The Relative Pleistocene Chronology of the South Kaipara District, New Zealand

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Summary

THE coast between Anawhata and Kaipara South Head is formed mainly by sands (wind-bedded and water-laid), pumiceous silts and muds classed as Kaihu Group (? late Pliocene to Pleistocene). Deposition was initiated by a sea-level rise of at least 850 feet about the close of Pliocene time, and continued throughout the Pleistocene during discontinuous retreat of the sea. Four formations are described within Kaihu Group; three were laid down as sands and muds during periods of high sea-levels related to interglacial stages, and the fourth was formed by accumulation of dune sands concurrent with regression of sea-level in an intercalated glacial phase. Each of the subaqueous formations has characteristic high-level surfaces of erosion or deposition so that interglacials and glaciations may be further recognized by alternation of terrace formation and valley-cutting across terraces. Correlations are made with the Pleistocene chronology of Europe.

INTRODUCTION

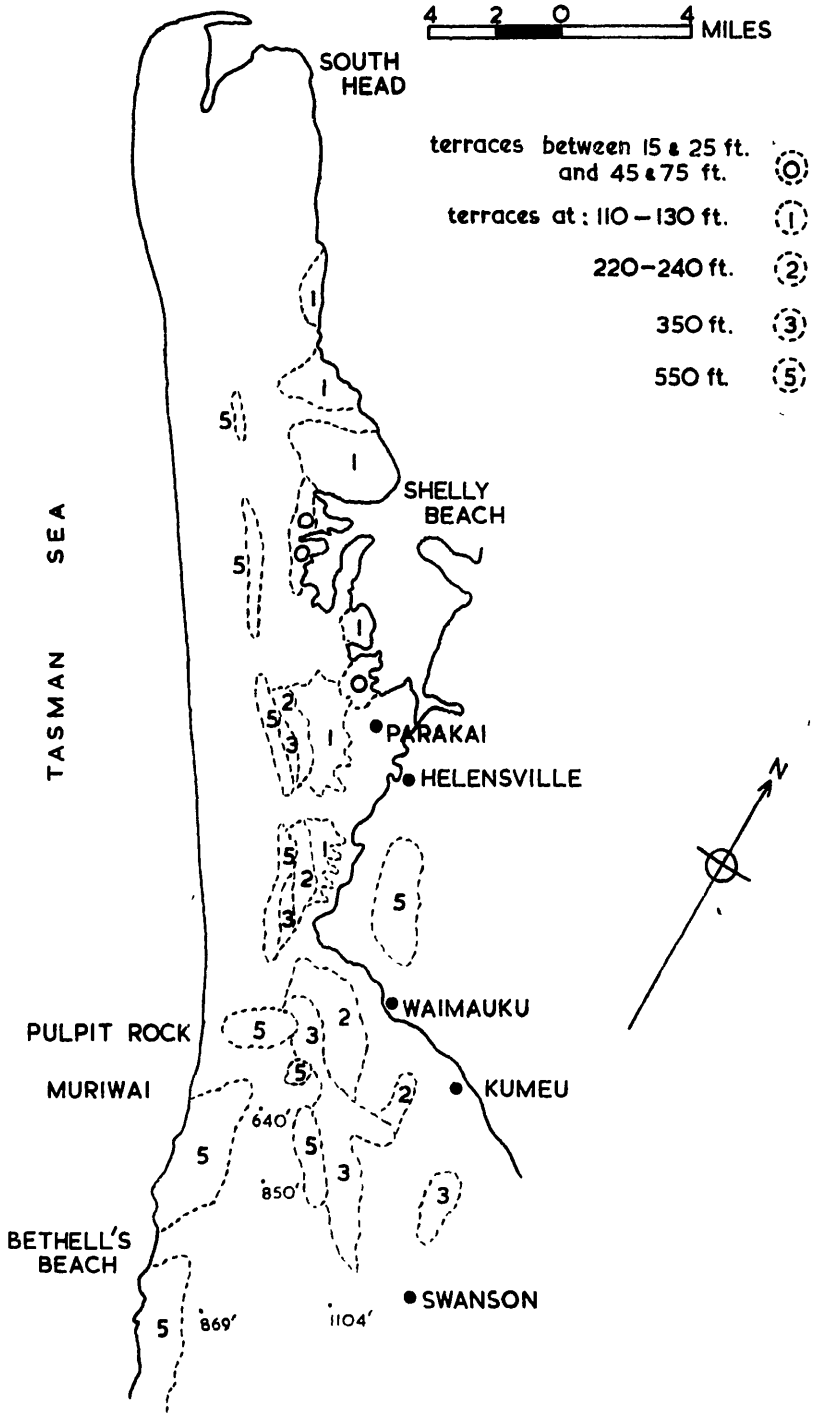
CONSOLIDATED, unfossiliferous, wind-blown and water-laid sands, grey muds and pumiceous silts with bands of lignite form a long coastal strip in the north-western part of Waitemata Survey District, Auckland (Fig. 1). They constitute the long peninsula that runs south from Kaipara South Head (passing below sea-level so that the basement on which they rest is not visible) and extend to south of Muriwai, where they underlie a well-defined high-level plateau and cover volcanic beds of the Manukau Breccia (lower Miocene).

Dieffenbach (1843) noted the same beds near Dargaville, and Hochstetter (1867) described similar sands and silts from the southern shores of Manukau Harbour as his Lignite Formation. Cox (1881) outlined the distribution of these younger beds and named them "consolidated sands with lignite." For the Dargaville-Rodney area Ferrar (1934) grouped these beds as the Kaihu Sands. Similar Pleistocene beds have been recorded by Searle (1944) on the northern shores of Manukau Harbour and by Gilbert (1921) on the peninsula which terminates at Manukau South Head.

