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Quaternary Geology of the South-west Auckland Coastal Region

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Abstract

SIX major oscillations of sea level are interpreted from Quaternary formations exposed in south-west Auckland coastal region. The formations, which are transgressive sequences of shallow subaqueous, littoral, and aeolian sediments, are integrally associated with a flight of terraces the altitudes of which compare very closely with similar surfaces around South Kaipara Harbour (described by Brothers, 1954). Marker horizons of pumiceous silt within the older formation indicate that differential tectonic movements ceased in this region in Nukumaruan times. All the described deposits constitute the Kaihu Group—the oldest member formation being Pliocene in age and six younger formations being Quaternary. Correlations with Wanganui are postulated, and K/Ar age determinations from basalts interbedded with sequences of inferred Hautawan and Nukumaruan ages form the basis for an early Pleistocene time scale.

INTRODUCTION: OUTLINE OF UPPER TERTIARY HISTORY

A LARGE marine embayment, within which shelf sediments were accumulating, existed in the south-west Auckland and King Country region during Oligocene times (Fleming, 1962; Barrett, 1962). Deposition ceased early in the Miocene as the sea-floor everted to become a warped and fractured land (Henderson and Grange, 1926; Fleming, 1962), and movements which took place at that time generated most of the regional physiographic features of today.

Uplands to the west of the north–south trending fault zone which lies west of the Waipa River (cf. Kear, 1960) have a general crest altitude of 1,000ft, and fall away as a broadly warped surface towards the coast on the west. The coast itself is long, straight, and cliffed, interrupted only where the large dendritic harbours of Raglan, Kawhai, and Aotea extend inland. These harbours occupy depressions formed by west-trending faults and associated downwarps that formed during the Miocene movements.

The emerging surface was taken over by a tectonically controlled drainage pattern, the major elements of which survive today. Some few streams appear to have been unaffected in their courses by wasting-off of Tertiary cover, and still follow either their ancient dip-consequent courses (e.g., Waingaro Stream and others draining into Raglan Harbour—Fig. 1) or their controlling fault-angle consequent lines (e.g., Marakopa River). Slow tilting of fault blocks led in some

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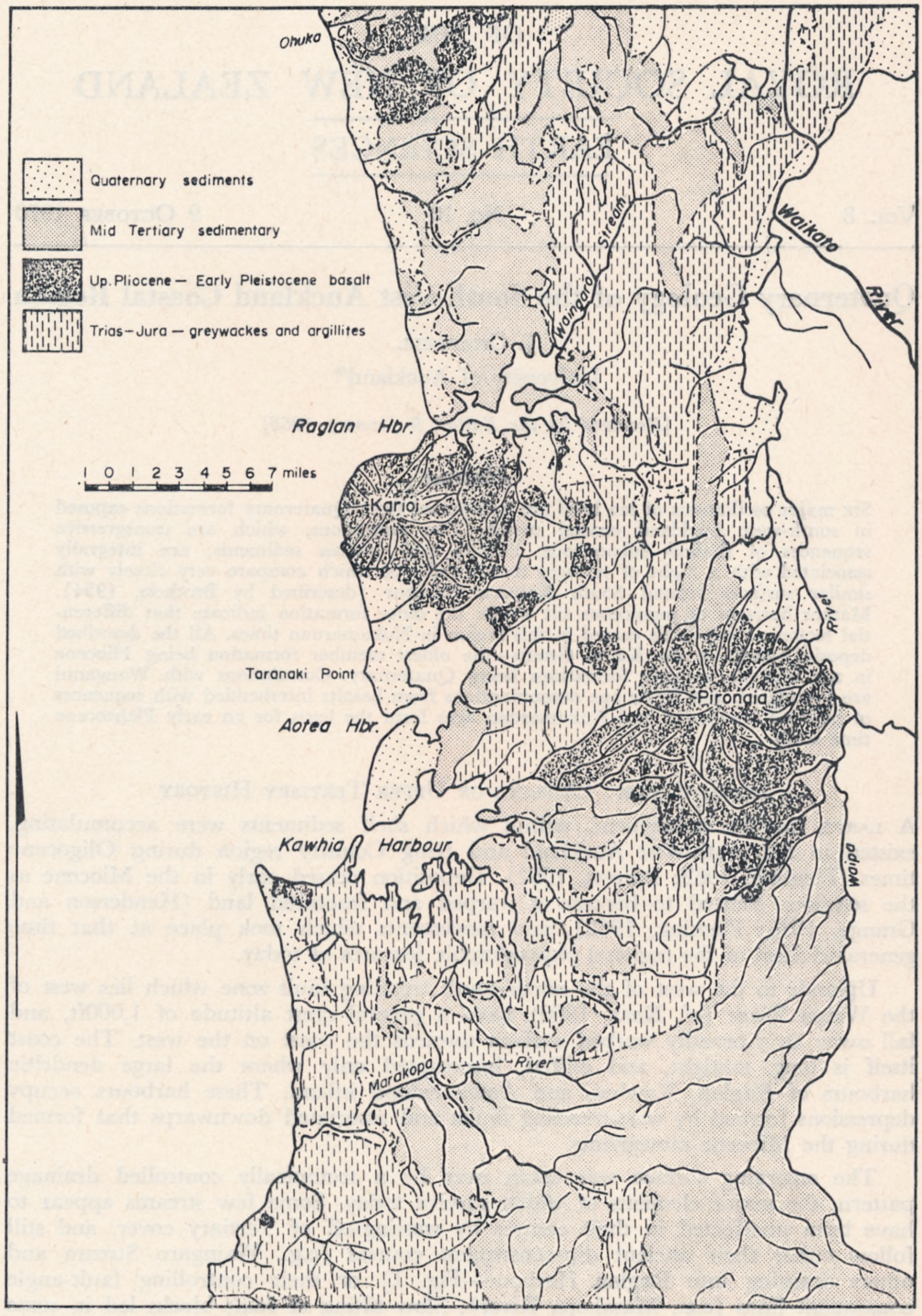

FIG. 1.—Drainage pattern and generalised geology for south-west Auckland.

cases to antecedent drainage (e.g., Maire Stream north of Raglan, described by Dow, 1957). The present centrifugal drainage patterns were largely established when basaltic eruptions took place at Karioi, Pirongia, and other associated centres (indicated by the drainage patterns shown in Fig. 1).

Slightly before the time when eruptions started fossiliferous sandstones were accumulating in the vicinity of the present coast (Kear, 1957; Schofield, 1958), and shortly afterwards a marine transgression commenced, the maximal position of which is represented by a comparatively widespread marine platform lying at altitudes of 550 to 600ft. Sediments deposited during this transgression mantle the flanks of the basalt volcanoes (Dow, 1957; Player, 1958; Chappell, 1964). A downstepping sequence of thalassostatic surfaces is developed across these transgressive sediments and the older rocks alike, the altitudes of the inner margins of the members of the series being 350ft, 220ft, 140ft, 70ft, 35ft and 7ft—a sequence which compares closely in terms of altitudes with a flight of similar surfaces occurring in the Kaipara district on the west coast north of Auckland, described by Brothers (1954). The altitude of any one surface varies little from point to point along the south-west Auckland coast, which suggests that there have been no appreciable differential movements in the region since the highest surface formed.

The terrace surfaces are to a large extent constructional, each being the culmination of a transgressive formation of aeolian, littoral, esturine, and shallow-marine sediments. Interpretation of the series of surfaces and associated sediments is the subject matter of this paper.

THE UPPER CENOZOIC DEPOSITS: THE KAIHU GROUP

There are strong resemblances of stratigraphy and lithology between the bulk of upper Cenozoic deposits and terraces of south-west Auckland coastal region, and those of the South Kaipara district described by Brothers (1954). Brothers recognised four formations, which were associated with certain surfaces within a downstepping flight of six terraces, and these deposits he classed together as the Kaihu Group. Of the base of the group, Brothers (1954) writes: "The basal sediments of the Kaihu Group at some distance below sea level may rest on Pliocene beds and themselves be of late Pliocene age." In several coastal sections in south-west Auckland flat-lying Pliocene rocks disconformably underlie sediments deposited during the first major late-Cenozoic transgression (i.e., that which culminated with the development of the marine platform at 600ft), and these Pliocene beds are the lowest in a succession of upper Cenozoic deposits which unconformably overlie mid-Cenozoic rocks. Kear (1957) extended the Kaihu Group south from Kaipara to include Pliocene and early Pleistocene beds exposed in the Kaawa–Ohuka coastal section (about 7 miles south of Port Waikato). The Group is here extended farther southwards, and the following definition is proposed.

The Kaihu Group includes all poorly to moderately consolidated sediments which unconformably overlie well lithified rocks of Altonian age or older in the west Northland–south-west Auckland region.

