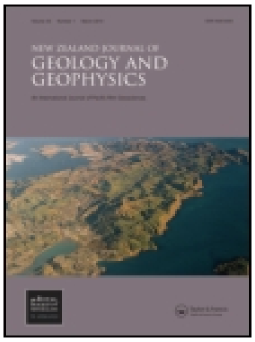

Taylor & Francis
Taylor & Francis Group

New Zealand Journal of Geology and Geophysics

ISSN: 0028-8306 (Print) 1175-8791 (Online) Journal homepage: http://www.tandfonline.com/loi/tnzg20

Late quaternary dune sands and associated deposits near Aotea and Kawhia Harbours, north island, New zealand

C.F Pain

To cite this article: C.F Pain (1976) Late quaternary dune sands and associated deposits near Aotea and Kawhia Harbours, north island, New zealand, New Zealand Journal of Geology and Geophysics, 19:2, 153-77, DOI: 10.1080/00288306.1976.10423515

To link to this article: http://dx.doi.org/10.1080/00288306.1976.10423515

N.Z. *Journal of Geology and Geophysics Vol. 19, No. 2 (1976)*: 153–77

LATE QUATERNARY DUNE SANDS AND ASSOCIATED DEPOSITS NEAR AOTEA AND KAWHIA HARBOURS, NORTH ISLAND, NEW ZEALAND

C. F. PAIN

*Soil Bureau, DSIR, Havelock North, New Zealand**

ABSTRACT

Late Quaternary dune sand formations in the sand country areas near Aotea and Kawhia Harbours are described and discussed. Kaihu Group sediments are noted, and three new members of eolian sand are named and defined. These are: the **Te Akeake Sands Member** of the Waiau B Formation, deposited between *c.* 83 000 years and *c.* 42 000 years ago; the **Paparoa Sands Member** of the Mitiwai Sands Formation deposited about 2000 years B.P.; and the **Nukumiti Sands Member,** also of the Mitiwai Sands Formation, deposited between the time of first Maori occupation of the area, *c.* 800 years B.P., and the present.

The Te Akeake Sands Member was deposited during a period when a lower sea level exposed a ready source of sand. The cause of dune building is not known for the Paparoa Sands Member; however, deposition of the Nukumiti Sands Member was initiated by disturbance of the Paparoa Sands Member by Maori agriculture. Geomorphic features of the three members include dune lakes impounded by the Te Akeake Sands Member, cliff-top dunes, both relict and actively developing, and parabolic dune forms. The latter are interpreted as the later stages of dune field development, when the sand was already partially stabilised.

Orientation of the parabolic dunes indicates that the resultant direction of sand-moving winds was from the south-west during the deposition of all three eolian sand members.

INTRODUCTION

The geology of the sand country on the west coast of the North Island, north of Cape Egmont, has been considered by various workers, including Brothers (1954), Chappell (1964; 1970), and Kear (1965). Others (e.g., Nicholson & Fyfe 1958) have discussed the availability and amounts of "iron-sand" present on the west coast. In this paper the results of a study of late Quaternary deposits near Aotea and Kawhia Harbours (Fig. 1) are presented and related to the late Quaternary history of that area.

LOCATION AND GEOLOGICAL BACKGROUND

A variety of rocks occur near Aotea and Kawhia Harbours. During Oligocene times shelf sediments were deposited over Jurassic greywackes and argillites (Kear 1960; Fleming & Kear 1960; Chappell 1970). Deposition ceased in the Miocene, and the whole area was uplifted, warped, and faulted. Subsequent erosion has removed much of the Tertiary cover in the area

Received 21 July 1975.

*Present address: Department of Geography, University of Papua New Guinea, P.O. Box 4820, University Post Office, Papua New Guinea.

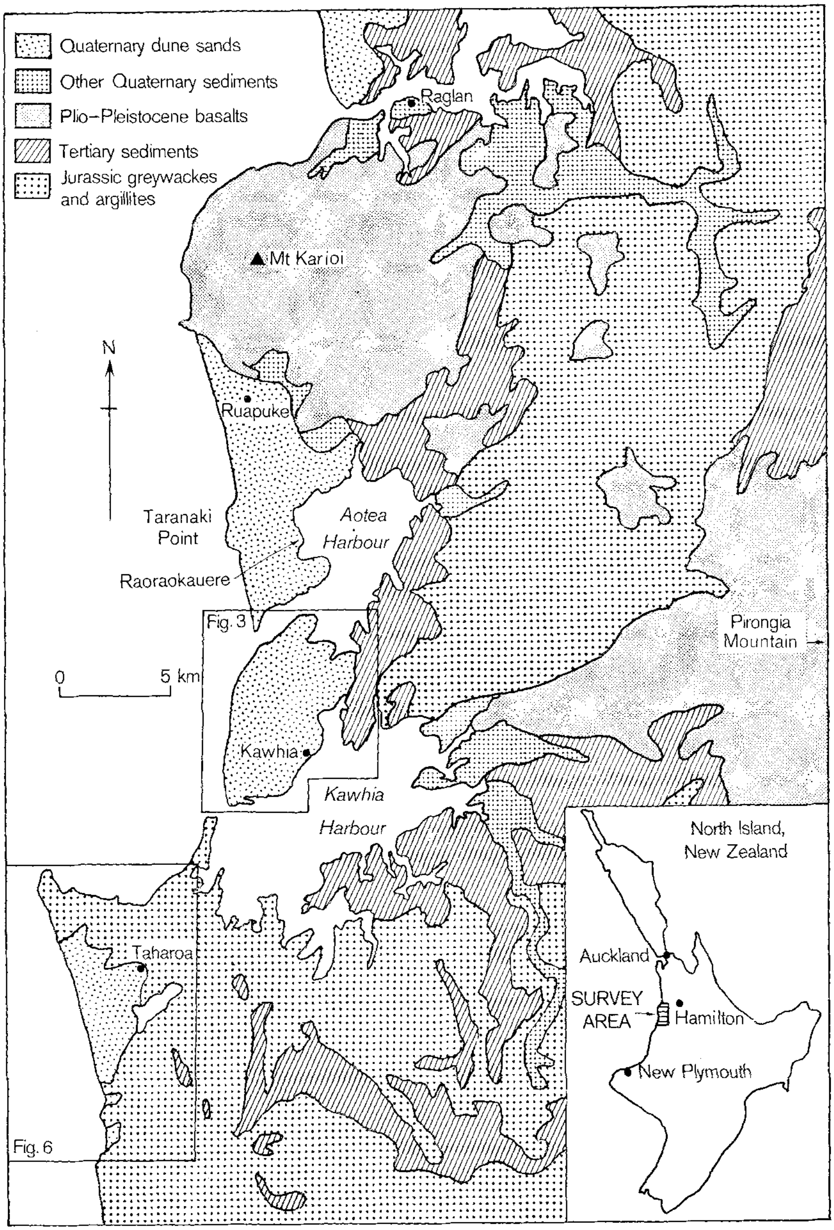

FIG. 1—Location and generalised geology of the study area. Geology after Kear (1960).

(Fig. 1). Aotea and Kawhia Harbours occupy depressions formed by west-trending faults and associated downwarps that formed during the Miocene movements (Chappell 1970). Beginning in the late Pliocene and continuing into the Pleistocene a series of eruptions built up the basaltic cones of Karioi and Pirongia, and laid down basalt in other smaller areas (Kear 1960) (Fig. 1). Basalt was also deposited at Taranaki Point, where it is now completely covered with younger deposits.

Near the coast the rocks discussed above are covered by Quaternary sediments. Within these Quaternary sediments Chappell (1964; 1970) has distinguished a number of formations consisting of eolian, littoral, estuarine, and shallow-marine sediments. This paper is concerned with these formations and particularly with those eolian materials which lie at or near the surface.

STRATIGRAPHY

Two kinds of deposits are considered here. First, tephras present near Aotea and Kawhia Harbours are briefly introduced. These tephras allow some tephrochronological control on the ages of the second kind of deposits, which are coastal sediments. The stratigraphic relationships between the coastal formations and the tephra formations are summarised in Fig. 2.

Tephra

Tephra deposits in the area have been discussed by Pain (1975). Of the tephras considered in that paper the following are used as marker beds.

KAUROA ASH FORMATION (Ward 1967)

Several of the upper members of this formation are found in the Taharoa and Kawhia areas. The Oparau Tephra Member of this formation has been tentatively assigned an age of 750 000 years (Pain 1975).

HAMILTON ASH FORMATION (Ward 1967)

Seven members designated by Ward (H1–H7) are recognised near Aotea and Kawhia Harbours. The Hamilton Ash Formation is older than 120 000 years (see Fig. 2; also Chappell 1975, p. 150).