The writer believes that their deposition at first took place under marine conditions but later was largely estuarine and that it began with a major rise of sea-level in the late Pliocene and was terminated by Flandrian transgression at the close of Pleistocene time. As in other parts of the world there was continuous regression of sea-level throughout the Pleistocene and in the South Kaipara district withdrawal took place from a position 550 feet higher than at present. The oscillatory effects of glacial eustasy varied the general theme of regression, and the resulting fluctuations of sea-level were reflected in the sediments of Kaihu Group by deposition of the three younger formations which are separated by erosion intervals.

FIGURE 1a

SKETCH MAP OF TERRACE DISTRIBUTION



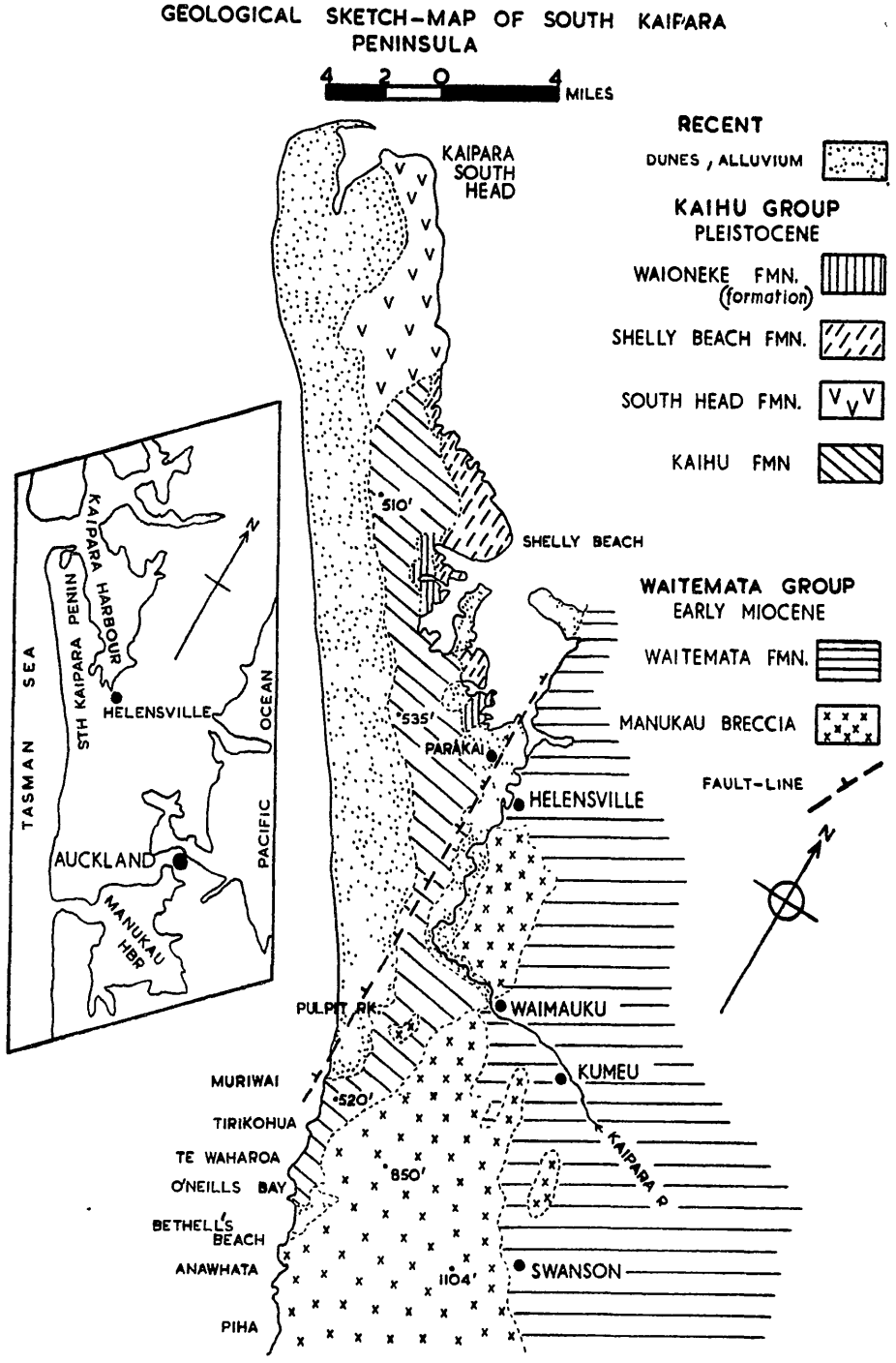

GEOLOGICAL SKETCH-MAP OF SOUTH KAIPARA PENINSULA
4 2 0 4 MILES
RECENT
DUNES, ALLUVIUM
KAIHU GROUP
PLEISTOCENE
WAIONEKE FMN. (formation)
SHELLY BEACH FMN.
SOUTH HEAD FMN.
KAIHU FMN
WAITEMATA GROUP
EARLY MIOCENE
WAITEMATA FMN.
MANUKAU BRECCIA
FAULT-LINE
KAIPARA SOUTH HEAD
510'
SHELLY BEACH
535'
PARAKAI
HELENSVILLE
PULPIT PK
WAIMAUKU
KUMEU
KAIPARA R.
520'
850'
1104'
SWANSON
MURIWAI
TIRIKOHUA
TE WAHAROA
O'NEILLS BAY
BETHELLS BEACH
ANAWHATA
PIHA
TASMAN SEA
STH KAIPARA PENIN
KAIPARA HARBOUR
HELENSVILLE
OCEAN
AUCKLAND
PACIFIC
MANUKAU HBR

FIG. 1.