Intercalated with the group, but not included within it, are lavas and agglomerates of the Alexandra Volcanics and Ngatutura Basalts (cf. Kear, 1960). In south-west Auckland seven formations of the Kaihu Group are recognised, while Brothers (1954) described four constituent formations in the Kaipara district. In both areas each formation is comprised of interdigitated terrestrial, littoral, and shallow-subaqueous sediments. Table I lists formation names from south-west Auckland and Kaipara, and shows the correlation between them.

TABLE I.—Correlations between Formations in south-west Auckland and Kaipara.

	S.W. AUCKLAND	KAIPARA (Brothers, 1954)
KAIHU GROUP	Recent	Recent
	Waiau B Formation	Waioneke Formation
	Waiau A Formation	Shelly Beach Formation
		South Head Formation
	Parawai Formation	
	Nihinihi Formation	
	Kaihu Formation	Kaihu Formation
	Kaawa Formation	

Within certain formations of the Kaihu Group horizons of pumiceous silt occur which are traceable over the length of the region and serve as marker horizons for correlation. Any one horizon may vary in altitude owing to (i) variations in original depth of deposition, and (ii) subsequent tectonic warping in the area. In the following description of the successive formations, attention is drawn to evidence for any such differential movements.

KAAWA FORMATION

There are four members:

Pourewa Lignite
Ohuka Carbonaceous Sandstone
Kaawa Sandstone
Kaawa Shellbed.

The Kaawa Formation is the lowest member of the Kaihu Group and takes its name from the Kaawa–Ohuka coastal section, described by Kear (1957). The formation is here extended to include rocks of similar facies and stratigraphic position, which occur to the south as far as Kawhia Harbour. Fig. 2 shows the

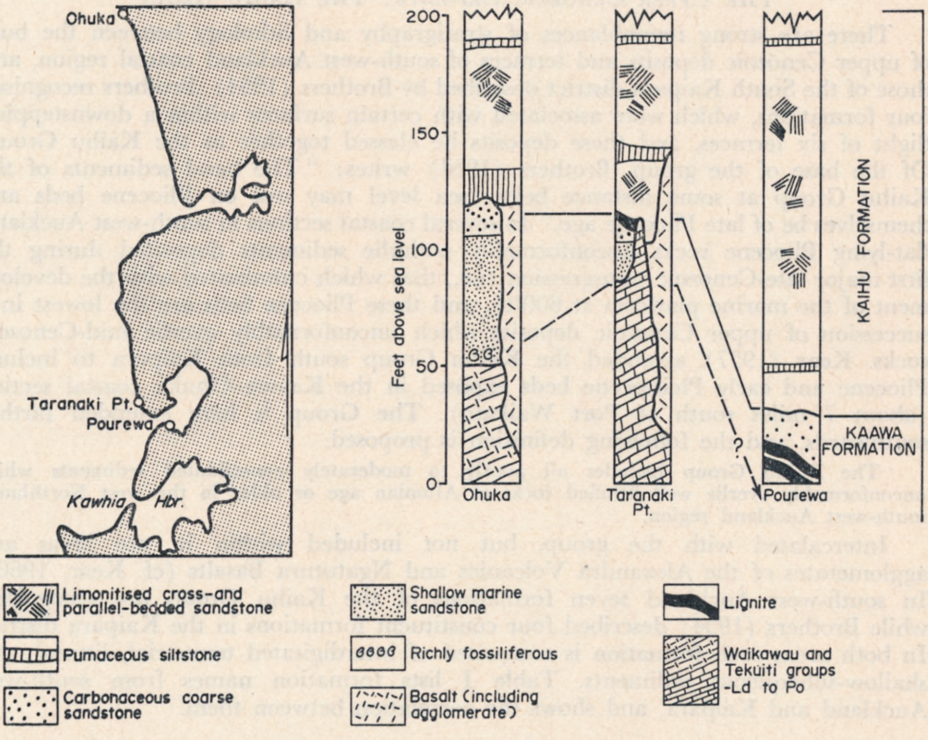

FIG. 2.—Three important sections of the Kaawa Formation. Note that the basalt at Ohuka and Taranaki Point fills valleys post-dating the Kaawa Formation, and the erosion surface truncating the basalt is the base of the Kaihu Formation.

relationship between three important sections. The term Kaawa Formation was used by Kear (1957) to include the basal Kaawa Shellbed and Kaawa Sandstone. The overlying Ohuka Carbonaceous Sandstone grades conformably up from the Kaawa Sandstone (Kear, 1957; Chappell, 1964), and the Formation is here extended to include this unit and its lateral equivalents elsewhere, such as the Pourewa Lignite.

The Kaawa–Ohuka Section

In addition to being important stratigraphically, this section is interesting because there are certain differences in altitude between two similar successions where they occur north and south of Ohuka Creek. Kear (1957) interpreted this to indicate a post-Kaawa differential movement, amounting to 45ft per mile of tilting to the south. The present writer has reinterpreted the depressed section as a massive block slide. The Kaawa section is critical to inferences of differential tectonic movements and overall changes of relative sea level, and hence some particulars of the section, which is shown in Fig. 3, are described here.

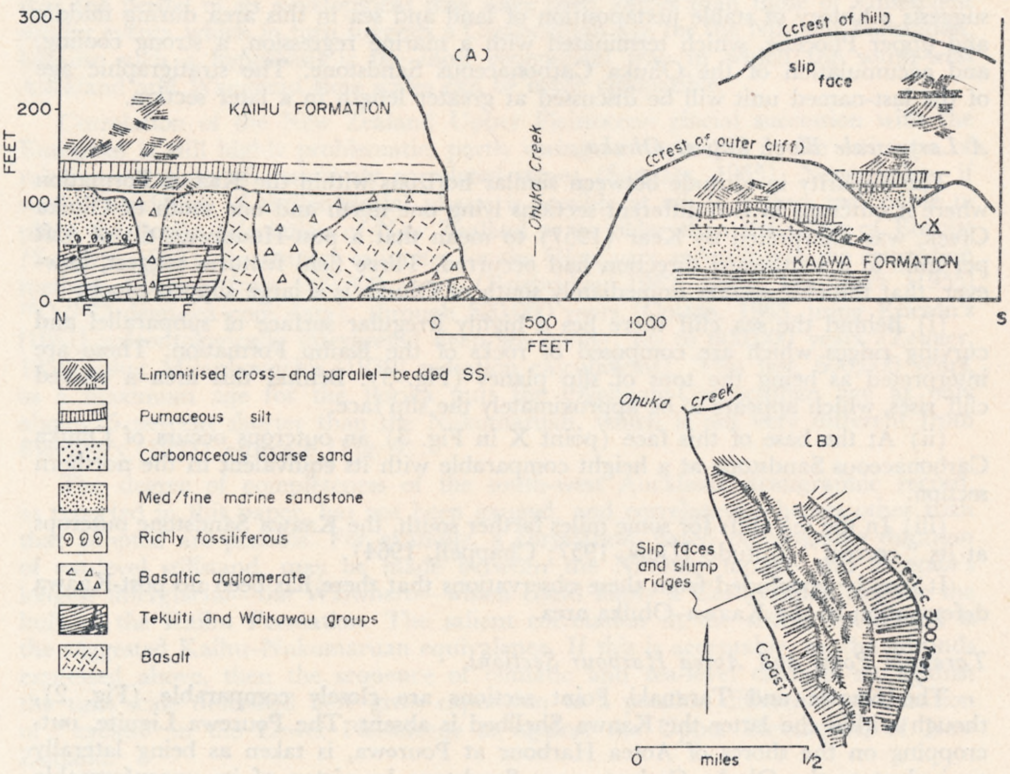

FIG. 3.—The Kaawa–Ohuka Section. Point X on the right side indicates the Ohuka Carbonaceous Sandstone where it outcrops at 120ft above sea level in the base of the inner, higher cliff.

Rocks of the Kaawa Formation within the section record a period of slow marine deposition in Pliocene times, which terminated with a strong deterioration of climate and a regression and fall of sea level. The basal Kaawa Shellbed is a blue-grey, very shelly, slightly muddy, fine to medium quartzose sandstone, and Laws (1950) interpreted its very rich molluscan fauna as indicating a depositional depth of 10–15 fathoms. Finlay and Marwick (1940) and Laws (1950) considered its age to be Opoitian. The underlying surface, cut across Oligocene rocks of the Waikawau and Te Kuiti Groups, is clean, sharp, and regular, and is here interpreted as a surface of marine planation.