LATE QUATERNARY TEPHRAS

These tephras overlie the Hamilton Ash Formation and include formations from the Okataina and Taupo Volcanic Centres as well as contributions from andesitic sources (Tongariro and/or Egmont). Within this sequence three rhyolitic tephras can be recognised: Taupo Pumice Formation, with an age of *c.* 1850 years B.P. (Pullar *et al.* 1973); Oruanui Ash (Vucetich & Pullar 1969), with an age of *c.* 20 000 years B.P. (Pullar *et al.* 1973), and Rotoehu Ash (Vucetich & Pullar 1969), dated at 41 700 $\pm$ 3500 years B.P. (Pullar *et al.* 1973).

	Coastal Formations			Tephra Formations	Age (years)
	Kear (1965)	Chappel (1970)	This Paper		
Kaihu Group	*Mitiwai Sands Formation*	"younger dunes"	*Nukumiti Sands Member*		post-Maori occupation
		"older dunes"	*Paparoa Sands Member*	Taupo Pumice Formation	*c.* 1850
				Late Quaternary tephra beds with Rotoehu Ash at the base	41 700 ± 3500
	Bothwell sands	*Waiau B Formation*	*Te Akeake Sands Member*		≤ 83 000 *c.* 107 000
		Waiau A Formation *Parawai Formation*		Hamilton Ash Formation	120 000 — 125 000
		Nihinihi Formation *Kaihu Formation*		Kauroa Ash Formation (upper members)	< ?750 000

FIG. 2—Stratigraphy and correlations of coastal sediments and tephras near Aotea and Kawhia Harbours. Coastal formation names used in this paper are in italics. Tephra correlations are explained in Pain (1975). Sources of age estimates are given in the text.

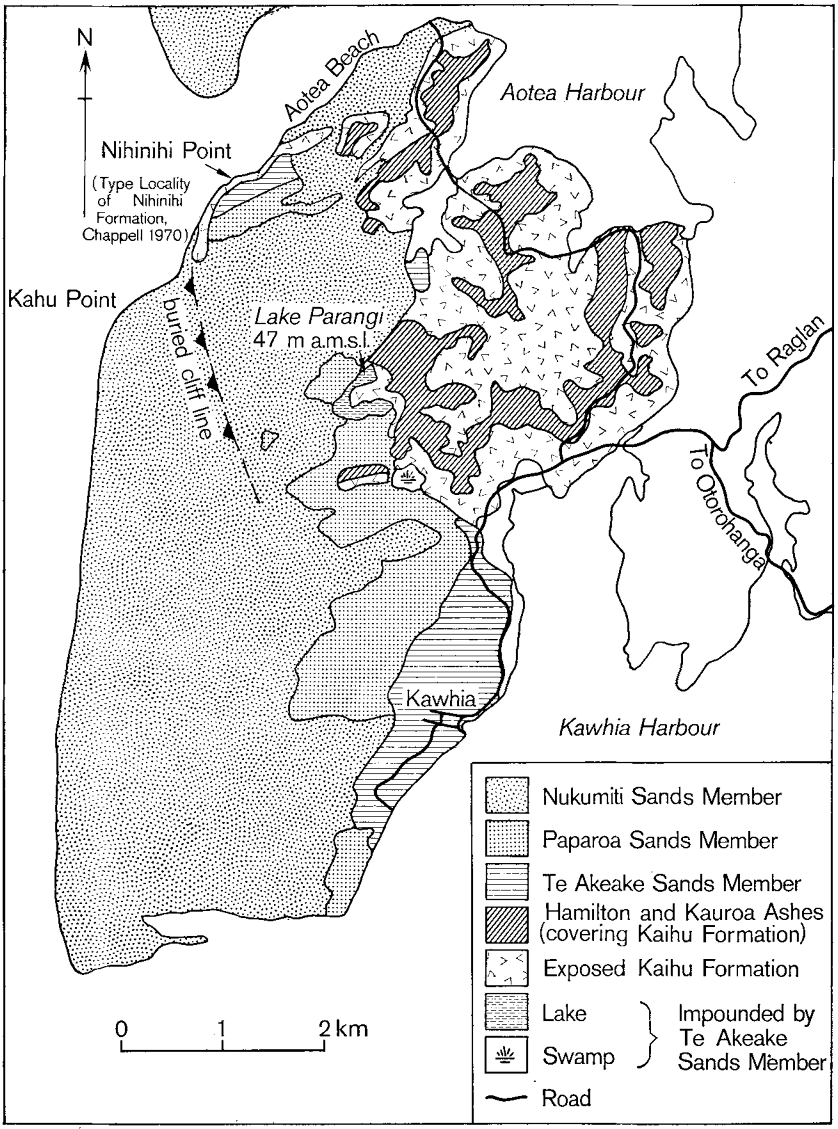

FIG. 3—Quaternary geology of the Kawhia area. See Fig. 1 for location.

Both Oruanui and Rotoehu Ashes are present at Taharoa. Rotoehu Ash, at the base of the late Quaternary tephras, is recognisable throughout the study area and forms an important marker bed. Taupo Pumice Formation has been recognised both in sea-rafted, wind-blown secondary deposits, and in primary airfall deposits in the study area. Primary sea-rafted Taupo Pumice Formation at Ruapuke Beach is also reported by Wellman (1962).

Coastal Formations

The coastal formations considered here fall within the Kaihu Group (Kear 1965); Kear used the name to refer to all Pliocene–Quaternary formations, of coastal facies, along the west coast of Auckland Province. Chappell (1970) defined the Kaihu Group in essentially the same way. Four formations from the Kaihu Group are recognised at Kawhia, and two at Taharoa. The stratigraphic units considered here are correlated with formations named by Kear (1965) and Chappell (1970), and three new members of formations named by those authors are defined here (Fig. 2).

KAIHU FORMATION (Brothers 1954; Chappell 1970)

Chappell (1970) noted that the Kaihu Formation contains subaqueous sandstones, pumiceous silts, peats, muds, and dune sands. Members with these lithologies are all present in the area of Kaihu Formation on the Kawhia peninsula (Fig. 3). The upper part of the Kaihu Formation at Kawhia consists of cross-bedded eolian sands with some apparent weathering breaks between members. These dune sands are weakly to moderately weathered and commonly contain numerous thin iron and manganese pans. No dune forms are preserved and the Kaihu Formation has been dissected to form an area consisting of broad crests with slopes of 5°–10° and valley walls with slopes up to 40° (Fig. 4). The eolian sands of the Kaihu Formation are mantled by six members of the Kauroa Ash Formation which lie above the Oparau Tephra member further east (Pain 1975). Since Oparau Tephra has an age of 750 000 years, it is concluded that the upper surface of the eolian members of the Kaihu Formation is probably less than 750 000 years old. Chappell (1975), on the basis of uplift rates calculated from younger formations in the Kaihu Group, estimates that the upper part of the Kaihu Formation is *c.* 500 000 years old. Hamilton Ash Formation and the late Quaternary tephras both overlie the Kauroa Ash Formation on the undissected crests of the Kaihu Formation.

NIHINIHI FORMATION (Chappell 1970)*

Chappell (1970, p. 143) proposed the name Nihinihi Formation for " . . . a transgressive sequence of cross-bedded iron-stained medium to coarse sands, containing pumice silt horizons and occasional silts and muds and minor conglomerates . . . ". On the Kawhia peninsula it is exposed between

*Chappell (1970, p. 143, fig. 7) shows the grid reference for the type section of Nihinihi Formation as N64/325186, but this reference does not occur on Sheet N64 (NZMS 1). The correct grid reference for the type section is N73/327187 (N73, 2nd ed. 1974) (J. Chappell pers. comm. 1975).

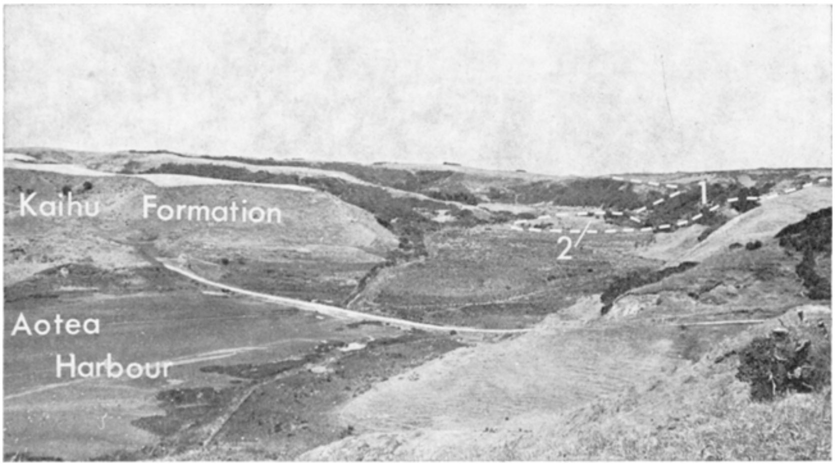

FIG. 4—The dissected area of the Kaihu Formation inland of the active dunes at Kawhia. 1 = Nukumiti Sands Member (Mitiwai Sands Formation). 2 = Te Akeake Sands Member (Waiau B Formation). View looking south from Morrisons Road (N73/349190).