Terrace Nomenclature.

In the development of the relative chronology presented in this paper it has been necessary to use terraces cut on the Kaihu sediments as markers in a succession of Pleistocene sea-level movements. A sketch map showing the distribution of the terraces is given in Fig. 1a. Where a terrace is characterized by a single height—e.g., the 550ft. terrace, a dissected plateau type of surface exists in the field with usually no recognizable slope towards either the Tasman Sea or Kaipara Harbour. Such a condition is found in the higher terraces at 550ft. and 350ft. above modern sea-level. During the evolution of the present topography these high-level terraces have been partially destroyed and are now represented mainly by accordant flat-topped spurs and ridges distributed over wide areas.

A range of heights—e.g., 220–240ft. and 110–130ft., indicates that the terrace concerned slopes from a recognized upper limit, usually against a higher feature on the original landward margin, to a lower limit on the seaward side. On South Kaipara Peninsula these terraces all slope towards Kaipara Harbour.

Flights of small terraces rarely more than 300 yards long are present on valley walls on the eastern side of South Kaipara Peninsula and lie between the heights 15ft. to 25ft. and 45ft to 75ft. These heights do *not* represent the seaward slope of this particular group of terraces; rather, they indicate the range of heights within which a number of flat surfaces are located.

The higher terraces at 550ft., 350ft., and 220–240ft. have a composite origin. In the southern part of Kaipara district these surfaces have been eroded in the lower Miocene Manukau Breccia and Waitemata sandstones; nearer to South Kaipara Peninsula they are surfaces of deposition underlain by material derived locally from Tertiary rocks and detritus brought into the area from further south by coastal currents. The lower terraces at 110–130ft., and between 15ft. to 25ft. and 45ft. to 75ft., are entirely built surfaces in the South Kaipara district where they are underlain by estuarine beds and correspond in type with Zeuner's (1950) thalassostatic terraces. Further south, near Auckland, surfaces of erosion at these lower levels are cut on Tertiary sedimentary rocks.

Stratigraphic Terminology.

The stratigraphy of the Pliocene-Pleistocene beds in North Auckland has never been clearly defined, mainly due to a lack of fossils above the Opoitian (upper Pliocene) horizon. In order to apply the geologic time scale to the relative chronology determined by sea-level movements arbitrary limits have been placed upon the terms Pliocene and Pleistocene in the Auckland area.

The Opoitian beds at Otahuhu (Marwick, 1948), 10 miles south of Auckland city, are the only fossiliferous Pliocene deposits near to the South Kaipara district. The beds are not deformed, probably post-date the block faulting of the North Auckland area, and are located some 50ft. to 70ft. below modern sea-level; there is an upwards transition into conformable unfossiliferous pumiceous sediments similar to those forming the bulk of Kaihu Group. Although the evidence is insufficient, the tentative conclusion is drawn that the same stratigraphic condition exists in the South Kaipara district—i.e, the basal sediments of Kaihu Group at some distance below sea-level may rest on Pliocene beds and may in part themselves be of late Pliocene age. The general absence of marine Pliocene beds above sea-level on North Auckland Peninsula (Brothers, 1954a)

suggests that extrapolation of the Otahuhu succession to the Kaipara district may not be as speculative as it appears.* Reference to a possible Pliocene age for the basal beds of Kaihu Group or for sea-level movements is therefore made only on the tentative basis of the assumption outlined above. The rise of sea-level responsible for the deposition of Kaihu Formation, the oldest formation of Kaihu Group, at a maximum height about 600ft. above the position of the Otahuhu Pliocene beds may therefore be regarded as a continuance of late Pliocene transgression (Fig. 5). This is an extremely speculative suggestion which probably is an over-simplification of the true sequence of events; but it will serve as an hypothesis in the absence of any further information concerning this part of the Pliocene-Pleistocene history of the North Auckland area. Nevertheless, in this paper the development of the 550ft. surface of erosion and deposition is taken as Pleistocene in age.

The division of Pleistocene time into Early, Middle and Late has been carried out according to the thickness, areal extent and nature of the various formations within Kaihu Group. The basis for subdivision in this manner is fundamentally unsound since it presupposes uniform rates of sea-level rise and fall, an unvaried climate, and a constant tempo of erosion. However, the periods of time allotted to the various formations must be broadly correct.

The end of Pleistocene time is taken at the commencement of Flandrian transgression (Fig. 5); i.e., at the end of the last glacial phase when return of melt water to the ocean caused a final submergence of the North Auckland area and formed the present highly embayed coastline. The term " Flandrian " has been used by Zeuner (1950, p. 128) and Cotton (1951) in the same manner. Under this scheme all post-Flandrian events are equivalent, so that " Recent " is synonymous with " post-glacial ".

STRATIGRAPHY

The chronological order and the general characteristics of the four formations within Kaihu Group are shown in Fig. 5 and in the following table:

(1) *Kaihu Formation* (? late Pliocene to early Pleistocene): Horizontally bedded or massive coarse sandstones, pumice silts and variegated muds with local dune sand members. Terraces are present at 550ft., 350ft., and 220ft to 240ft. above modern sea-level

(2) *South Head Formation* (mid-Pleistocene): Dark brown wind-blown sands with original dune forms still preserved.