The shellbed passes gradationally up into the Kaawa Sandstone within which there are no breaks or discontinuities. Bedding in this fine to medium sandstone becomes more distinct towards the top, where it comprises simple wavy laminae, sometimes rippled. The transition upwards into the Ohuka Carbonaceous Sandstone is a completely gradational change to brownish-grey carbonaceous fine sand with thin interbedded silt and peat lenses, which in turn passes up into coarse white laminated sandstone bedded in long tapering sets of laminae and here interpreted as upper berm deposits.

Palynologic investigation of the carbonaceous sandstone was made by Couper and McQueen (1954), who considered the flora to indicate a climate about 5°C cooler than the present one, and the age to be Nukumaruan. This determination is the basis for the classification of the unit by Kear (1957) as Lower Nukumaruan, i.e., Hautawan (cf. Fleming, 1962), the important factor for correlation being the indication of the first strong cooling in late Cenozoic times. The stratigraphy thus suggests a history of stable juxtaposition of land and sea in this area during middle and upper Pliocene, which terminated with a marine regression, a strong cooling, and accumulation of the Ohuka Carbonaceous Sandstone. The stratigraphic age of the last-named unit will be discussed at greater length in a later section.

A Large-scale Block Slip at Ohuka

The disparity in altitude between similar horizons within the Kaawa Formation where it outcrops in two different sections lying one north and one south of Ohuka Creek, was interpreted by Kear (1957) to mean that a post-Hautawan tilt of 45ft per mile in a southward direction had occurred. Three field features suggest, however, that the cliff section immediately south of Ohuka is a large slipped block:

(i) Behind the sea cliff there lies a highly irregular surface of subparallel and curving ridges which are composed of rocks of the Kaihu Formation. These are interpreted as being the tops of slip planes (Fig. 3). Behind this area a curved cliff rises, which appears to be approximately the slip face.

(ii) At the base of this face (point X in Fig. 3) an outcrops occurs of Ohuka Carbonaceous Sandstone at a height comparable with its equivalent in the northern section.

(iii) In the sea cliffs for some miles farther south, the Kaawa Sandstone outcrops at its "correct" altitude (Dow, 1957; Chappell, 1964).

It may be concluded from these observations that there has been no post-Kaawa deformation in the Kaawa–Ohuka area.

Taranaki Point and Aotea Harbour Sections

The Kaawa and Taranaki Point sections are closely comparable (Fig. 2), though within the latter the Kaawa Shellbed is absent. The Pourewa Lignite, outcropping on the shores of Aotea Harbour at Pourewa, is taken as being laterally equivalent to the Ohuka Carbonaceous Sandstone by virtue of its unconformable relationship with the overlying Kaihu Formation and also of the contained flora. The flora were determined by Dr W. F. Harris and considered by him to indicate a climate much cooler than the present. (Floral lists are presented in an appendix.) The altitude of the Ohuka Carbonaceous Sandstone at both Ohuka and Taranaki Point is 110ft, while the Pourewa Lignite outcrops at sea level. This difference may be interpreted as meaning that relative downsinking of the Kawhia–Aotea depression continued into post-Hautawan times. The altitudes of pumiceous marker horizons in the overlying Kaihu Formation, where it outcrops around the shores of Aotea and Kawhia harbours, corroborate this.

KAIHU FORMATION

The term Kaihu Formation was first applied by Brothers (1954) to horizontally bedded massive coarse sandstones, pumice silts, and variegated muds with local dunesand members in the South Kaipara district of Northland. These beds were deposited during a marine transgression which reached a height of at least 550ft above present sea level; transgression commenced, he suggested, in Opoitian times and included the deposition of Pliocene strata at Otahuhu (and therefore, by implication, the correlative Pliocene beds in the Kaawa section).

The nature of the unconformity between the Kaawa Formation and the overlying Kaihu Formation, in the south-west Auckland sections, indicates a reversal in this "post-Opoitian transgression". Where it is exposed in the sea cliffs of the area, the Kaihu–Kaawa unconformity presents the aspect of a plane surface cut by valleys of various width and with steep declivities. These extend below present sea level (e.g., at Kaawa section, Fig. 3, and at Taranaki Point), and a water borehole 1½ miles north of Taranaki Point indicates Kaihu sands to nearly 200ft below sea level (Chappell, 1964). This allows the following more precise definition to be made:

> The Kaihu Formation includes all rocks on the west coast between northern Kaipara and Marakopa, which everywhere rest unconformably on rocks of Kaawa Formation or older, and form a continuous sequence, containing marine members, to an altitude of at least 500ft.

The formation contains horizontally- and cross-bedded subaqueous sandstones, pumiceous silts, peats, muds, and dunesands; all are moderately well compacted, and sandy phases contain an average 35 percent titanomagnetite and are heavily limonitised. Fig. 4 shows the essential features of the formation in the Kawhia–Aotea area.

Important as marker beds are two pumice-silt horizons which allow correlations to be made between the rather fragmentary sections and hence serve to indicate the nature of post-Hautawan differential movements. These horizons are not universally present in Kaihu Formation sections as they wedge out against old shorelines preserved within the succession, and furthermore their vertical stratigraphic distance from any other horizon varies as intervening sedimentary facies change. Nevertheless, the two marker horizons are definable in terms of altitude.

Pumice Silt P1 is the lower and thicker, ranging from 30ft down to 2ft thick. It occurs up to 140ft above sea level in the sea-cliff sections and, where it occurs in sections about Kawhia and Aotea harbours, P1 is everywhere 70ft or more lower

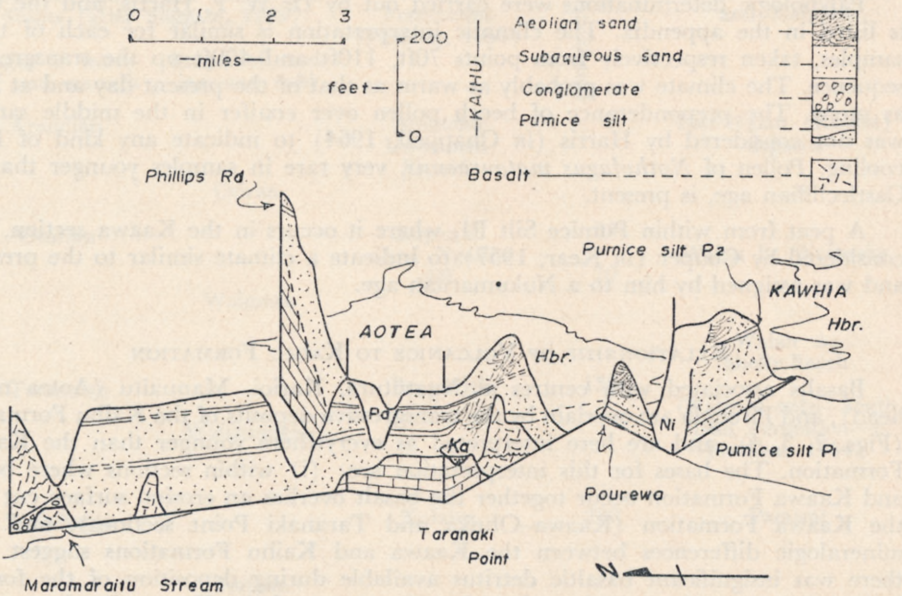

FIG. 4.—"Fence diagram" linking Kaihu sections in Kawhia–Aotea area. The change in altitude of P1 from Taranaki Point to Pourewa is thought to indicate post-Kaawa deformation, which had largely ceased by time of deposition of P2. Note Parawai (Pa) and Nihinihi Formations filling valley cut in Kaihu Formation.

than its lowest occurrence in sea-cliff exposures. Within several such harbour-side exposures the overlying subaqueous sands pass up into littoral and aeolian sands within vertical distances of 10–20ft (Fig. 4). This consistent disparity of altitudes is here interpreted as indicating that differential movement of 60ft or more has occurred between the Kawhia–Aotea depression and the Taranaki Point–Kaawa block since Hautawan times. Sections similar to those of Kawhia–Aotea were not seen near Raglan Harbour, and hence the nature of post-Hautawan movements, if any, are not known for this depression.

Pumice Silt P2. This bed is consistently thinner than 2½ft, and occurs up to 190ft above present sea level. At this height it wedges out against littoral beds and dunesands of ancient shorelines within the Kaihu Formation, in sections exposed both on the coast and within Kawhia and Aotea Harbours. The conclusion is that differential tectonic movements had largely ceased by the time P2 was deposited.

Reversals within the Kaihu Transgression

One other thin pumice silt horizon is found within the Kaihu Formation, occurring about 400ft above sea level where the formation outcrops beside Phillips Road, in the high ground immediately north of Aotea Harbour. The bed, which is known only from this area, underlies a fossil soil which in turn is buried by littoral and subaqueous sands. This section implies a reversal in the general positive sea-level movement of the Kaihu Transgression—the amplitude of the fluctuation being 15ft or more. Similar sections exposed at two other localities in the region may indicate fluctuations of the same order as having occurred when the relative (Kaihu-transgression) sea level stood 150 and 185ft above the present sea level datum. There is within these last two sections, however, a stratigraphic ambiguity, in that the beds above the buried soils may belong to the younger Nihinihi or Parawai Formations.

