithic grains	12·9	11·0	10·8	6·2	–	–	28·2	5·2	2·6	17·4
Mafic minerals	1·7	rare	rare	rare	5·0	rare	1·4	rare	3·4	2·2
Fossils	–	–	5·0	–	–	1·2	1·4	–	rare	1·6
Glauconite	rare	rare	1·0	rare	–	rare	rare	–	rare	rare
Pyrite	rare	rare	–	–	–	rare	3·0	1·2	rare	rare
Zeolites	–	–	–	10·4	7·2	35·6	38·2	–	rare	9·0
Calcareous matrix	–	–	–	–	–	–	–	–	56·0	–
Detrital matrix	6·6	4·8	8·8	12·0	rare	–	–	7·0	–	7·2
Indeterminate minerals and pore spaces	–	1·4	1·2	12·0	14·6	–	–	11·2	–	0·4

*University of Auckland Geology Department Rock Catalogue Number.
†Rare = <1%

or of a lining of natrolite and a central filling of crystalline analcime, or of analcime only. Occasional phenocrysts of hypersthene and clinopyroxene are unaltered.

The dike rocks are also glassy and converted to palagonite. In these rocks there are numerous phenocrysts of plagioclase (An_{40-60}) up to 2 mm in length. Vesicles are lined with fibrous chlorite, and the centres are either empty, or filled with microcrystalline chlorite and/or analcime. In an apparent flow rock quarried at N33/820242 the petrography is similar; secondary calcite replaces some of the palagonite without, however, affecting the vesicles.

In thin section the palagonite varies in colour from green through blue-green and yellow-green to brown. The palagonitised rock is very susceptible to weathering, with the production of limonite which renders the palagonite opaque. In outcrop the weathered rocks are brown to deep brown in colour.

Motuouhi Formation

Rocks of this formation are distinctive in hand specimen, resembling tough brown argillite. Thin sections comprise small angular glass shards, 0·1 to 0·5 mm in diameter, with angular to subangular plagioclase crystals and occasional subangular quartz. The glass shards are replaced by yellow-brown chloritic material, and there is an indeterminate fine matrix.

Provenance

The sedimentary rocks are derived mainly from a volcanic source. Therefore the presence of *in situ* volcanics (Oruawharo Hyaloclastite Member and Motuouhi Formation) suggests a local derivation. The minor constituents quartz, zircon, and some non-volcanic lithic grains, however, have clearly come from further afield, and it is concluded from the pebbles in the Matapoura Conglomerate Member that a major source area lay to the north (Ballance 1974). Other constituents, particularly argillaceous biomicrites, were derived from the underlying West Northland Chaos-breccia, which has been shown to have formed highs against which the Timber Bay Formation was banked. This source was particularly important in the Okahukura Formation on adjacent Puketotara Peninsula (see above; Carter 1971).

STRUCTURE

The Waitemata and Waitakere Groups on Okahukura generally dip west at angles ranging from 5° to 11°. Departures from the westerly dip are locally numerous, for example in the Timber Bay Formation on the northern shore, where they result in part from intraformational folding. Anticlines and complementary synclines in the north and centre of the peninsula (Fig. 3) do not persist along the strike.

As discussed previously, there is no evidence for major faults in the area. The Ministry of Works bore at N33/814207 penetrated what was described as fault pug between 32 and 35 m, and the straightness of Kahutaewao Creek suggests fault control, but there is no other evidence for faults.

Intraformational structures include small faults, with displacements varying up to several metres, and both open and complex small folds.

GEOLOGICAL HISTORY

The oldest rock unit on Okahukura Peninsula is inferred to be the West Northland Chaos-breccia, a very extensive olistostrome-cum-mélange which extends from the Waikato Fault northwards to beyond North Cape (Ballance & Spörli in prep.). It consists of sedimentary constituents ranging in age from Upper Cretaceous to Oligocene (Hornibrook *et al.* 1974) and Tangihua igneous masses that may be Jurassic (Brothers 1974). It is inferred to have been emplaced by gravity glide, into a structural depression which was created by earth movements accompanying the propagation through New Zealand of the Indian-Pacific plate boundary, during the Waitakian Stage (upper Oligocene to lower Miocene) (Ballance in prep. b).

The Chaos-breccia then formed the floor of the Waitemata flysch basin (Ballance 1974). The western margin of the basin was formed by the newly constituted Waitakere Magmatic Arc (Ballance in prep. b), and the rocks of the Waitemata and Waitakere Groups on Okahukura accumulated on the slope separating the Arc from the flysch basin. The Timber Bay Formation (Waitakian–Otaian, upper Oligocene–lower Miocene) is thought to represent an outer shelf-upper slope deposit, as indicated by the rippled fine sands, occasional turbidites, the intraformational slumping, and the foraminifera (B. W. Hayward pers. comm.). There was a significant volcanic contribution to the sediments, but they were distal with respect to the volcanic source, which is inferred to have been some distance to the west, perhaps on the present continental shelf (Davey 1974). There is evidence that the Timber Bay Formation accumulated on an irregular floor of olistostrome.

Significant uplift during the Otaian (lower Miocene) caused local erosion of the Timber Bay Formation and the deposition of the Okahukura Formation. A number of lithofacies comprise the formation, which is characterised by rapid lateral changes in lithology and thickness. A NNW–SSE trending belt of coarse andesite/diorite conglomerate (the Matapoura Conglomerate Member) was flanked to the south-west by flysch-like deposition and to the west by cross-bedded sands. On Puketotara Peninsula, to the north, the same belt of coarse conglomerate is flanked to the west by finer conglomerates showing much channelling and lensing. Volcanic supply was again important, and the deposits were more proximal than the Timber Bay Formation, but no *in situ* volcanics are recorded yet. The diorite pebbles are thought to have been derived from Tangihua igneous masses in the West Northland Chaos-breccia, probably to the north of Kaipara Harbour, and to have been transported south along a shelf which included Puketotara and Okahukura, before being introduced into the flanking flysch basin further south through submarine valleys (Ballance 1974).

Further movements and erosion, later in the Otaian, saw the establishment of volcanic vents in western Okahukura, and the contemporaneous deposition of fossiliferous mudstones and volcanic sandstones of the Pakaurangi Formation (Upper Otaian–Altonian, lower Miocene). Rapid lateral changes in sediment type, and many internal discontinuities are apparent. The Oruawharo Hyaloclastites accumulated as a large lens in northern Okahukura. Foram faunas in N33/f568 imply a *Robulus* biofacies (B. W. Hayward pers. comm.), which on Vella's (1962) scheme suggests an outer shelf/upper

bathyal environment. A final eruptive phase is recorded in the hyalocalstites of the Motuouhi Formation.

The main Kaikoura Orogeny (Brothers 1974) caused tilting to the west and some folding, and took place later than Altonian (lower Miocene). Erosion continued until the Quaternary, when minor quartz-rich sands accumulated, apparently during glacial periods. In post-glacial times an extensive dune and interdune complex has been welded onto the western edge of the Peninsula.

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