(3) *Shelly Beach Formation* (mid-Pleistocene): Horizontally bedded, fine-grained pumiceous sandstones, pumice silts and muds with lignites. These beds cover low-lying dunes of South Head Formation and underlie a terrace at 110ft. to 130ft above modern sea-level.

(4) *Waioneke Formation* (late Pleistocene): Mainly highly pumiceous silts with local sandy facies, usually not bedded. The silts occur as infill remnants on the sides of valleys cut across Shelly Beach and South Head Formations; terraces underlain by Waioneke Formation typically lie between 15ft to 25ft and 45ft. to 75ft. above modern sea-level.

(1) *Kaihu Formation* (? late Pliocene to early Pleistocene).

Since they were deposited during a major rise of sea-level believed to have occurred about the close of Pliocene time, beds of this formation have the

* See also: D. A Brown, " Polyzoa from a Submerged Limestone off the Three Kings Islands, New Zealand " *Annals & Mag Nat Hist*, (12) 7, 415–437, 1954.

greatest area and thickness of any of the formations in Kaihu Group (Fig. 1). South of Muriwai Kaihu Formation overlies the Miocene pyroclastics of the Manukau Breccia, but to the north it extends below sea-level and forms the greater part of South Kaipara Peninsula.

Between Bethell's Beach and Pulpit Rock (2½ miles north of Muriwai) sands and silts form a plateau which averages 550ft. in elevation and locally rises to as much as 690ft. where dune sands have been developed at the top of the succession. Fairly coarse grey sandstones at 250ft. above sea-level on a ridge north of Anawhata Beach, and silts and sandstones at the south end of Bethell's Beach are remnants of the southerly continuation of this plateau North of Bethell's Beach the flat surface is well preserved and is half a mile wide, widening to 1½ miles near Muriwai.

One of the best exposures of the basal contact of Kaihu Formation is located in the northern corner of the first bay south of Bethell's Beach where highly weathered, marine Tertiary tuffs are unconformably overlain at 130ft. above sea-level by a succession of sands, silts and muds (Fig. 2). A similar sequence is well displayed at Erangi Point, between Bethell's Beach and O'Neill's Bay, but at higher levels wind-bedded brown sands of varying thickness appear and are covered by variegated muds or lenses of pumiceous silt. Taylor (1927) recorded a small pocket of pumice silts and peaty material at 200ft. above sea-level in the upper reaches of Waiti Stream, a tributary of Waitakere River, and about two and a half miles inland from Bethell's Beach. The writer failed to locate this outcrop, but volcanic tuffs which Taylor reported as resting on top of the silt may actually be consolidated brown sands of Kaihu Formation. On Te Waharoa and Tirikohua headlands the vertical successions from the basal contact for 300ft. up to mudstones underlying the plateau surface are well exposed. Half a mile east of the coastline the plateau rises gently to 690ft. and is underlain by beds of dune sand. The plateau surface is normally underlain, however, by water-laid deposits visible in two good exposures. At one of these, a quarter of a mile east of the junction of Taiapa and Oaia Roads, eroded tuffs of the Manukau Breccia are overlain at 490ft. above sea-level by a thin band of mudstone. The mudstone merges upwards into 2ft. of coarse black sand capped by current-bedded sandstone which becomes increasingly finer in texture towards the plateau surface at 520ft. The other exposure is on the side of the most northerly obvious remnant of the plateau where a perfectly flat surface is preserved on the ridge between Paekawau Lake and Pulpit Rock, two and a half miles north of Muriwai. Here the closing sequence, above a basal contact at 280ft. above sea-level, is from current-bedded yellow sandstone to white pumice silt in a 6ft. band at 530ft.

Inland from the Muriwai-Anawhata coastline, and on the eastern side of Waitakere Hills, remnants of terraces at levels lower than 550ft. are widely distributed at heights of 350ft. and 220ft. to 240ft. Between Waimauku and Swanson these surfaces are not generally underlain by sediments of Kaihu Formation except west of Waimauku, where the 220ft. to 240ft. level overlies water-laid sands and silts 154ft. thick thinning out westwards towards a ridge of Manukau Breccia near Taiapa Road. The distribution of these Pleistocene surfaces of erosion and of deposition suggests a paleogeographical picture in which the Waitakere Hills formed an elevated resistant mass in an area to the south of a line joining Bethell's Beach and Kumeu. The existence of this highland is indicated

by the absence of Kaihu Formation on high terraces of marine erosion at 550ft, 350ft., and 220ft. to 240ft., and by the increasing irregularity of the basal contact of Kaihu Formation with the Manukau Breccia as a traverse is made south along the coastline from Muriwai to Bethell's Beach. North of the Bethell's-Kumeu line Kaihu Formation increases in thickness, underlies the same high surfaces, and for 4 miles south of Muriwai maintains a very regular basal contact.

West of Kaipara River and north-west of Pulpit Rock and Waimauku to near Kaipara South Head, Kaihu Formation passes below sea-level and in no place is seen to rest on older rocks such as Manukau Breccia. It seems most likely that a meridional fault was responsible for the termination of the Miocene volcanic rocks at Pulpit Rock. This is indicated by the abrupt cessation of tuffaceous Miocene sandstones along a line joining Pulpit Rock and Parakai Springs; east of this line these sandstones form a floor to Kaipara Valley at depths averaging 80ft. below sea-level, but to the west bore logs do not record them at depths up to 300 feet. A magnetic survey at Parakai by Jones (1939, p. 85 B) gave " no reason to deduce a basic dyke or flow close to the surface . . . such as gives rise to thermal springs in many cases " and thus supports the suggested location of the fault-line. There must, however, have been erosion and retreat of the fault-