Kaihu Formation Palynology

Palynologic determinations were carried out by Dr W. F. Harris, and the flora is listed in the appendix. The climatic interpretation is similar for each of three samples, taken respectively from points 70ft, 110ft and 400ft up the transgressive sequence. The climate was probably as warm as that of the present day and at least as moist. The preponderance of beech pollen over conifer in the middle sample was not considered by Harris (*in* Chappell, 1964) to indicate any kind of local cooling. Pollen of *Nothofagus matauraensis,* very rare in samples younger than of Castlecliffian age, is present.

A peat from within Pumice Silt P1, where it occurs in the Kaawa section, was considered by Couper (*in* Kear, 1957) to indicate a climate similar to the present, and was assigned by him to a Nukumaruan age.

Relationship of Volcanics to Kaihu Formation

Basalts associated with centres at Ngatutura, Karioi, Manuaitu (Aotea north head), and Pirongia are overlain by the transgressive deposits of the Kaihu Formation (Figs. 2, 3, 4), and are here interpreted as everywhere younger than the Kaawa Formation. The bases for this interpretation are: (i) within sections where basalt and Kaawa Formation occur together the basalt overlies an erosion surface cut into the Kaawa Formation (Kaawa–Ohuka and Taranaki Point sections), and (ii) mineralogic differences between the Kaawa and Kaihu Formations suggest that there was insignificant basaltic detritus available during deposition of the former beds (e.g., ore grains constitute less than 1 percent of the Kaawa Sandstone, but average 35 percent of the bulk of the Kaihu).

The lavas extend down to below present sea level and, where exposed in present sea cliffs, are seen to be columnar jointed. They have neither pillow structures nor glassy selvages, and individual flows are most often topped by thin layers of small scoriaceous blocks. All this indicates that relative sea level was lower than the present when the lavas were erupted. Within the time interval ranging from the commencement of the Kaawa regression to the main Kaihu transgression, there occurred an oscillation of sea level which achieved an altitude of at least 65ft above present sea level. The record is seen in the cliff section of Marumaruaitu stream mouth, shown in Fig. 5.

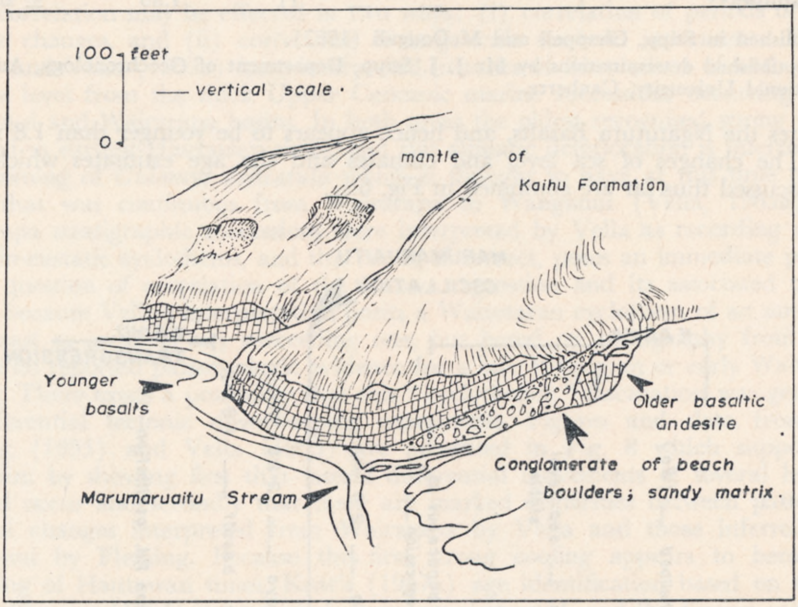

FIG. 5.—The Marumaruaitu section, showing a transgressive formation of beach boulders, at least 80ft thick, separating the lower lavas (2.4 million years) from the upper (2.28 million years).

The Marumaruaitu Section

Within this section a basaltic andesite underlies a wedging bed of beach boulders of the same basaltic material. The boulder bed is a transgressive deposit, overlapping an ancient cliff cut into the basaltic andesite, and it itself overlain by a series of flows of columnar basalt. The interface between the base of the upper lavas and underlying sandy matrix at the top of the boulder bed is everywhere clean and sharp, without selvage or pillow structure. The flow is interpreted as being terrestrial. This means that an oscillation occurred (hereafter referred to as the Marumaruaitu oscillation) during which sea level reached a height of at least 65ft above before withdrawing to below present sea level. The Kaihu transgression is the next recorded movement of sea level.

K/Ar Age Estimates of the Basalts

Specimens of the lavas in the important coastal sections were collected for K/Ar dating by Mr J. J. Stipp and Dr I. McDougall of the Department of Geochronology, Australian National University. Determinations from the Taranaki Point and Marumaruaitu lavas are the basis of an age estimate for the Pliocene–Pleistocene boundary in New Zealand of 2.5 million years (Stipp, Chappell and McDougall, 1967), and these results are listed in Table II, along with age determinations of the Ngatutura basalt. The K/Ar estimates indicate that the Marumaruaitu oscillation commenced later than 2.4 million years ago, and that the sea had withdrawn again to below datum by 2.28 million years ago. The Kaihu transgression

Table II.—K/Ar Ages (m/y).

Locality	No. of Determinations	Age	Total Std. Error
Taranaki Point*	8	2.50	± 0.10
Marumaruaitu Stream—upper lavas*	5	2.28	± 0.15
Marumaruaitu Stream—lower lava*	2	2.41	± 0.1 ?
Ngatutura**	11	1.80	± 0.24

* Published in Stipp, Chappell and McDougall (1967).

** Unpublished determinations by Mr J. J. Stipp, Department of Geochronology, Australian National University, Canberra.

post-dates the Ngatutura Basalts, and hence appears to be younger than 1.8 million years. The changes of sea level and climates and the age estimates which have been discussed thus far are combined in Fig. 6.

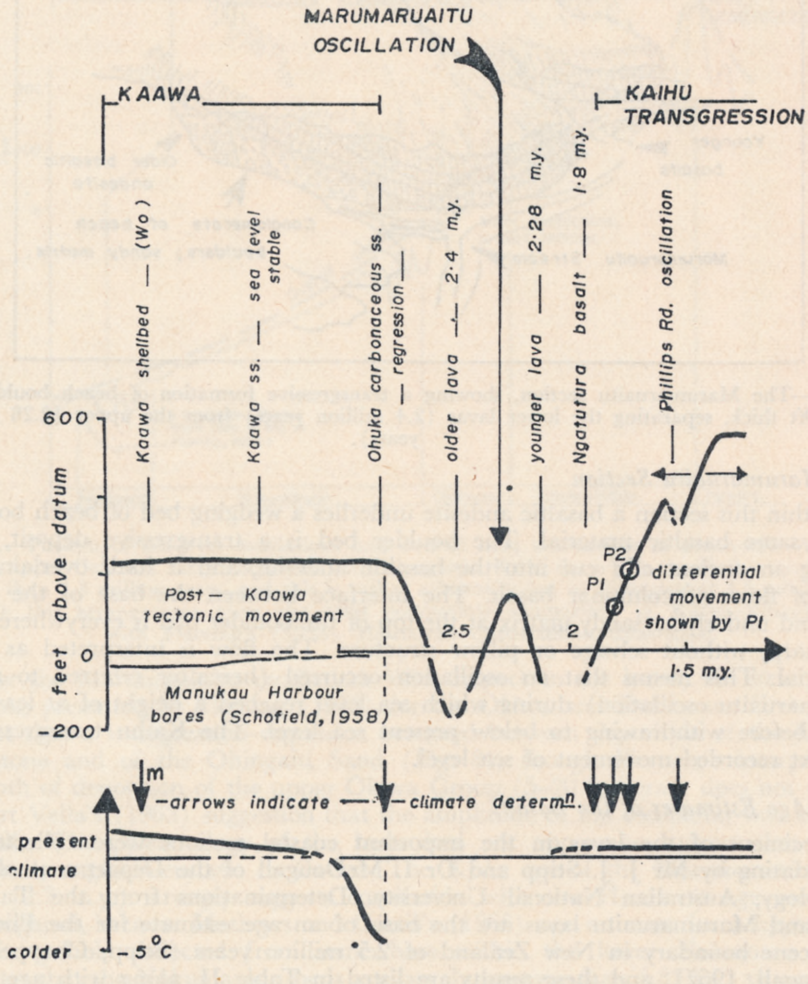

Fig. 6.—Oscillations of sea level and climate in the early Pleistocene, deduced from south-west Auckland material. All climate determinations are palynologic (Couper and McQueen, 1954; Harris, in this paper), with the exception of the Opoitian molluscan faunule at Kaawa Creek (labelled with arrow m).