Nihinihi and Aotea Beach (Fig. 5) where it occurs in a valley cut into the Kaihu Formation. In most places the Nihinihi Formation rests disconformably on the Kaihu Formation, but at Aotea Beach a small pocket of tephra, tentatively correlated with the Kauroa Ash Formation, lies between the two coastal formations (Fig. 5). The Nihinihi Formation is probably older than the Hamilton Ash Formation, although there are no exposures showing the relationships between the two formations in the Taharoa and Kawhia areas. Rotoehu Ash certainly postdates the Nihinihi Formation (Fig. 5).

PARAWAI FORMATION (Chappell 1970)

Parawai Formation is the name proposed by Chappell (1970) for "a sequence of fawn coloured horizontally and cross-bedded medium coarse sands, containing pebble beds which in turn contain clasts of older formations of the Kaihu Group." The formation crops out in the area north of Taranaki Point (Fig. 1). Chappell (pers. comm. 1975) reports that he has observed beds of the Hamilton Ash Formation overlying the Parawai Formation near Taranaki Point, but this observation has not been reconfirmed. The Parawai Formation is not considered in any detail here.

WAIAU A AND WAIAU B FORMATIONS (Chappell 1970)

These formations, named by Chappell (1970), consist of "poorly consolidated, almost unstained shallow subaqueous sands and silts, eolian sands, and stream gravels." They are separated by a soil-mantled erosion surface. North of Aotea Harbour Waiau A beds are more extensive than Waiau B beds. South of Aotea Waiau B beds predominate. According to Chappell

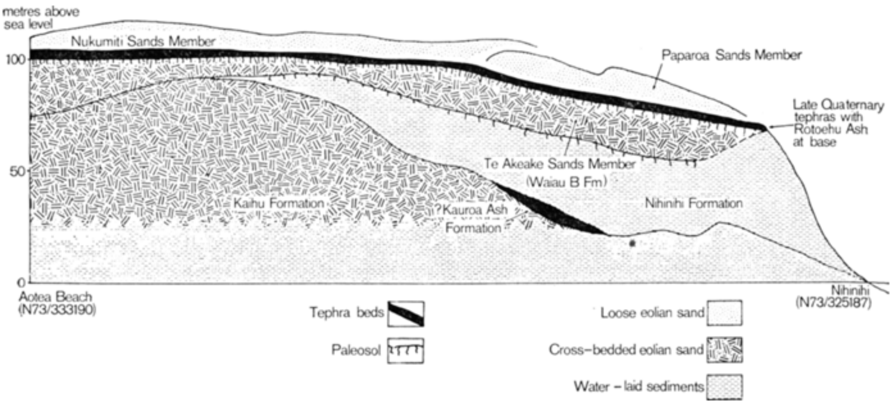

FIG. 5—Composite stratigraphy between Nihinihi and Aotea Beach at the northern end of the Kawhia peninsula, as viewed from the north, based on field sketches and photographs. The Nukumiti Sands and Paparoa Sands Members lie to the south of the lower formations, which are exposed along the shore.

(1975) the Waiau A Formation is about 120 000 to 125 000 years old, and the Waiau B Formation is about 105 000 to 107 000 years old. Beach deposits at Te Akeake, near Taharoa (Figs 6, 7), are considered to belong to the Waiau B Formation "unamed member". Much more widespread, however, are eolian sands which overlie the littoral deposits of the Waiau B Formation at Te Akeake (Fig. 7) and the Nihinihi Formation at Aotea Beach (Fig. 5). These sands are here named and defined as a member of the Waiau B Formation.

Te Akeake Sands Member (new name)

The name **Te Akeake Sands Member** is proposed for the eolian sands at the top of the Waiau B Formation. The name is taken from Te Akeake, on the coast west of Taharoa (N73/229027*) (Fig. 6). At Te Akeake, the type site, the member rests on a distinct blocky clay paleosol developed from Jurassic greywacke, and on subaqueous beds of the Waiau B Formation (Fig. 7). The member is overlain by Rotoehu Ash and other late Quaternary tephras (Figs. 2, 7). Rotoehu Ash rests on a paleosol formed from the eolian sand; this paleosol defines the top of the Te Akeake Sands Member.

Most exposures of the Te Akeake Sands Member exhibit light grey, firm, massive sand. However, in some exposures, commonly where wind has fretted the sand, eolian bedding planes are a distinctive feature. The sand is occasionally compacted and lightly cemented with iron and manganese, but more usually it is loose, and readily erodable when exposed to the wind.

---

*Grid reference based on the national thousand-yard grid of the 1:63 360 topographical map series (NZMS 1); unless noted otherwise, editions are as follows: N64, 1st ed. 1953; N73, 1st ed. 1953.

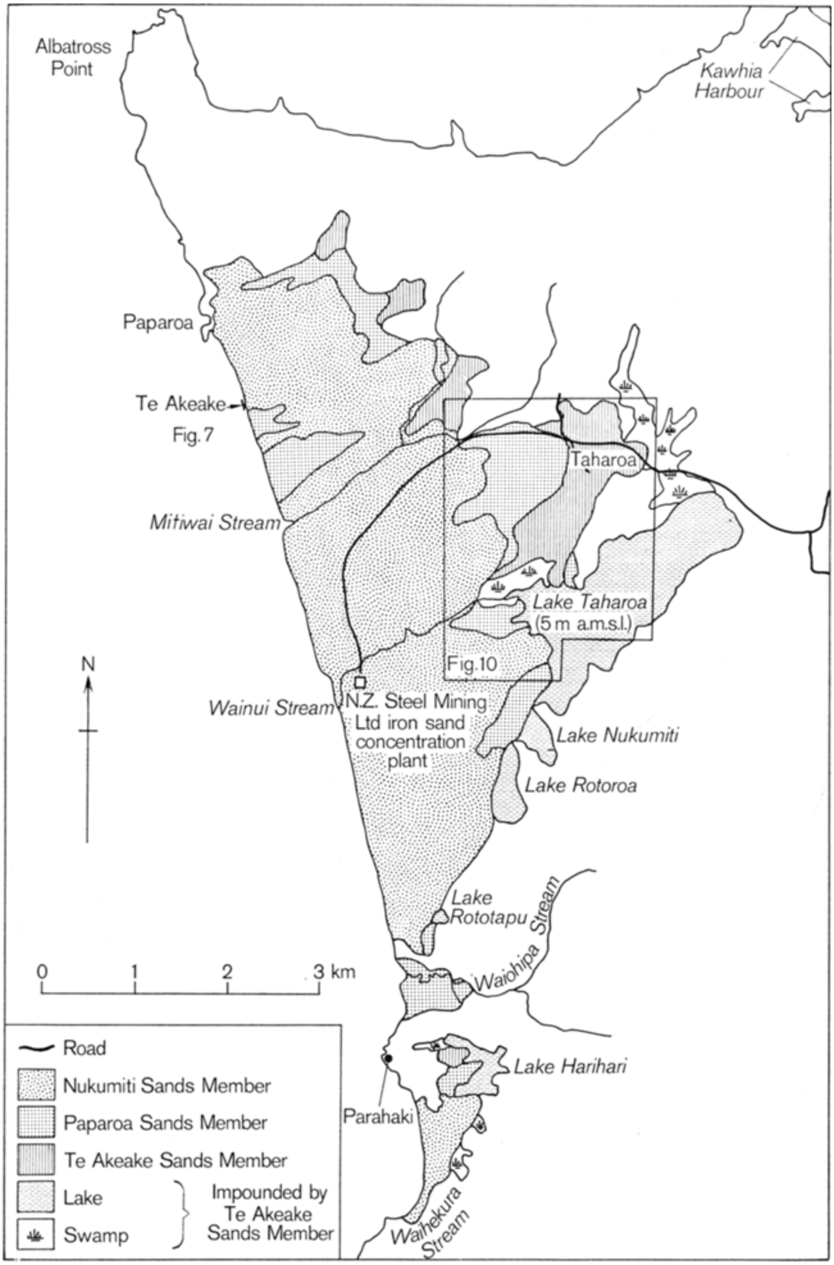

FIG. 6—Quaternary geology of the Taharoa area. See Fig. 1 for location.