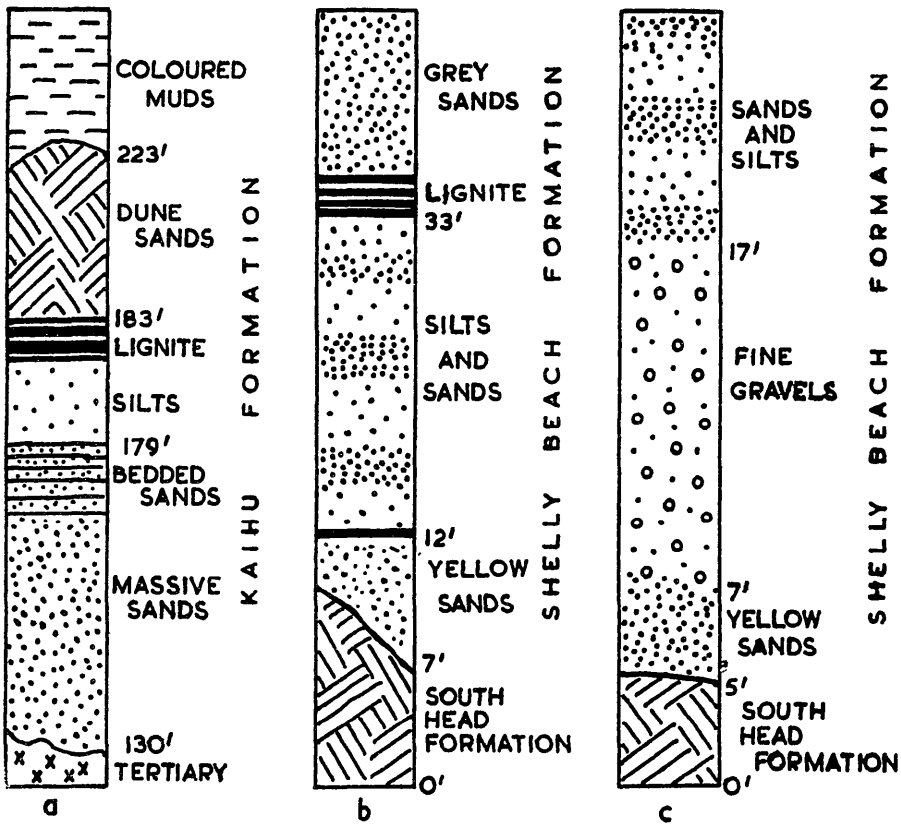


FIG. 2.—Stratigraphic columns of Kaihu Group: (a) at the northern corner of the first bay south of Bethell's Beach; (b) and (c) south of Shelly Beach wharf. Heights shown are measured above modern mean sea-level.

line scarp for steep bluffs of Tertiary rocks lie in a north-south line two miles to the east along the side of Kaipara Valley and continue for some miles north of Helensville. Penecontemporaneous subaerial erosion reduced the north end of the present Waitakere Hills by some 500 feet.

The absence of hard basement rocks below Kaihu Formation on South Kaipara Peninsula has tended to accelerate destruction of the narrow belt of higher terrace features that are continuous with those already described near Muriwai and Waimauku. Nevertheless, visual observations and statistical topographic analyses using the methods of Baulig (1935) have confirmed the presence of surfaces at 350ft. and 220ft. to 240ft. immediately west of the fault-line—i.e., west and south-west of Parakai. The inferred position of the 550ft. level would thus fall on the dissected but remarkably even crestline of South Kaipara Peninsula as far north as Shelly Beach. The period of fault-line development and immediately subsequent erosion therefore antedated the 550ft. sea-level and was at least pre-Pleistocene in age. The surfaces carried by Kaihu Formation may therefore be safely used for discussion of sea-level movements without complication by post-Tertiary differential warpings.

In the area between Pulpit Rock and Shelly Beach, Kaihu Formation is composed of light-coloured water-laid pumiceous sandstones, siltstones and pumiceous muds similar to those already described from south of Muriwai The freshest outcrops are in cuttings made for roads that follow the flat-topped spurs west of Helensville and on the crest of the peninsula where wind-scour has excavated many hollows and removed part of the Recent dune sand cover.

(2) *South Head Formation* (mid-Pleistocene)

South Head Formation is formed by dark brown or reddish brown consolidated dune sands with large-scale wind-bedding. The sands are coarse in texture and poorly compacted, and leaching by groundwater has produced many limonite pans characteristic of this formation, especially near the shoreline. The dunes outcrop over an area of only 12 to 15 square miles at Kaipara South Head; along their southern margin they overlie Kaihu Formation, but for the main part they pass below sea-level.

In aerial photographs (Fig. 3) the outlines of Pleistocene dunes can be easily identified and show them to be large, irregular, lobate transverse dunes aligned with respect to a south-west wind and similar to modern dunes behind Muriwai beach. An interesting feature is that the transition from the subaqueous beds of Kaihu Formation to the South Head dunes is marked in the field not only by a change from red- and yellow-stained sediments to dark brown sands, but also by a change from scrub-covered wastelands to fertile farm pastures This contrast in soil fertility is attributed to mineralogical differences between the water-laid and the wind-blown materials; that is, in the latter there is a much higher content of ferromagnesian minerals.