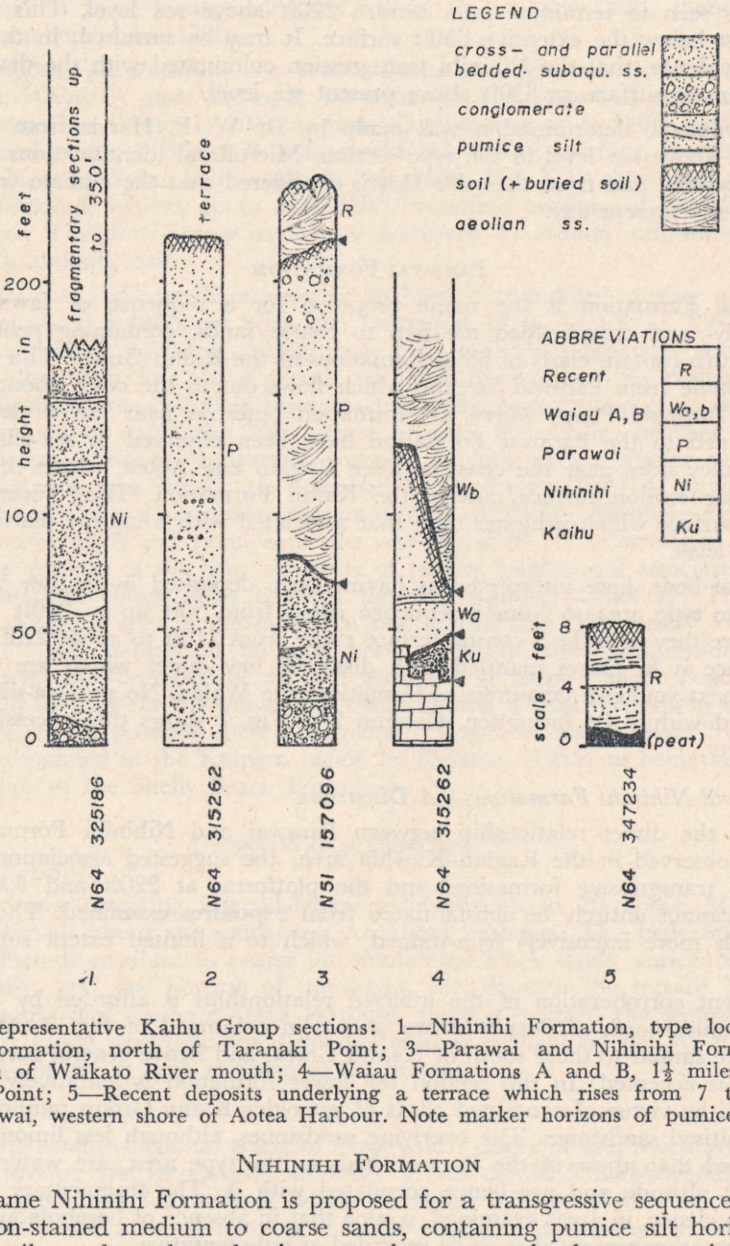

FIG. 7.—Representative Kaihu Group sections: 1—Nihinihi Formation, type locality; 2—Parawai Formation, north of Taranaki Point; 3—Parawai and Nihinihi Formations, 8 miles north of Waikato River mouth; 4—Waiau Formations A and B, 1½ miles north of Taranaki Point; 5—Recent deposits underlying a terrace which rises from 7 to 12ft, at Papahutiwai, western shore of Aotea Harbour. Note marker horizons of pumiceous silt.

NIHINIHI FORMATION

The name Nihinihi Formation is proposed 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—the latter containing clasts of the Kaihu Formation. The formation takes its name from Nihinihi, south head of Aotea Harbour. Four pumice silt horizons are present in the type section (shown in column 1 of Fig. 7), occurring at altitudes of 35ft, 65ft, 120ft and 150ft, and these serve to distinguish between Nihinihi and Kaihu Formations.

A transgressive sequence 170ft thick outcrops in the type section, and, although exposures seen in the Kawhia–Raglan area were not numerous enough to allow the fragmentary sections to be pieced together to extend the column farther upwards, the Nihinihi transgression seems to have achieved an altitude of 350ft. This is because the next youngest transgressive formation—the Parawai (described below)—is seen to terminate in a terrace 220ft above sea level. This terrace is next lowest below the extensive 350ft surface. It may be surmised, in the absence of other evidence, that the Nihinihi transgression culminated with the development of an extensive surface at 350ft above present sea level.

A palynologic determination was made by Dr W. F. Harris from a sample taken 17ft above sea level in the type section. Microfloral identifications are listed in the appendix, and from these Dr Harris considered that the climate was similar to that of the present day.

Parawai Formation

Parawai Formation is the name proposed for a sequence of fawn-coloured horizontally- and cross-bedded medium to coarse sands, containing pebble bands which in turn contain clasts of older formations of the Kaihu Group. The formation takes its name from Parawai Stream, which flows out to the coast about 1½ miles north of Taranaki Point, where the formation outcrops near the stream mouth. Beds assigned to the Parawai Formation have been observed in sea-cliff sections and on valley sides near the coast between Raglan and Aotea, where they overlie an irregular erosion surface cutting the Kaihu Formation. They never underlie any land surface which is higher than that associated with a marine platform 220ft above sea level.

Parawai beds, here interpreted as having been deposited in shallow water, are seen in the type area to form a sequence rising from 50ft up to 210ft above sea level, where they underlie a coastal terrace rising from 210ft to about 220ft altitude. This terrace is in places mantled with dissected low dunes which are associated with the next youngest transgressive formation, the Waiau. No pumice-silt horizons were found within the formation. Column 2 of Fig. 7 shows the succession at the type locality.

Parawai and Nihinihi Formations—A Discussion

Because the direct relationship between Parawai and Nihinihi Formations has not been observed in the Raglan–Kawhia area, the suggested association between these two transgressive formations and the platforms at 220ft and 350ft above sea level cannot entirely be substantiated from exposures examined. The Nihinihi is generally more intensively iron-stained, which to a limited extent supports the suggestion.

Apparent corroboration of the inferred relationships is afforded by a sea-cliff section, 8 miles north of Port Waikato, shown in column 3 of Fig. 7. Altitudes of terraces are similar to those south of Kaawa Creek, and hence general correlation of the areas is accepted. In this section the lower formation is tentatively identified as Nihinihi by virtue of contained clasts of yet older Kaihu Group pumice siltstone and limonitised sandstones. The overlying sandstones, although less limonitised and consolidated than those of the Parawai beds in the type area, are waterlaid to at least 200ft altitude and are hence correlated with it. The fragmentary nature of the field evidence, in areas examined, is such that in absence of borehole information the interpretation presented must be regarded as only tentative.

Waiau Formations A and B

Less extensive terraces, lying 120–130ft and 60–70ft above sea level, are preserved at intervals about the harbours and coastal valleys of the region. Small benches occur occasionally at 35ft. Most of these surfaces are cut into older rocks of the Kaihu Group, but in some areas they are seen to be built of poorly consolidated, almost unstained shallow-subaqueous sands and silts, aeolian sands, and stream gravels. These beds overlie irregular erosion surfaces, frequently soil-mantled, developed across rocks of the Parawai, Nihinihi, or Kaihu Formations. Although dunesands within these younger deposits extend up to over 350ft, there are no waiterlaid members above 130ft.

These deposits all constitute the Waiau Formation, which is divided into two sets of beds, Waiau A and Waiau B, by virtue of a soil-mantled erosion surface which cross-cuts those water-laid Waiau beds which extend up to 130ft. Aeolian and isolated littoral sands of Waiau B beds overlie this erosion surface, the maximum observed altitude of Waiau B littoral beds being 40ft. Fig. 7(4) shows sections. The Waiau B dunesands extend up to over 350ft, mantling portions of the 220ft and 350ft surfaces. The dune forms have been destroyed by erosion and subsequently mantled with andesitic ash.