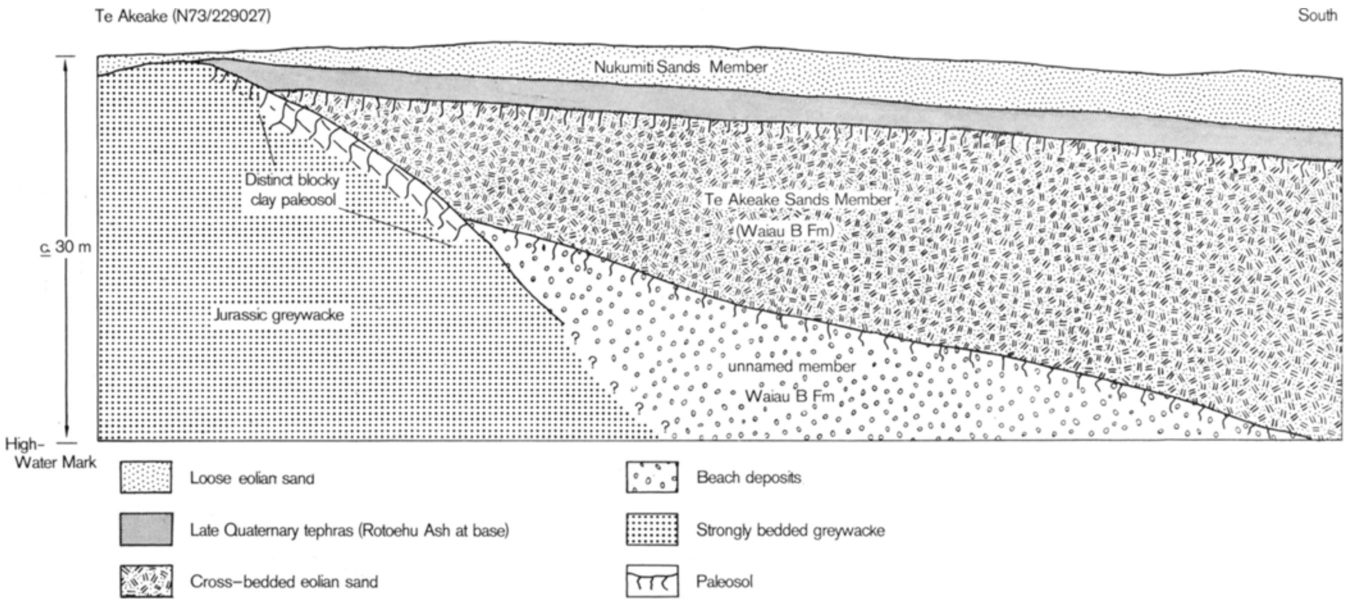

FIG. 7—Stratigraphy at Te Akeake, the type site of the Te Akeake Sands Member. Based on field sketches and photographs. See Fig. 6 for location.

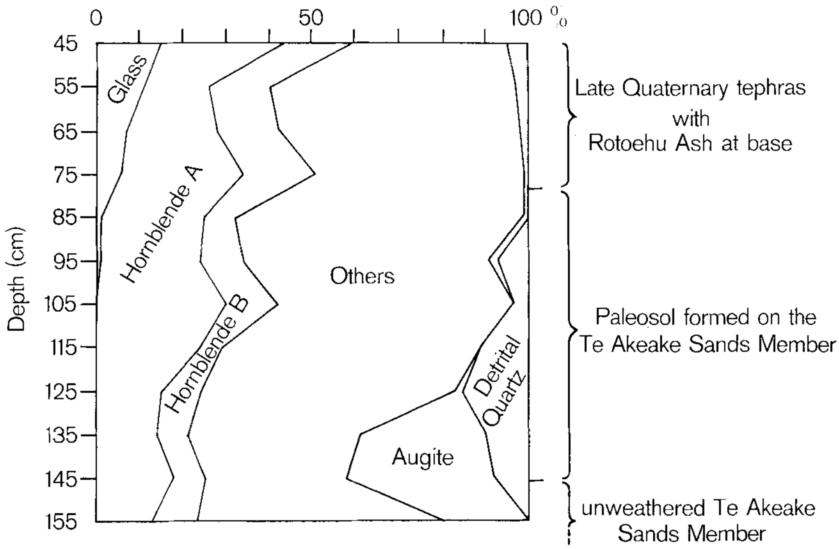

FIG. 8—Sand mineralogy of the Te Akeake Sands Member and the overlying late Quaternary tephra at Huki Road, Kawhia (N73/351135).

The member is generally uniform in its characteristics throughout its thickness, except for the upper part, which may be a different colour because of weathering and the presence of the paleosol which defines the top.

The upper boundary of the Te Akeake Sands Member requires more detailed comment since it is an important feature both for recognising the member and for estimating its age. Recognition of the contact between Rotoehu Ash and the underlying paleosol may be difficult in the field because of the similarity of the two materials. There are, however, some features which assist in the recognition of this contact. The presence of late Quaternary tephra is easily noted by the very friable nature of the upper part of the tephra column, above Rotoehu Ash. Rotoehu Ash is not as friable as the overlying tephras, but may usually be recognised by the presence of "creamcakes" of relatively little-weathered tephra. Where Rotoehu Ash overlies the Te Akeake Sands Member the "creamcakes" occur as white to pale yellow discrete nodular features, with occasional larger lenses (see fig. 6 of Pain 1975). The paleosol formed on the Te Akeake Sands Member is also darker in colour than the overlying tephra.

A limited study of the sand mineralogy of the top of the Te Akeake Sands Member and the overlying late Quaternary tephras was undertaken to confirm the location of the contact between the two units. The two units were sampled at 10-cm intervals over a depth that included Rotoehu Ash and the paleosol on the Te Akeake Sands Member as well as unweathered sand. The results are summarised in Fig. 8. As expected, the tephras contain volcanic glass while the underlying Te Akeake Sands Member does not. On the other hand, detrital quartz is confined to the eolian sand, and augite is much more abundant in the eolian sand than in the tephras (Fig. 8). The differences between the two types of materials are thus confirmed, but the boundary between the two units is not sharp, which indicates that some degree of mixing may have taken place. This mixing may be attributed to additions of wind-blown sand to the surface during the period when the tephras were being deposited, rather than post-depositional mixing of the two units.

Remnants of the dune field represented by the Te Akeake Sands Member lie inland of younger dunes in the transgressive sequence (Figs. 3, 6). Dunes of the Te Akeake Sands Member are generally lower in elevation than the younger dunes, and pass under them from inland, in the Taharoa and south Kawhia areas. In the north Kawhia and Ruapuke areas (Fig. 1), on the other hand, the Te Akeake dunes overlie older units of the Kaihu Group at altitudes up to 300 m, commonly as cliff-top dunes. In all three areas the Te Akeake dunes have been subdued by erosion and by the covering of late Quaternary tephras. However, remnants of parabolic dune forms may be recognised both on the ground and on aerial photographs.

The Te Akeake Sands Member crops out at various points among younger dunes in the Taharoa and Kawhia areas; these exposures are readily recognised by their cover of distinct yellow-brown material (the tephra and/or paleosol) which contrasts with the grey colours of the younger dune sands. The member is also exposed in the cliffs developed at the northern end of the Kawhia peninsula (Fig. 5), and in the cliffs that extend the length of the Taharoa dune field (Fig. 6), falling from 40 m at the northern end to 2–3 m along the beach in the south, from Mitiwai Stream to Waihekura Stream. At several places along this part of the coast the Te Akeake Sands Member, together with the paleosol formed on it and part of the cover of late Quaternary tephra, passes under present-day beach sands. This may be seen at Te Akeake, and immediately west of the N.Z. Steel Mining Ltd. helicopter pad, 1 km north of the concentration plant (N73/236998), as well as at Waihekura Stream mouth. The distribution of the Te Akeake dunes, together with the presence of cliffs cut into the member along the length of the coast, indicates that the lakes and swamps shown in Figs 3 and 6 are impounded behind the Te Akeake dunes, rather than the older of the Holocene dunes as suggested by Chappell (1970).

Te Akeake Sands Member must be older than *c.* 42 000 years B.P., because it is overlain by Rotoehu Ash. Since there is a paleosol developed on Te Akeake Sands Member it is reasonable to assume that the member was deposited an appreciable time before Rotoehu Ash. The actual length of time involved cannot be estimated from the paleosol because not enough is known about the conditions of its formation.

The age of the subaqueous members of the Waiau B Formation may be assumed to relate to a period of high sea level during the last interglacial (Chappell 1970; 1975), and the Te Akeake Sands Member to a period when sea level was falling, or at a low stand, since the member has been shown to pass under the present sea level. Chappell (1975) concludes that the subaqueous part of the Waiau B Formation reates to the −15 to −6 m stand of sea level dated at between 105 000 and 107 000 years by Bloom *et al.* (1974) in New Guinea and Barbados. This correlation is accepted by the present writer.