A most important point is that the crests of some of these fossil dunes are less than 200ft. in height, and therefore they post-date the high-level erosion-surfaces at 550ft., 350ft. and 220ft to 240ft. that cut across Kaihu Formation. However, the dunes have been cut across by a terrace at the lower level of 110ft to 130ft. This demonstrates that the ocean regressed below present sea-level after cutting the 220ft. to 240ft. level on Kaihu Formation, allowing a dune area to develop north of the distal end of a spit which joined the mainland at Pulpit

Rock. The spit, or embryo South Kaipara Peninsula, was composed of sands and muds of Kaihu Formation which carried the 550ft. terrace in addition to surfaces at 350ft. and 220ft. to 240ft. both north and south of Muriwai.

The relationship between the two formations is even more clearly shown at Kaipara North Head where, on the eastern side, the dunes fill old valleys carved in Kaihu Formation and cut below modern sea-level across the 220ft. to 240ft. erosion surface. Thus, in the cliff sections, the brown dune sands of South Head Formation are seen side by side with the older, lighter-coloured subaqueous beds.

(3) *Shelly Beach Formation* (mid-Pleistocene).

Horizontally-bedded pumiceous sands, silts and muds with thin lignite bands cover low-lying dunes of South Head Formation on the eastern side of the peninsula. These estuarine sediments are best exposed in cliffs at the holiday resort called Shelly Beach, but members of the same formation extend southwards to Helensville and for some distance along the western side of Kaipara Valley. The formation characteristically underlies a terrace ranging from 110ft. to 130ft. above modern sea-level.

By its stratigraphic position Shelly Beach Formation shows that after the period of subaerial sedimentation, during which the South Head dune mass was built, a rise of the ocean reached a maximum at 130ft. above its present height. Marginal dunes of South Head Formation were buried beneath fine-grained sands and muds that floored a terrace now exposed between the heights 110ft. and 130ft. The terrace may be traced as a plane of erosion on Tertiary sandstones south of Waimauku, but between Waimauku and Shelly Beach surfaces of erosion or deposition at this level indicate no more than probable continued retreat of the sea from the earliest-formed 550ft. plateau borne by Kaihu Formation. Only at Shelly Beach and northwards, where the drowned subaerial members of South Head Formation are exposed, can an oscillation of sea-level be verified. Cliff sections for 600 yards south of Shelly Beach wharf show the eroded sand dunes overlain by sands and silts with intercalated lenses of unsorted gravels containing sandstone pebbles derived from both Kaihu and South Head Formations (Fig. 2).

(4) *Waioneke Formation* (late Pleistocene).

Distinctive grey-white silts and muds, with notably higher pumice content than other sediments in Kaihu Group, are plastered on the sides of wide steep-walled valleys or embayments cut across the 110ft. to 130ft. level of Shelly Beach Formation. In some places the silts abut against the dark brown subaerial beds of South Head Formation previously drowned (Fig. 4d). Sandy facies are locally dominant, and lignites have limited occurrence as, for example, in a thin lense at the end of the peninsula north of Shelly Beach.

Within the valleys two groups of narrow terraces are present on the silts, with individual terraces rarely more than 300 yards long lying at heights between 15ft. to 25ft. and 45ft. to 75ft. above modern sea-level. Waioneke Formation must have been deposited as complete valley infillings by estuarine sediments up to the 75ft. level by an advance of the ocean, but the greater part of the silts was eroded by cutting of the subsequent lower erosion surfaces during the pre-Flandrian regression. Remnants of the higher terraces are preserved on the sides of drowned valleys at Waioneke School and one mile south of the intersection of Shelly Beach Road and South Head Road.

The Geological History of Kaihu Group

The history closely follows the sequence of events inferred by Turner and Bartrum (1929) for the Takapuna-Silverdale area on the Auckland east coast, so the table produced by these authors (pp. 892–3) is reproduced here alongside a summary of events in the South Kaipara district.

Takapuna-Silverdale Area:	*South Kaipara District:*
(1) Main uplift of the Kaikoura orogeny.	(1) Ditto; dated as early to mid-Miocene (a) Submergence of at least 850ft., allowing deposition of *Kaihu Formation.*
(2) Peneplanation.	(2) Ditto; represented by the 550ft. surface of erosion and deposition.
(3) Uplift, varied by at least one minor oscillatory movement in the reverse direction, and punctuated by periods of approximately constant sea-level which are represented by:	(3) Ditto; regression of the ocean was interrupted by two, and possibly three minor transgressions.
(a) "350ft." erosion surface.	(a) 350ft. surface of erosion (a_1) 220ft. to 240ft. surface of erosion (a_2) Accumulation of the dunes of *South Head Formation* during continued regression of the ocean beyond its present level.
(b) "100ft. to 120ft." erosion surface.	(b) 110ft. to 130ft. surface of erosion and deposition. Regression was interrupted by a positive movement of sea-level; this reached a maximum of 130ft. above modern sea-level and allowed the deposition of *Shelly Beach Formation.*
(c) "40ft. to 60ft." erosion surface. A slight negative movement of the strand immediately preceded this standstill.	(c) 45ft. to 75ft. surfaces of erosion or deposition. Regression followed stage (3b) and was again interrupted by transgression which reached a maximum of 75ft above modern sea-level and allowed the deposition of *Waioneke Formation.* Subsequent discontinuous retreat of the sea carved terraces on this formation at heights between 45ft to 75ft. and at the
(d) 20ft. to (?)-10ft. erosion surfaces	(d) 15ft. to 25ft. erosion surfaces.
(4) Acute elevation represented by trenches now drowned.	(4) Ditto; regression of the ocean con-continued to at least 190ft. below modern sea-level.
(5) Submergence followed by small sub-Recent uplift.	(5) Ditto; Flandrian transgression marking the end of the Pleistocene. The final minor retreat of the ocean (8ft to 12ft.) was post-Flandrian in age.