The Waiau A beds are here thought to have accumulated during a marine transgression which culminated with the formation of a terrace at 130ft above datum. Steep erosion surfaces cutting these beds indicate subsequent withdrawal of the sea to less than 30ft above present sea level. Evidence of the Waiau B beds is by itself insufficient to definitely suggest a transgression–regression cycle associated with development of either the 70ft terrace or with the smaller benches at 35ft. The 70ft surface, however, appears to correlate directly with a similar surface in the south Kaipara area which was described by Brothers (1954) as having been formed at the end of a marine transgression during which the Waioneke Formation of shallow water muds and pumiceous silts was deposited. The correlation may be made on the grounds of the close similarity of terrace heights and associated transgressive formations which exists between the two regions (Table I). Therefore, because the Kaipara area is the definitive one in this case, the term " Waioneke transgression " will henceforth be used here to denote the transgression which culminated with the formation of the 70ft surface. The name " Shelly Beach transgression " will be used for the movement that achieved a relative position of 130ft, in preference to the possible alternative name " Waiau A transgression ", because it was first recognised in the Kaipara region by Brothers (1954) as being associated with deposition of the Shelly Beach Formation.

POST-WAIAU DEPOSITS

Seven-foot Terrace

A low terrace overlying intertidal-zone sediments up to 7ft above M.H.W.L. occurs at intervals about the south-west Auckland harbours. The beds underlying the terrace include medium to coarse unconsolidated black sands, variegated muds and peats, silts, and one horizon of pumiceous silt. Beneath the terrace where it occurs at Rauraukere, western Aotea Harbour, there is exposed the section shown in Fig. 7(5). Floral determination from the peat is thought by Dr W. F. Harris to indicate a climate at least as warm as the present.

Sand Dunes

Within the extensive coastal tracts of " ironsand " dunes of south-west Auckland, two major groups are recognised, an older group of fixed, soil-covered, partly dissected parabolic and longitudinal dunes (hereafter informally referred to as the " older dunes ") and a younger group of active barchans and transverse dunes and partially fixed parabolic dunes. Where they occur as dune fields beside the entrances of the west coast harbours, the older dunes cover the older deposits of the Kaihu Group, and locally rise as a mantle to over 400ft above sea level. The Taharoa Lakes, south of Kawhia, and Lake Parangi, at Kawhia, are impounded by these older dunes which in turn encroach upon the 7ft terrace. A 20ft continuous core was collected from the westernmost swamp of Lake Harihari (south-westernmost of the Taharoa group of lakes) by using a Hiller auger. No sedimentologic variations occurred within the subaqueous part of the core (lower 12ft), which was composed of carbonaceous, silty, pale-yellow mud. Microflora indicate a climate similar to the present (identifications listed in the appendix).

Within the active younger dunes there is an observed relationship between dune form and plant fixing, to the effect that transverse dunes blow through and become parabolic when patches of vegetation become established. The period for which these dunes have been active is uncertain, as the relationship is unclear between them and bayhead deposits of littoral sands containing waterborn blocks of Taupo Pumice (dated A.D. 150—Wellman, 1962). Fleming (1953) attributed the mobilisation of active dunes in the Wanganui region to overgrazing by European-introduced livestock. The manner in which the sands of the very extensive "older dunes" and of the Waiau B dunes were mobilised is not clear, however, although Kear (1964) relates dune-building with times of falling sea level, when abandoned strands may have supplied the necessary sand.

Correlations With Kaipara and Wanganui

The south-west Auckland flight of terraces correlate directly, in terms of altitude, with those of south Kaipara which were described by Brothers (1954). Correlations between constituent formations of the Kaihu Group in both areas have been

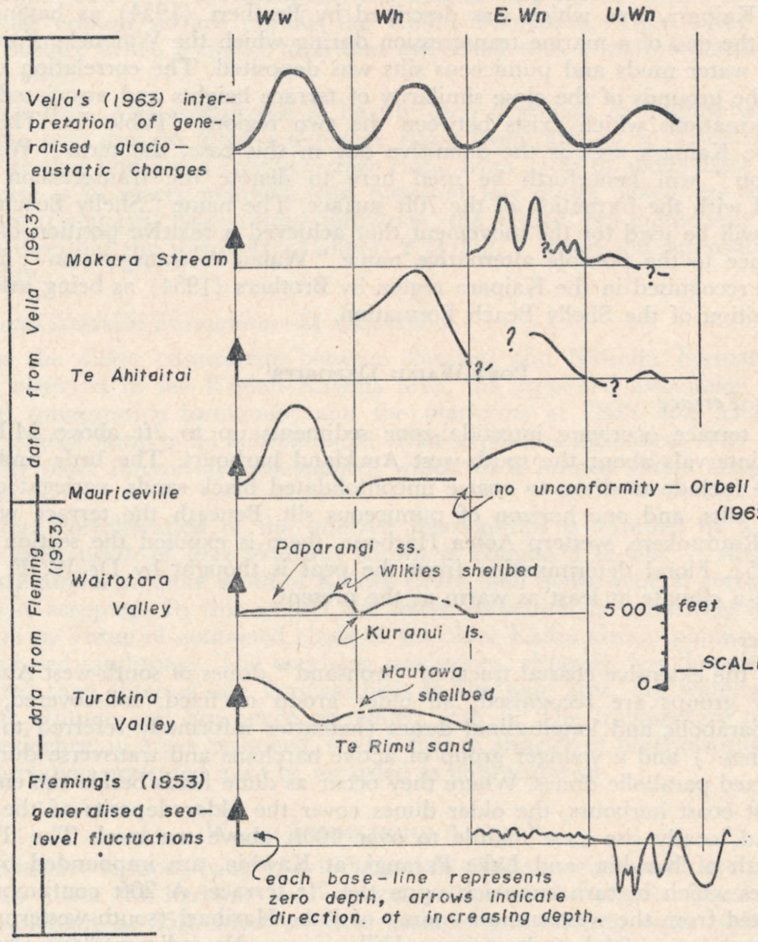

Fig. 8.—Curves of relative land–sea movements from selected areas showing that differential tectonic movements have occurred. The amplitudes of these movements suggest that certain of Vella's (1963) cyclothems may be tectono-eustatic rather than glacio-eustatic. The curves are constructed from data in Fleming (1953) and Vella (1963).

described above, and these correlations are summarised, together with the interpreted history of sea-level changes, in Fig. 9.

The starting point for correlation with the Plio-Pleistocene succession of the Wanganui district described by Fleming (1953), is the Kaawa Shellbed of Otaian age. Above this, in the younger formations of the Kaihu Group, direct correlations with Wanganui cannot be made palynologically, as sufficient extinct species have not been identified in the south-west Auckland material. Proceeding from this point, correlation may be effected in two ways: (i) correlation of periods of strong climatic changes, and (ii) correlation of large-scale sea-level movements. Fleming (1953) and Vella (1963a) have interpreted histories of fluctuations of both climate and sea level from the thick Upper Cenozoic marine successions occurring in the Wanganui and Wairarapa basins. In both areas the oldest recognised strong cooling occurred in earliest Hautawan times, and this climatic deterioration is inferred from the incoming of *Chlamys delicatula* which is thought to have at this time invaded a sea that was continuous from Wairarapa to Wanganui (Vella, 1963a). The Wairarapa stratigraphic successions were interpreted by Vella as recording a series of glacio-eustatic cyclothems, and this result, if correct, poses an immediate problem to the question of correlation of the Kaawa regression and its associated cooling. This is because Vella's interpretation posits a Waitotaran cyclothem of an amplitude of at least as great as any succeeding one, but based on stratigraphy from which there is no reported paleontologic evidence for a late Waipipian or early Waitotaran cooling. There exists a possibility that this "cyclothemic" fluctuation was generated by differential tectonic downwarping movements. Figures and data from both Fleming (1953) and Vella (1963) are presented in Fig. 8 which support this suggestion by showing first that lateral differential movements of several hundred feet did occur and secondly that there are marked disparities between patterns of sea-level changes interpreted from Wairarapa by Vella and those inferred from Wanganui by Fleming. Because the first strong cooling appears to herald the beginning of Hautawan times, Kear's (1957a) age identification based on Couper and McQueen's (1954) palynology is therefore supported, and the Kaawa regression is here taken to be coeval with an early Hautawan marine withdrawal, which is suggested to have accompanied the first Upper Cenozoic glaciation.