The Waiau B terrace in the present study area is about 20 m above present sea level (Chappell 1970). This means that the Taharoa coast has been uplifted 26 m in the last 107 000 years, a mean rate of uplift of about 0·25 to 0·3 mm/year. This compares with Chappell's (1975) estimate of 0·3 mm/year calculated from the present height of the 125 000-year terrace on the south Auckland west coast (the Waiau A Formation of Chappell 1970). An uplift rate of 0·25 mm/year is thus used for the following estimates of relative sea level in the Taharoa–Kawhia area. Using evidence from New Guinea, Bloom *et al.* (1974) show that absolute sea levels during the sea level maxima of 83 000 years and 62 000 years ago were −13 m and −25 m, respectively. This means that the 83 000-year strandline at Taharoa is now at (83 × 0·25) − 13 = +7 m, while the 62 000-year strandline is now at (62 × 0·25) −25 = −9·5 m, assuming uniform uplift.

The Te Akeake Sands Member could have begun its formation at any time since sea level fell below its present relative level in the area, some time between 83 000 years and 62 000 years ago. It seems most likely that dune building took place during a period of falling sea level following either the 83 000-year high or the 62 000-year high, or both. During these periods there would be a plentiful supply of sediment from the newly exposed sea floor (see below).

UNDIFFERENTIATED POST-WAIAU B DEPOSITS

Alluvial and colluvial deposits lying stratigraphically between the Te Akeake Sands Member and Rotoehu Ash occur in isolated patches in the study area. These deposits are similar in most respects to materials being deposited on small fans in the area at present; they consist of gravel-sized clasts scattered through a sandy matrix derived from dune material. Occasionally the deposits are weakly bedded. A representative exposure of these materials occurs on the edge of Aotea Harbour at Raoraokauere (Fig. 1) (N64/345242). At that site the following sequence is exposed:

	Depth (cm)
Topsoil with well developed nut structure, and shells scattered throughout. Probably a Maori cultivation and/or occupation layer.	0–28
Yellow-brown friable late Quaternary tephras.	28–65
Light yellow-brown friable late Quaternary tephras mixed with wind-blown sand.	65–130
A zone of varying thickness containing "creamcakes" of fine sandy, light yellow, Rotoehu Ash.	130–135
Light yellow-brown to grey sands and silts with occasional gravels, comprising fan deposits.	135–240
Clayey peat with tree remains. Wood samples collected from here were identified as matai (*Podocarpus spicatus*) and totara (*P. Totara* or *P. hallii*) (R. J. S. Cassels pers. comm.) This unit is generally covered at high tide.	240–270+

The sequence described above occurs at the foot of a fan-shaped landform unit that is at present being truncated by wave action from Aotea Harbour. It indicates the burial of an area of forest by fan sediments derived from the Te Akeake Sands Member and underlying materials at some time before the deposition of Rotoehu Ash, when the relative sea level in the area was lower than it is at present. This interpretation conflicts with Chappell (1970), who suggested that the Raoraokauere materials and their associated land surface represented a post-glacial high sea level of +2 m; although Chappell noted an horizon of "pumiceous silt" he did not recognise it as Rotoehu Ash. Thus the Raoraokauere site represents fan formation during a glacial low sea level rather than terrace development during a post-glacial high sea level.

MITIWAI SANDS FORMATION (Kear 1965)

Kear (1965) used the name Mitiwai Sands to refer to loose grey sands on the west coast of the North Island; these sands he considered to be late Holocene in age. The Mitiwai Sands Formation has two eolian sand members with distinct age differences; these are the "older dunes" and "younger dunes" of Chappell (1970) (Fig. 2). These two members are named **Paparoa Sands Member** and **Nukumiti Sands Member**, respectively, and are described below.

Paparoa Sands Member (new name)

The name **Paparoa Sands Member** is proposed for the older of the two dune sand members falling within the Mitiwai Sands. The name is derived from a small bay at the northern end of the Taharoa dune field (Fig. 6) (N73/224039), and the type locality is about 200 m west of Taharoa School (N73/263028), on the southern side of the road leading to the N.Z. Steel Mining Ltd. iron sand concentration plant. The member is composed of titanomagnetite-rich, loose sand with rare dune bedding. The Paparoa Sands Member rests disconformably on the eroded surface of the Te Akeake Sands Member and its cover of late Quaternary tephras. It is capped by the sandy Parangi soils (Pain in press), which have in places been buried by younger dune sands. The Parangi soils, whether buried or at the present surface, define the upper boundary of the Paparoa Sands Member.

The Paparoa dunes generally occur inland of the younger member of the Mitiwai Sands (Nukumiti Sands Member), although they also occur near the coast as cliff top dunes at the northern end of the Taharoa and Kawhia areas (Figs 3, 6). The dunes exhibit well developed parabolic dune forms and have a well defined inland margin where they overlap dunes of the Te Akeake Sands Member (Fig. 9). The Paparoa Sands Member is also exposed in small areas among dunes of the Nukumiti Sands Member (see below) where it has been covered and subsequently re-exhumed. The Parangi soils protect the underlying Paparoa Sands Member from rapid wind erosion in these areas. The Parangi soils are also associated with Maori midden remains, which consist of heaps of shells of mainly mussel, tuatua, pipi, and cockle (R. J. S. Cassels pers. comm.). These middens

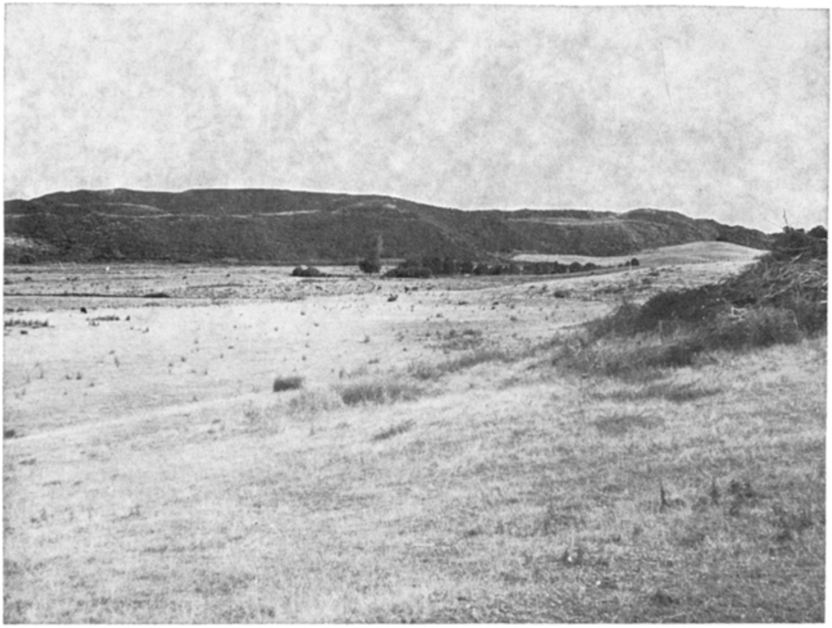

FIG. 9—Dunes of the Paparoa Sands Member (background) overlapping Te Akeake dunes (foreground) at Kawhia (N73/350135). View looking NNW.

rest on Parangi soils; in fact, the presence of a midden in the midst of an area of bare sand is an almost certain indication that remnants of Parangi soils and an exposure of the Paparoa Sands Member will also be present.

Taupo Pumice Formation, with an age of *c.* 1850 years B.P. (Pullar *et al.* 1973), has been identified in two positions relative to the Paparoa Sands Member. First, lumps of pumice occur within the top 20 cm of Parangi soils on the Paparoa Sands Member in the Taharoa area. These pumice lumps are predominantly light coloured with linear vesicules, rounded to angular, soft, and easily broken and crushed with the fingers. These characteristics identify the pumice as most likely to be derived from the Taupo Pumice Formation. Other pumice lumps, occurring in the same position, are grey with white mineral inclusions, well-rounded with spheroidal vesicules, and almost impossible to break with the fingers. W. A. Pullar (pers. comm.) indicates that this grey pumice is similar to an unusual type of Taupo Pumice Formation found in the Bay of Plenty. Pullar suggests that both types of pumice are derived from the Taupo Pumice Formation. The pumice presumably reached its present position by sea rafting to the Taharoa beach, and then wind transport to the dune surface. The presence of the pumice within the Parangi soils suggests that it arrived on the dunes during the last stages of their formation; the pumice could not be blown into the soil once a vegetation cover had been established. The second occurrence of Taupo Pumice Fomation is within a peat deposit in the

Kawhia area. The peat was formed during the period when the Paparoa dunes were forming, and contains a band of pumiceous sand 1·5 cm thick (Pain 1975).