The movements of sea-level involved in the chronology of Kaihu Group are shown graphically in Fig. 5, where European correlatives, discussed later, have also been inserted.

At the end of the Tertiary era the mainland in the South Kaipara region was formed by a block of hills at least 1,000ft. in height carved in lower Miocene sandstones and pyroclastics of Waitemata Group. The elevation of these rocks is attributed to the northern equivalent of Kaikoura uplift, dated as early to mid-Miocene,

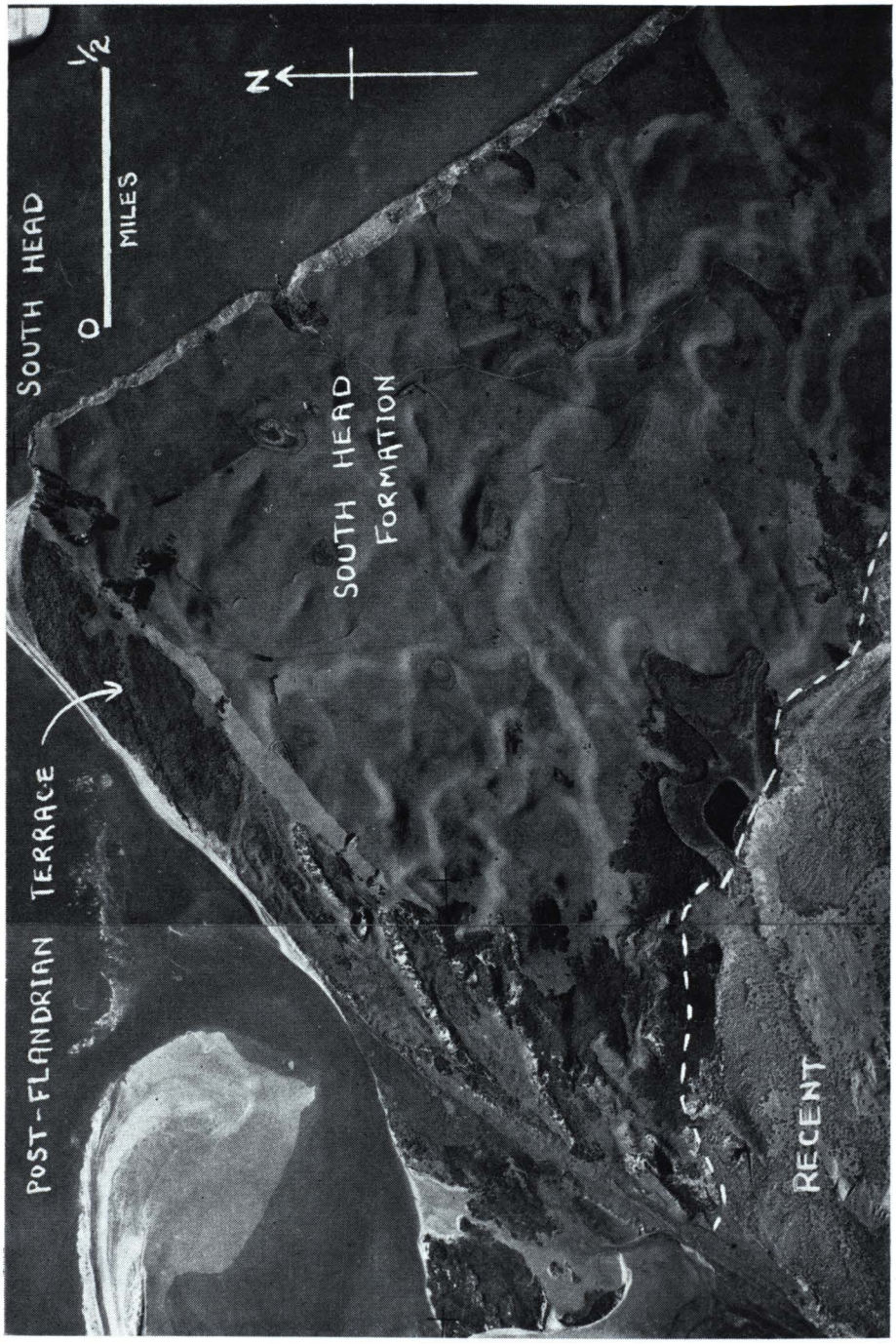


FIG. 3.—Aerial photograph of fossil dunes, forming South Head Formation, at Kaipara South Head. Exhumed traces of the dunes are seen in plan on the post-Flandrian 8ft. terrace which lies in front of the abandoned sea cliff running south-west from South Head. The dunes have the general transverse and lobate pattern that is produced at right angles to a formative wind. Here, the effective Pleistocene wind direction has been from the south-west—i.e., parallel to the present prevailing wind on this coast. Recent wind-blown sand, mainly planted with grasses, occupies the lower left portion of the photograph below the white dashed line. The hook at the end of the South Head sandspit appears in the upper left corner.