Although satisfactory palynologic correlations are not possible at this stage, and pumice horizons cannot be correlated through to Wanganui (cf. Kear, 1957b), and although the record of sea-level oscillations interpreted from the south-west Auckland deposits is almost certain to be incomplete, there are nevertheless certain similarities between apparent time scales and also between patterns of sea-level changes from the two regions. The period from the time of cessation of deposition of the Kaawa Formation until the climax of the Kaihu transgression was one of general submergence in the south-west Auckland coastal region, whereas the post-Kaihu trend has been one of general emergence. Superimposed on this secular apparent sea-level change were oscillations, inferred to be glacio-eustatic, with amplitudes of the order of several hundreds of feet. The Wanganui basin has a similar history of general subsidence continuing into mid-Pleistocene times and this was followed by general emergence, although the magnitude of the secular movements were about four times as great. The patterns of sea-level changes with respect to the two regions are compared in Fig. 9. The point at which regional transgression changed to regression occurred at the end of Castlecliffian times in Wanganui. Although the south-west Auckland terraces can be traced south into north Taranaki, where their altitudes are found to increase steadily (Chappell, 1964), which suggests a possible tectonic linking with the Wanganui area, one cannot straightforwardly correlate the point of reversal of regional movement in south-west Auckland (i.e., the top of the Kaihu Formation) with this Late Castlecliffian event in Wanganui. Such a correlation would imply a Castlecliffian age for the Kaihu Formation—assigned to the Nukumaruan by Kear (1957; 1960)—and a probable Nukumaruan

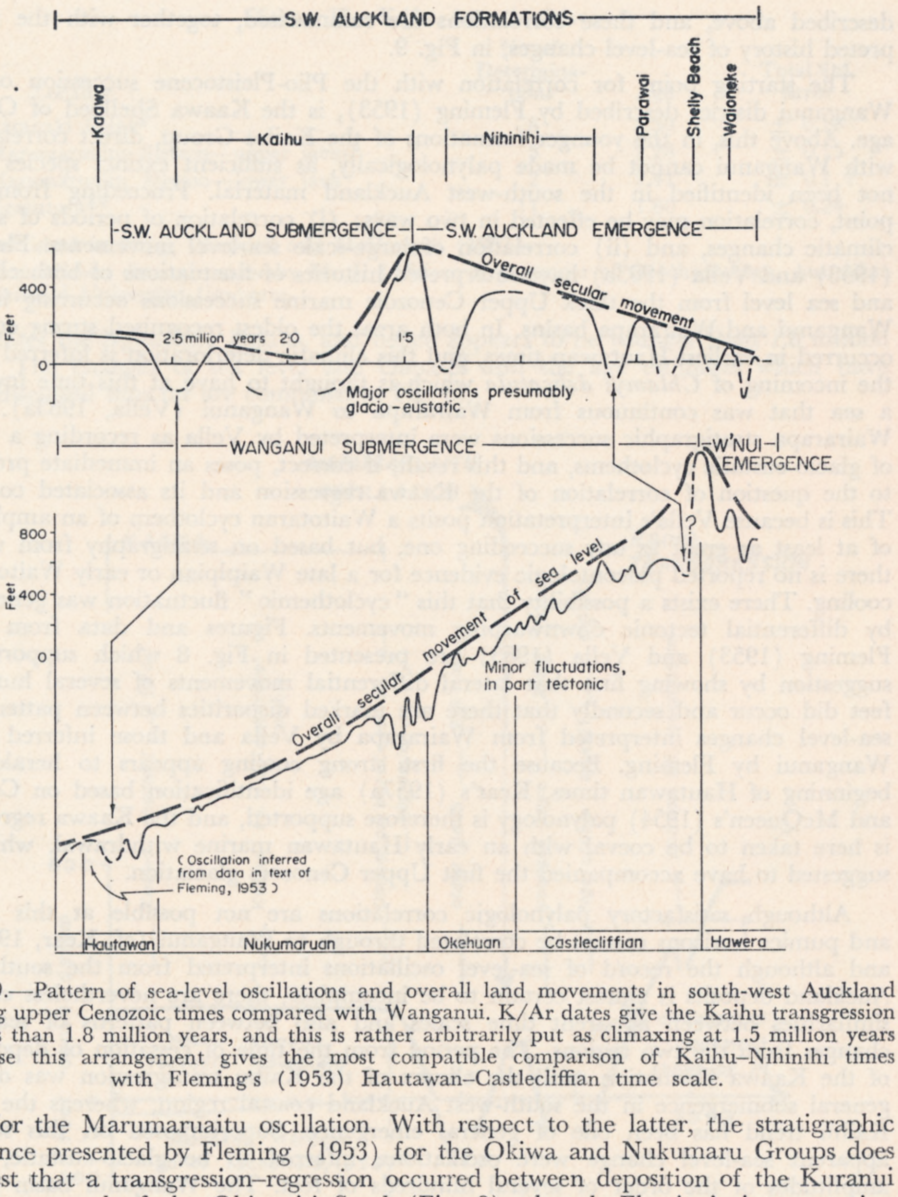

Fig. 9.—Pattern of sea-level oscillations and overall land movements in south-west Auckland during upper Cenozoic times compared with Wanganui. K/Ar dates give the Kaihu transgression as less than 1.8 million years, and this is rather arbitrarily put as climaxing at 1.5 million years because this arrangement gives the most compatible comparison of Kaihu–Nihinihi times with Fleming's (1953) Hautawan–Castlecliffian time scale.

age for the Marumaruaitu oscillation. With respect to the latter, the stratigraphic evidence presented by Fleming (1953) for the Okiwa and Nukumaru Groups does suggest that a transgression–regression occurred between deposition of the Kuranui Limestone and of the Ohingaiti Sand (Fig. 8), though Fleming's interpretation of depth of deposition of the upper Okiwa Group (5–20 fathoms) does not tend to support Vella's (1963) suggestion that the amplitude of the oscillation was as much as 300ft. The paleontology of the beds does not appear to suggest that this is necessarily a glacio-eustatic oscillation. The K/Ar age of the Marumaruaitu oscillation (2.3 m.y.) strongly suggests correlation with this Hautawan-age oscillation of Wanganui, because Mathews and Curtis's (1966) age estimate for a hypersthene andesite pebble collected from somewhere within the lower Nukumaru Group indicates that the Nukumaruan beds are largely younger than 1.85±15 percent m.y. Although Mathews and Curtis's is a single determination from a sample with a high atmospheric argon contamination (94 percent), their age estimate lies in compatible relationship with Fleming's stratigraphic time scale and the absolute dates from south-west Auckland (Figs. 6 and 9). Although a maximum age only is known for the Kaihu Formation (1.8 m.y., from the Kaawa section), the writer supports a Nukumaruan age as there appears to be no record of a large oscillation between Marumaruaitu regression and Kaihu transgression. If correct, this means that the reversal in tectonic movement occurred in south-west Auckland at about the end of Nukumaruan times, and was hence earlier than the post-Castlecliffian tectonic reversal of Wanganui.

The period of change from general subsidence to general emergence is one during which glacio-eustatic oscillations of sea level are most likely to be poorly recorded in a coastal landscape, because any number of interglacial maxima occurring at this time of zero tectonic vector will all achieve similar elevations above any particular datum. A thalassostatic land surface developed during such a period may therefore be a composite form related to an indeterminate number of interglacial maxima. The implication is that unrecognised oscillations may have occurred between the transgressive and regressive successions in south-west Auckland and possibly Wanganui, which dictates that one cannot correlate Nihinihi and younger formations with the post-Nukumaruan sequence of Wanganui by the method of counting oscillatory cycles forward from the Nukumaruan. Assuming, however, that the terraces and associated formations of south-west Auckland are related to glacio-eustatic fluctuations, then correlations with the extensive terrace formations of the Pouakai Group of Wanganui can be made by counting back from the present.

TABLE III.—Correlations.

New Zealand Upper Pleistocene Stages (after Suggate, 1965)		Wanganui Formations (Fleming, 1953)	Terrace altitude in feet (S.W. Auckland)	South-west Auckland and Kaipara
Stages of warming and warmth	Stages of cooling and cold			
Aranuian		Aramoho Un-named Papaiti	7	Post-Waiau (Recent) deposits
	Otiran			
Oturian		Rapanui —and Ngarino cliff	35 70	Waiau B; Waioneke
	Waimean			
				Waiau A; Shelly Beach
Terangian		Brunswick	130	(Kaipara only—South Head Formation—*v.* Brothers, 1954)
	Waimaungan			
Waiwheran		Kaiatea	220	Parawai
	Porikan			
		? upper levels of the Kaiatea; or Castlecliffian?	350	Nihinihi

Table III presents the suggested correlations. The relationship between the Pouakai Group succession and glacial–interglacial periods follows Fleming (1953) and Suggate (1965). The 60ft terrace of south-west Auckland and the equivalent Waioneke Formation described from Kaipara by Brothers (1954), although not so far dated by ^{14}C, is taken to be definitely older than the interstadial transgression which culminated at a general level 30 to 50ft lower than present sea level (Curray, 1961; Cotton, 1962). The Wanganui correlative of the 60ft terrace that invokes the least amount of differential tectonic movement is with terraces of the Rapanui Formation (which is also older than the 30,000-year interstadial, as shown by ^{14}C age for Kaiwhara Alluvium being > 45,000-year [Ferguson and Rafter, 1959], which is considered to be of Last Interglacial age by Fleming [1953]). Although Grant-Taylor (1964) infers a cool fluctuation between formation of the Ngarino cliff and the lower Rapanui cliff (both developed within the Rapanui Formation) these have been grouped together in the Oturi (last) Interglacial by Suggate (1965). The tentative correlation by Brothers (1954) of the Waioneke Formation and its associated 65ft and 35ft terraces with the Monastirian (last) Interglacial of Europe was made from a consideration of world-wide glacio-eustatic changes, and hence the correlation of the 60ft terrace with the Ngarino surface and the 35ft terrace with the Rapanui surface makes for a consistent although somewhat circumstantially-based pattern.