The two occurrences of Taupo Pumice Formation associated with the Paparoa dunes indicate that the dunes began their formation well before the Taupo Pumice eruptions of *c.* 1850 years B.P., and finished their formation following the Taupo eruptions. The presence of midden materials overlying the Parangi soils indicates that the Paparoa dunes became stable and developed a soil cover before the first Maori settlers arrived in the area.

Nukumiti Sands Member (new name)

The name **Nukumiti Sands Member** is proposed for the youngest eolian sands of the Mitiwai Sands Formation. The name is taken from a small lake south of Lake Taharoa (Fig. 6) (N73/262992) and the type locality is that proposed by Kear (1965) for the Mitiwai Sands, near Mitiwai Stream (N73/235015). The Nukumiti Sands Member consists of loose eolian sand, largely in the form of active transverse dunes with occasional barchans. Linear dunes and sand drifts are also present, especially in the Taharoa dune field.

The Nukumiti dunes consist of large areas of gentle slopes separated by steep slip-off slopes. The slip-off slopes are generally at right angles to the prevailing wind, from the south-east, while the gentle slopes have no preferred orientation. The forms found in some parts now covered by Nukumiti Sands Member are influenced by underlying sands of the Paparoa Sands and Te Akeake Sands Members; these latter members show through the cover of Nukumiti Sands in some places.

Nukumiti dunes lie immediately behind the beach and extend inland for distances up to 3 km (Figs 3, 6), encroaching on Paparoa and Te Akeake dunes. The dunes are generally bare and active, although some areas have been recently stabilised and have a cover of grass, lupins, manuka, and bracken fern. Where these dunes are stable Taharoa soils have formed on them (Pain in press). The upper boundary of the member is thus defined as either the present active dune surface, or the Taharoa soils. Taharoa soils may be distinguished from Parangi soils by their much lighter colour, because of a low organic matter content, and their much shallower profile (Pain in press). The lower boundary of the member is the surface formed on all those units over which Nukumiti dunes have been blown. Generally this is confined to the Paparoa Sands and Te Akeake Sands Members and their associated soils and tephra cover.

The Nukumiti Sands Member is obviously modern in age. However, there is some evidence that Nukumiti dunes started to form during the early stages of Maori occupation of the area. This evidence is further discussed below.

LATE QUATERNARY DUNE FORMATION

The lower eolian sand members of the Kaihu Group are not sufficiently represented either in cliff exposures or on the present surface to allow discussion of their origin and morphology. Thus the following discussion is limited to Te Akeake, Paparoa, and Nukumiti dunes, of late Quaternary age.

Causes of Dune Building

For active dune building to be maintained there must be a steady supply of sand. This sand can be derived either from the erosion of older dunes, or from the sea, via the beach (Bird 1968). Thus causes of dune initiation may be divided into two groups; those associated with events causing erosion of previously stable dunes, and those associated with an increase of the supply of sand from the sea and beach. The dunes discussed here provide examples of both types of causes.

Kear's (1964) suggestion that dune building on the west coast of the North Island may be the result of an increase in supply of sand due to a falling sea level has already been noted in relation to the Te Akeake Sands Member. However, the question arises as to whether the abandoned sea floor remained bare for sufficiently long periods to maintain a steady supply of sand. This probably depends on the rate of retreat of the shoreline; if the shoreline retreated slowly enough for the abandoned strands to be colonised by vegetation, then lowering sea level may not be an adequate explanation on its own.

Amounts and rates of shoreline retreat during periods of lowering sea level affecting the Te Akeake dunes were calculated from bathymetry data (van der Linden 1973), and two estimates of the relative sea level during two low stands. The first uses data from Chappell (1974) and Bloom *et al.* (1974), corrected for an uplift rate of 0·25–0·3 mm/year, and the second uses levels reported by McDougall & Brodie (1967) from evidence in the off-shore sediments. The rates and amounts are shown in Table 1. The rates of retreat obtained indicate that the sea floor may have been exposed

TABLE 1—Rates and amount of shoreline retreat during periods of falling sea level at Taharoa.

Age (years)	Relative Sea Level* (m)		Amount of Shore Retreat† (km)		Rate of Shore Retreat (m/year)	
	(1)	(2)	(1)	(2)	(1)	(2)
83 000 70 000	+7 to +9 at or below −50	– −128	>5·5	59	>0·4	4·5
62 000 55 000	−9·5 below −85	– −73 to −109	>30	18–47	>4·3	2·6–6·7

*Age estimates for high and low stands of sea level taken from Bloom *et al.* (1974).
†Shoreline retreat was calculated using bathymetry from van der Linden (1973) and paleo-sea levels relative to the present Kawhia coast. The latter were derived using (1) data on eustatic stands of low sea level from Bloom *et al.* (1974) and Chappell (1974), corrected for an uplift rate of 0·25 to 0·3 mm/year, and (2) data from off-shore sediments reported by McDougall & Brodie (1967).

fairly rapidly over periods of several thousand years; it seems likely that there was a marked increase of sand supply due to a retreating shoreline, and once the sand started to move and form dunes their self-perpetuating nature would have ensured very little vegetation growth. From these suggestions we can postulate an increasing supply of sand and the building of a large dune field from below present sea level to the inland margin of the Te Akeake dunes (Figs 3, 6). At its maximum extent the active Te Akeake dune field may have been more than 40 km wide. First, the low angle shelf which was then exposed would be conducive to the building of a wide dune field. Second, the generally more vigorous wind conditions prevalent during glacial periods (Wilson & Hendy 1971; Hays & Perruzza 1972; Parkin & Shackleton 1973) would provide more energy for sand transport than there is at present, and thus larger dune systems could be expected. Certainly the distribution of sea floor sediments reported in McDougall & Brodie (1967, p. 30) does not conflict with the postulated presence of such a dune field.

Dune fields have been attributed to the sweeping shoreward of a dune complex by rising seas (e.g., Thom 1965). If this explanation applies to the Te Akeake field, dune formation would have occurred during the transgression culminating 62 000 years ago; the transgression to 42 000 years ago took place after stabilisation of the Te Akeake dunes. Formation of the Te Akeake dunes may well have taken place during both falling and rising sea levels. The presently available evidence does not allow a firm conclusion to be drawn, but the age relations and the lack of a *c.* 42 000 years B.P. dune field appear to support the former view.

The explanation of increasing sediment supply because of falling sea level cannot be used to explain the initiation of the Paparoa dunes, since they were formed during the latter part of the Holocene, when sea levels were relatively stable. In fact, no evidence was found near the Aotea and Kawhia Harbours to suggest a cause for the initiation of the Paparoa dune building phase, although early Holocene readjustment of the coastline could be a factor. Similarly Cowie (1963) could suggest no real causal factor for the Foxton dunes, which were forming in the Manawatu during much the same period as the Paparoa dunes. Cowie questioned whether eruptions from the Taupo, Tongariro, or Egmont volcanic centres could have caused an increase in supply of sand from the beaches in Manawatu; another explanation could be increases in erosion in the hill country supplying sediment to the west coast rivers. Further study is required to establish the cause for the development of Paparoa dunes, and their correlatives up and down the west coast of the North Island.

The supply of sand for building the Nukumiti dunes is at present coming partly from the beach and partly from the erosion of older dunes, especially the Paparoa dunes. It seems clear that the initiation of this latest phase of dune building is related to instability of the Paparoa dunes rather than to an increase in the supply of sand from the sea. The close association of remnant Parangi soils with middens in what are now areas of bare sand suggests that it was the movement of sand which caused the Maoris to abandon their middens and associated occupation sites. A possible suggestion is that the Maoris may have caused the Paparoa dunes to become unstable, leading to the subsequent invasion of the middens by Nukumiti dunes. In fact Cassels (1973, and pers. comm.), using archaeological evidence, suggests that Maori agriculture and other activities on the north head of Aotea Harbour upset the stability of the sand dunes. European agriculture, beginning about 100 years ago, did little to stabilise the sand, and may in fact have aggravated the situation. Only at Kawhia is some effort being made to stabilise the dunes by forestry development. Thus the formation of Nukumiti dunes can be attributed largely to instability of the Paparoa dunes initiated by Maori occupation from *c.* 800 years B.P. (R. J. S. Cassels pers. comm.) and continued by European land uses.

The Nukumiti dunes in the present study area are equivalent in age to the Motuiti and Waiterere dunes in the Manawatu (Cowie 1963). Cowie suggests that the Motuiti dunes were initiated by Maori destruction of vegetation on stable dunes about 750 years B.P., and that the Waiterere dunes were caused by European overgrazing about 120 years B.P. More recently McFadgen (1974) has shown that the Waiterere dune-building phase began 400–500 years B.P., which coincides with an increase in the Maori occupation of the area. However, McFadgen considers that climate deterioration may be a partial explanation of the dune instability. There is no basis for distinguishing two dune sand units within the Nukumiti Sands Member, so it is concluded that dune-building has been taking place since Maori occupation began in the area, with spasmodic colonisation of small areas by vegetation for short periods. Those areas which are stable at present contain Taharoa soils (Pain in press).

Geomorphic Features of the Dune Systems

The dune systems developed on the Te Akeake Sands, Paparoa Sands, and Nukumiti Sands Members contain examples of three geomorphic features which are of interest in the development of sand dunes. These are dune lakes, cliff-top dunes, and parabolic dune morphology on the stabilised dunes.

Dune Lakes

Several lakes are present in the study area, on the inland margins of the Kawhia and Taharoa dune fields (Figs 3, 6). Swamps, which may have begun as lakes, are also present. It has been shown that these lakes are impounded by the Te Akeake Sands Member, and are therefore older than Rotoehu Ash, at *c.* 42 000 years B.P. The lakes and swamps present in the study area all have one origin; they were impounded when dunes were built across the mouths of valleys, ponding back the streams. In the Kawhia area Lake Parangi and the small swamp to the south both lie in a valley cut into the Kaihu Formation, of Quaternary age (Fig. 3). In the Taharoa area, on the other land, Lake Taharoa and four other lakes to the south are all impounded in valleys cut into Jurassic greywacke.

These lakes, particularly Lake Taharoa, appear to offer a long record of environmental change recorded in their sediments. This record may extend back more than 50 000 years, and should contain evidence of dune building phases and tephra deposition, as well as a record of vegetation change obtainable from pollen analyses. Chappell (1970), who obtained a 6-m core from Lake Harihari, at the southern end of the Taharoa area (Fig. 6), reports no sedimentologic variations and notes a microflora indicating a climate similar to the present. Evidence of dune-building phases and tephra deposition may, however, be deeper than 6 m below the lake bottom. Lake Taharoa, because of its size, would seem to offer the best possibilities for such evidence.

Cliff-top Dunes

Dunes occurring on cliff tops with no obvious supply of sand are present along the coast throughout the study area, within both the Te Akeake Sands and Paparoa Sands Members. Jennings (1967) has discussed the origin of such dunes in Australia, and suggests several different mechanisms for their emplacement:

(1) The dunes may have been built from sand drifting to the top of the cliff from an inland source; in the present study area this would mean a sand source on the Aotea and Kawhia Harbours. This seems unlikely because the harbour sediments are predominantly finer than the dune sand. Also wind directions, as evidenced by the dunes themselves, do not support such a source.

(2) Following dune building on a sloping shore area, sea level rose and cliff retreat within the underlying material took place, leaving the dunes stranded on the cliff top. This explanation is not favoured in the present area because it would imply cliff retreat taking place since the stabilisation of the Paparoa dunes, < 1850 years B P. Such cliff retreat does not seem likely in view of the presence of primary sea-rafted Taupo Pumice Formation (*c.* 1850 years B.P.) behind the foredune on Ruapuke Beach (Wellman 1962), below the very cliffs which would need to retreat.

(3) The cliff-top dunes were built during a period when sea level coincided with the top of the cliffs; after the sea retreated, the dunes were left on the cliffs. Again, this origin is unlikely in the study area because sea levels are known to have been lower than present during Te Akeake dune building, and at about present level during Paparoa dune building. Also, the elevations of the cliff-top dunes range from less than 30 m to more than 100 m, with no concomitant range of dune ages.

(4) The cliff-top dunes were emplaced during a period when there was sufficient dry land below the cliff to allow the building of a sand ramp to the top of the cliff; the dunes were then formed on the cliff top where such ramps spilled over onto the gentle land surface on top. When sea level rose again the sand ramps would easily be removed. This explanation is preferred by Jennings (1967) for the Australian dunes he considered, and is also valid for the cliff-top dunes in the present study area. In the case of the Te Akeake dunes, it has already been shown that they were built during a period of low sea level, which would provide the necessary building area for the sand ramps.

The Paparoa cliff-top dunes are not so easily explained since sea level is not known to have been lower during the period of their formation. In relation to this, however, Nukumiti cliff-top dunes which are forming at present may be cited as evidence that such dune formation does not require a wide dune belt seaward of the cliff line. At the northern end of the Kawhia peninsula there is a buried cliff, cut in Kaihu and Nihinihi Formations (Fig. 3). At present, active dunes spread from the coast up a sand ramp such as that postulated above, and onto a gentle land surface more than 100 m in altitude. At its narrowest point the strip of sand between the high water mark and the cliff is less than 250 m wide. The Paparoa cliff-top dunes may be the result of a temporary widening of the area seaward of the cliff line in the study area. These features all support Jenning's (1967) conclusion (mechanism 4 above).

Parabolic dune morphology

Parabolic dunes are an outstanding feature of the Te Akeake and Paparoa dune fields. Within these areas parabolic dune crests are frequent and rise above the generally gentle slopes of the interdune areas (Fig. 10). This contrasts with the Nukumiti dunes, where large transverse dunes with occasional barchans dominate, and parabolic dunes are rare. These differences are related to two stages in the development of dune field morphology in the study area.

Bird (1968) notes that parabolic dunes develop where the vegetation cover on unconsolidated sand is destroyed locally, allowing movement of the sand (also Cowie & Smith 1958). Such destruction, he suggests, may take place by burning, overgrazing or other excessive use, and periods of generally drier conditions than usual. The sand begins moving as a blowout, and then develops into a parabolic dune with an advancing nose of loose sand and trailing arms of partly-fixed sparsely-vegetated sand.

When the dunes of the study area are considered in detail it can be seen that the three dune systems have basically similar overall morphology— they are transverse dunes with large areas of gentle slopes separated by steeper slopes. In the two older systems parabolic dune forms appear to be superimposed on the underlying transverse dunes. It seems likely that the development of parabolic dunes in this context represents the last stages of dune formation, when large areas of the dune field were stabilised by vegetation, and local blowouts, sometimes developing into larger parabolic dunes, were the only kind of sand movement taking place. The future development of the Nukumiti dunes could well be stabilisation by vegetation followed by the development of blowouts and parabolic dunes to produce a dune field morphology similar to that of the Te Akeake and Paparoa dune fields.

Wind Directions

Wind directions operating at the time of sand dune development can be estimated from the morphology of the upper surface of the dune field. Figure 10 illustrates the orientation of the parabolic dune crests and wind drift lines on the Te Akeake Sands, Paparoa Sands, and Nukumiti Sands Members in part of the Taharoa area. The axis of a parabolic dune, defined as the line bisecting the angle between the trailing arms and directed towards

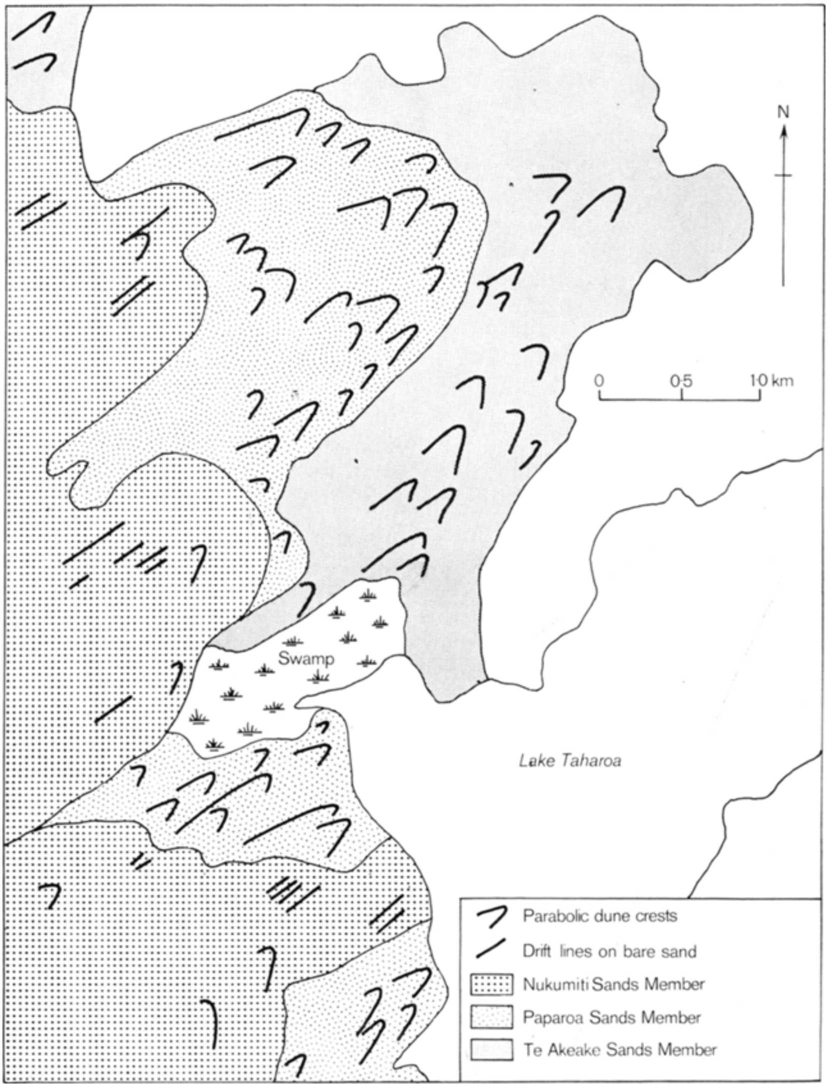

FIG. 10—Part of the Taharoa area, showing location and orientation of parabolic dunes. Drawn from vertical aerial photograph. See Fig. 6 for location.