The marine regressions which followed the Parawai and Waiau A (= Shelley Beach Formation of Kaipara) transgressions are of a magnitude which invites correlation with major glacio-eustatic cycles and suggests that these are south-west Auckland equivalents of Kaiatea and Brunswick Formations of Wanganui. Grant-Taylor (1964) indicates that the Kaiatea is divisible into three parts, as is the Albion Formation of Westland, described by Suggate (1965), which can be correlated, in part at least, with the Kaiatea. Of the Albion Formation Suggate writes: "Detailed work is required to establish whether these three distinct levels (of the Albion) relate to a single interglacial period . . .", and it is the uncertainty centring around this part of the New Zealand mid-Pleistocene succession that makes unequivocal correlation of the Nihinihi impossible at this stage.

CONCLUSIONS

Marine deposition commenced in the south-west Auckland coastal region in Opoitian times. During the ensuing period there existed a stable juxtaposition of land and sea until Hautawan time, the onset of which was marked by a strong climatic deterioration and a fall of relative sea level of over 100ft. Basaltic vulcanism broke out at several centres, and in the early stages of the following submergence an oscillation of sea level occurred which had an amplitude of at least 65ft and appears to have been coeval with a similar event in the Hautawan in Wanganui. The coastal region submerged about 600ft during the Nukumaruan, and a consideration of ice volumes suggests that at least 300ft of this movement was not of glacio-eustatic origin, that is to say, total submergence (600ft) = 110ft (the relative sea level in Kaawa—non-glacial—times) + 200ft (the sea level change equivalent to an Antarctic icecap—cf. Donn *et al*, 1962—which is here assumed to have been no larger in pre-Pleistocene times than the present one and may have been smaller) + 300ft, not of glacio-eustatic origin.

Before the subsequent onset of cooler climate in Okehuan times (cf. Fleming, 1953) the Kaihu transgression had ceased, and during the course of the subsequent slow emergence of the south-west Auckland coastal area at least five major oscillations of sea level occurred before the present day. These oscillations, presumed to have been glacio-eustatic events, have their peaks represented in south-west Auckland by terrace surfaces which are thought to be correlatives of upwarped terraces in the Wanganui area.

These correlations have been taken back as far as the Waiwheran Interglacial Stage (as defined by Suggate, 1965) i.e., the Parawai Formation may be suggested to be coeval, in part at least, with the Kaiatea of Wanganui. However, even assuming the younger of the suggested correlations, the compound nature of the Kaiatea (Grant-Taylor, 1964) disallows precise correlation not only of the Parawai but also of the older Nihinihi. The latter cannot with assurance be identified with the Castlecliffian, if for no reason other than the probability that major oscillations went virtually unrecorded in the south-west Auckland region during the tectonic reversal that occurred after the climax of the Kaihu transgression. Only the fact that the Nihinihi terrace is about three times as extensive as lower surfaces suggests that the period of its development may have been longer than those of subsequent similar events, which in turn suggests a Castlecliffian age for the Nihinihi Formation, because such a hypothesis is the most economical way in which the south-west Auckland and Wanganui time scales can be made compatible.

Correlation of the New Zealand Upper Pleistocene glacial succession with the European is still highly problematic, partly owing to disparities in the estimates of relative durations of tentatively correlated stages (Suggate, 1965). Nevertheless, if world correlation of earlier glacial phases is possible at all, it is then reasonable to place the Porika Glaciation of New Zealand as no older than the Günz of Europe (Suggate, 1965). Recent age estimates for the Günz vary according to the estimation method, ranging from 320,000 years (Fairbridge, 1962, using Emiliani's [1955] $^{16}O/^{18}O$ deep-sea core data), through 500,000 years (Cotton, 1963, using Ericson's [1961] paleontologically interpreted deep sea cores), up to 600,000 years (Zeuner, 1959, using Milankovitch's [1930] radiation calculations). This last, 600,000 years, as a maximum age for the Porika puts the Okehuan–Castlecliffian age as only about 15 percent shorter than the Nukumaruan, which is not very different from Fleming's (1953) estimate (Fig. 9).

The degree of completeness of the south-west Auckland stratigraphic record, as reported in this paper, has not been gauged, and correlation schemes other than that adopted are possible. For example, a correlation, based on probable duration of sea-level stillstand, may be made between the Nihinihi terrace and Suggate's longest interglacial—the Waiwhero—which could imply a Castlecliffian age for the bulk of the Kaihu Formation. The salient correlation in the scheme presented is the suggested Kaihu–Nukumaruan equivalence. If this is acceptable, on the grounds expressed above, then the sequence of climatic and sea-level changes set against the time scale described here gives expression to a possible difference of duration of "cycles" in the Lower Pleistocene as against the Upper Pleistocene, of New Zealand.

ACKNOWLEDGMENTS

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I should especially like to thank Mr J. J. Stipp, of the Department of Geochronology, Australian National University, Canberra, for allowing the use of his unpublished age determinations of the Ngatutura basalt.

Appendix

Palynologic determinations from Kaihu Group samples, made by Dr W. F. Harris, N.Z. Geological Survey (*reported in* Chappell, 1964).

	KAAWA	KAIHU 1	KAIHU 2	KAIHU 3	NIHINIHI	RECENT 1	RECENT 2
Lycopods							
Lycopodium sp. *billardieri* type				1			
Ferns							
Gleichenia cunninghamii Heward ex Hook.		2					
Gleichenia sp. *circinata* type				1			
Hymenophyllum sanguinolentum (Forst.t.) SW						1	
Hymenophyllum sp.		1				1	
Total *Cyathea*	13	379	193	694	27	26	12
Phymatodes diversifolium (Wild) pic. ser.		2	3				1
Grammitis sp.		1			2		
Lindsaea trichomanoides Dryand		1					
Paesia scaberula (A. Rich.) Kuhn.		2					
Pteris comans Forst.f.				1	3		
Adiantum cunninghamii Hook.			1				
Unidentified ferns	12	26	26		8	4	2
Polypodiisporites inangahuensis (Coup) Pot.	4						
Conifers							
Podocarpus dacrydioides A. Rich.	2	1	1	1	10	19	4
Podocarpus spp. total	50	13	22	2	46	41	7
Dacrydium cupressinum Lamb	20	19	30	3	12	100	9
Phyllocladus sp.	1	9	11	1	1	11	1
Agathis australis Salisb.						1	
Beeches							
Nothofagus matauraensis Couper		2					
N. menziesii (Hook.f.) Oerst.	6	3	1	22		1	
N. spp. (*fusca* group)	100	18	36	41	6	6	9
Other trees and shrubs							
Pseudowintera sp.				2			
Laurelia novae-zelandiae A. Cunn.				17			
Weinmannia sp.		2					
Araliaceae		1	2			4	1
Knightia excelsa R.Br.		4	2		3	3	2
Melicytus sp.						2	
Aristotalia sp.		1					
Elaeocarpus sp.						2	
Dracophyllum sp.	1					1	
Total *Metrosideras*	5	100	100	1	21	24	100
Total *Leptospermum*	1	17	16			14	1
Eugenia maire A. Cunn.						6	
Corynocarpus laevigata of R. et G. Forst.							3
Myrsine sp.		13	15		4	5	9
Dodonaea viscosa Jacq.	3	4	2		100		3
Coprosma sp.	10	2	3	2	6	46	
Ascarina sp.	5	7	13	100	2		6
Cruciferae						7	1
Myriophyllum sp.					12		
Hydrocotyle novae-zelandiae D.C.						1	
H. sp.				1			
Umbelliferae		1	4				
Compositae		2					
Hebe sp.						19	
Unidentified		8	12	6	5	6	10
Monocotyledons							
Cordyline sp.							2
Astelia nervosa Banks and Sol.						1	
A. sp. (trinerva group)			1				
A. sp.					1		
Sparganium antipodum Graebner						4	
Typha muelleri Rhorb.					1	2	
Phormium sp.							1
Rhopalostylis sapida Wendl. and Drude		2	2	3	5	1	
Restionaceae		1					
Cyperaceae	1	2	2	1	4	2	2
Gramineae			1			3	

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