the advancing nose, is parallel to the resultant of on-shore winds of Beaufort Scale 3 or over (Bird 1968). Examination of Fig. 10 indicates that the directions of such winds during the formation of the three dune members was from the south-west. This conclusion differs from those reached by workers cited in Gage (1965) who have reported wind direction changes in more southerly parts of New Zealand during the late Quaternary. There is, however, a long period between the formation of the Te Akeake dunes and Paparoa dunes during which changes in wind directions may have taken place, but are not recorded in the study area.

CONCLUSIONS

Apart from two points (the age of the Raoraokauere deposits, and the age of the dune-impounded lakes), the findings of the present study are in general agreement with those of Chappell (1970). This paper amplifies the later part of the terrestrial record of late Quaternary history of the area, with tephrochronology playing a large part in this amplification.

The Paparoa and Nukumiti dune-building periods appear to be coeval with dune-building phases in the Manawatu reported by Cowie (1963). However, the Te Akeake dunes have no equivalent in the Manawatu. There was a long period between deposition of the Te Akeake Sands Member and the Paparoa Sands Member (about 40 000 years) when no events were recorded in sediments lying above present sea level in the study area. Such events may well be recorded on the shelf, which is > 50 km wide; indeed McDougall & Brodie (1967) present evidence for such events, although none are dated yet. Further work on the subaqueous beds present in the areas near Aotea and Kawhia Harbours, together with a study of sediments on the floor of Lake Taharoa, will amplify the Quaternary history of this interesting coastal area.

ACKNOWLEDGMENTS

I wish to thank Mr Richard Cassels, Department of Anthropology, University of Auckland, for discussions on the post-Maori occupation period in the area. I also wish to thank Mr G. E. Orbell, Soil Bureau, Hamilton, for helpful discussion and for commenting on the manuscript. Janet Richardson, Soil Bureau, Taita, carried out some of the sand mineral identifications. Dr W. A. Pullar, Soil Bureau, Rotorua, and Mr E. Griffiths, Soil Bureau, Havelock North, commented on the manuscript. I also thank Dr J. M. A. Chappell, Australian National University, Canberra, for useful comments and points of information.

REFERENCES

BIRD, E. C. F. 1968: "Coasts". Australian National University Press, Canberra. 246 p.

BLOOM, A. L.; BROECKER, W. S.; CHAPPELL, J.; MATTHEWS, R. K.; MESOLELLA, K. J. 1974: Quaternary sea-level fluctuations on a tectonic coast: new $^{230}Th/^{234}U$ dates from the Huon Peninsula, New Guinea. *Quaternary Research 4*: 185–205.

BROTHERS, R. N. 1954: The relative Pleistocene chronology of the south Kaipara district, New Zealand. *Transactions of the Royal Society of N.Z. 82* (3): 677–94.

CASSELS, R. J. S. 1973: Time factors in a prehistoric Maori ecosystem. *Abstracts for 9th Congress of the International Union for Quaternary Research, Christchurch, N.Z., 1973*: 59.

CHAPPELL, J. M. A. 1964: Quaternary geology of south-west Auckland and north Taranaki coast. (Unpublished M.Sc. thesis lodged in the Library, University of Auckland, New Zealand.)

——— 1970: Quaternary geology of the south-west Auckland coastal region. *Transactions of the Royal Society of N.Z. (Earth Science) 8 (10)*: 133–53.

——— 1974: Relationships between sea levels, ^{18}O variations and orbital perturbations, during the past 250 000 years. *Nature 252*: 199–202.

——— 1975: Upper Quaternary warping and uplift rates in the Bay of Plenty and west coast, North Island, New Zealand. *N.Z. Journal of Geology and Geophysics 18*: 129–55.

COWIE, J. D. 1963: Dune building phases in the Manawatu district, New Zealand. *N.Z. Journal of Geology and Geophysics 6*: 268–80.

COWIE, J. D.; SMITH, B. A. J. 1958: Soils and agriculture of the Oroua Downs, Taikorea, and Glen Oroua districts, Manawatu County. *N.Z. Soil Bureau Bulletin 16*. 56 p.

FLEMING, C. A.; KEAR, D. 1960: The Jurassic sequence at Kawhia Harbour, New Zealand. *N.Z. Geological Survey Bulletin 67*. 50 p.

GAGE, M. 1965: Some characteristics of Pleistocene cold climates in New Zealand. *Transactions of the Royal Society of N.Z. (Geology) 3 (2)*: 11–21.

HAYS, J. D.; PERRUZZA, A. 1972: The significance of calcium carbonate oscillations in eastern equatorial Atlantic deep-sea sediments for the end of the Holocene warm interval. *Quaternary Research 2*: 355–62.

JENNINGS, J. N. 1967: Cliff-top dunes. *Australian Geographical Studies 5 (1)*: 40–9.

KEAR, D. 1960: Sheet 4 Hamilton. "Geological Map of New Zealand 1:250 000". N.Z. Department of Scientific and Industrial Research, Wellington.

——— 1964: Coastal sand deposits—northwestern North Island. *N.Z. Journal of Forestry 9 (2)*: 139–45.

——— 1965: Geology of New Zealand's ironsand resources. Paper 219 *in*: *8th Commonwealth Mining and Metallurgical Congress, Australia and New Zealand, 1965. Publication 7.*

McDOUGALL, J. C.; BRODIE, J. W. 1967: Sediments of the western shelf, North Island, New Zealand. *N.Z. Oceanographic Institute Memoir Number 40*. 54 p.

McFADGEN, B. G. 1974: The significance of archaeological research. *N.Z. Archaeological Association Newsletter 17 (1)*: 27–30.

NICHOLSON, D. S.; FYFE, H. E. 1958: Borehole survey of North Island ironsands from New Plymouth to Kaipara Harbour. *N.Z. Journal of Geology and Geophysics 1*: 617–34.

PAIN, C. F. 1975: Some tephra deposits in the south-west Waikato area, North Island, New Zealand. *N.Z. Journal of Geology and Geophysics 18*: 541–50.

——— (in press): Soils of the Taharoa–Kawhia coastal area, North Island, New Zealand. *N.Z. Soil Survey Report.*

PARKIN, D. W.; SHACKLETON, N. J. 1973: Trade wind and temperature correlations down a deep-sea core off the Saharan coast. *Nature 245*: 455–7.

PULLAR, W. A.; BIRRELL, K. S.; HEINE, J. C. 1973: Named tephras and tephra formations occurring in the central North Island, with notes on derived soils and buried paleosols. *N.Z. Journal of Geology and Geophysics 16*: 497–518.

THOM, B. G. 1965: Late Quaternary coastal morphology of the Port Stephens–Myall Lakes area, New South Wales. *Royal Society of New South Wales Journal and Proceedings 98*: 23–36.

VAN DER LINDEN, W. J. M. 1973: Mokau bathymetry. "N.Z. Oceanographic Institute Chart, Coastal Series 1:200 000". N.Z. Department of Scientific and Industrial Research, Wellington.

VUCETICH, C. G.; PULLAR, W. A. 1969: Stratigraphy and chronology of late Pleistocene volcanic ash beds in central North Island, New Zealand. *N.Z. Journal of Geology and Geophysics 12*: 784–837.

WARD, W. T. 1967: Volcanic ash beds of the lower Waikato Basin, North Island, New Zealand. *N.Z. Journal of Geology and Geophysics 10*: 1109–35.

WELLMAN, H. W. 1962: Holocene of the North Island of New Zealand: a coastal reconnaissance. *Transactions of the Royal Society of N.Z. (Geology) 1 (5)*: 29–99.

WILSON, A. T.; HENDY, C. H. 1971: Past wind strengths from isotope studies. *Nature 234*: 344–5.