About the close of Pliocene time a positive movement of sea-level commenced and both north and south of Muriwai pumiceous muds and sands were deposited as the basal sediments of Kaihu Formation. The composition of the sands, fresh feldspar with quartz and pumice, points to a main source in the rhyolites of the central volcanic plateau of the North Island. South of Muriwai these sediments were gradually spread over an irregular basement of Manukau Breccia, but north of Pulpit Rock deeper water existed in the tectonically-formed Kaipara embayment and an embryo South Kaipara peninsula was soon built out. The rise of sea-level was not rapid, for locally, consolidated dune sands rest on top of the silts and muds at the base of the succession south of Muriwai. Silt layers at higher levels possibly represent lake beds which formed in interdune hollows, although the sea eventually reached and maintained for a considerable time a level at least 550ft. above its present level. This long still stand of sea-level allowed deposition of muds and silts that form the surface of the present 550ft. plateau between Bethell's Beach and Shelly Beach. South of Anawhata concurrent normal erosion of the Tertiary volcanic rocks carved at the same height a flat erosion surface, rarely more than one mile in width, which is preserved on stream interfluves and rises gently inland. During this still stand also, local sand dunes added another 100ft. or more of cross-bedded sandstone to the surface of the plateau of deposition which rises to a maximum height of 690ft. south-east of Muriwai. Although the beginning of this important rise of the sea has been dated as late Pliocene (Fig. 5) it must be emphasised that no shelly beds have been found beneath the 550ft. surface and therefore no certain age can be assigned to Kaihu Formation. Nevertheless, the occurrence of Pliocene fossils 50ft. to 70ft. below sea-level near Otahuhu, 10 miles south of Auckland city, suggests that transgression commenced in the Opoitian and continued through to the early Pleistocene. Marwick (1948) pointed out that unfossiliferous sediments conformably overlying the shell beds at Otahuhu may be basal members of a younger formation.

Recession of ocean-level followed the development of the 550ft. plateau and was punctuated by periods of constant sea-level during which erosion surfaces were carved at 350ft. and 220ft. to 240ft. on both Kaihu Formation and Tertiary volcanics and sandstones. It was during this period of regression that subaerial sedimentation became important, but it was not until the sea had withdrawn beyond the 220ft. to 240ft. mark to a position well below modern sea-level that the dune mass of South Head Formation was formed. The dunes were added to the distal end of the spit that extended north from Pulpit Rock and was built mainly of subaqueous materials belonging to Kaihu Formation. When the sea had withdrawn from the 550ft. level and cut terraces on the underlying sediments at 350ft. and 220ft. to 240ft., South Kaipara Peninsula was in existence in roughly its modern form. The abundance of rhyolitic debris in Kaihu Formation and the outlines of the fossil dunes of South Head Formation show that the peninsula was controlled in its growth by the same combination of south-west wind and long shore drift to the north that operates at present.

After the sea had retreated to a position well below modern sea-level and the dune sands of South Head Formation had accumulated, there was a change in the direction of movement of the strandline and the general theme of regression was interrupted by a minor transgression. This advance of the sea reached a maximum position 130ft. above its present level. The estuarine sediments of Shelly

Beach Formation infilled the southern reaches of Kaipara Harbour and at the northern end of the peninsula were spread over low-lying dunes of the South Head Formation. As well as receiving sand over-carried from the dunes to the west, the new South Kaipara estuary was built up to the 130ft. level by debris which in general was finer-grained and more pumiceous than the materials of preceding formations. Searle (1944) recorded similar pumice silts at heights about 120ft. near Blockhouse Bay at Manukau Harbour.

When the main trend of regression was resumed, deposition of Shelly Beach Formation ceased; the 110ft. to 130ft. terrace and the sediments below it were exposed to erosion as the sea retreated once more to below modern sea-level. Base-level must have been considerably lowered over a long period for wide valleys were carved across the 110ft to 130ft. surface, producing terrace remnants separated by deep embayments.

A second transgression of the sea allowed the embayments in Shelly Beach Formation to be filled to a maximum height of 75ft. above present sea-level by the highly pumiceous estuarine silts of Waioneke Formation (Fig. 4). During subsequent discontinuous retreat, the sea carved terraces on this formation at levels grouped between 45ft. and 75ft. and between 15ft. and 25ft. This was the last major regression of the strand-line, and it reached a minimum below modern datum of 190ft., a figure taken from bore records in Waitemata Harbour.

The final transgression (Flandrian) then drowned the valleys of Kaipara River and other streams entering Kaipara Harbour, while the western side of South Kaipara Peninsula was cut back to form a line of cliffs now partially masked by Recent dune sands (Brothers, 1954b). Recent retreat of the sea from the post-glacial maximum level was responsible for beaches and benches 8ft. to 12ft. above modern mean sea-level and commonly filling bay-heads. A most striking example is the wide plain, only a few feet above sea-level, which lies in front of steep cliffs near Kaipara South Head (Fig. 3).

Rhyolitic debris from the central volcanic plateau, brought to the west coast by Waikato River and swept northwards by longshore currents, has formed the greater part of the sediments in Kaihu Group. In addition, there is evidence to suggest that a mantle of pumice from the same source was spread subaerially over the South Kaipara region. A bed of pumice tuff, with typical vitroclastic texture in thin-section, has been found at the top of sea-cliffs half a mile south of Bethell's Beach. Lyons (1932) noted subaerial pumice deposits in the Mangatawhiri-Mangatangi district, west of the Firth of Thames, and Healy (1935) suggested that pumice silts of Pleistocene age in the Hunua area were residues of earlier extensive eruptive showers. Wong (1946) recorded a pocket of rhyolitic pumice on the flanks of Mt. Albert, a basaltic debris cone at Auckland. These pumice showers seem to have spread as far north as the Kaipara district.

Correlation With the Pleistocene Chronology of Europe

That the North Auckland Peninsula is non-seismic and apparently quite stable has been commented upon by several writers (e.g., Cotton, 1951; Gage, 1953); the area has been free from differential warping movements during Pleistocene time when sea-level oscillations were taking place. Recognition of these fluctuations of sea-level as glacio-eustatic phenomena is supported by the absence of tilt on either the earliest and youngest terraces or their underlying beds, despite

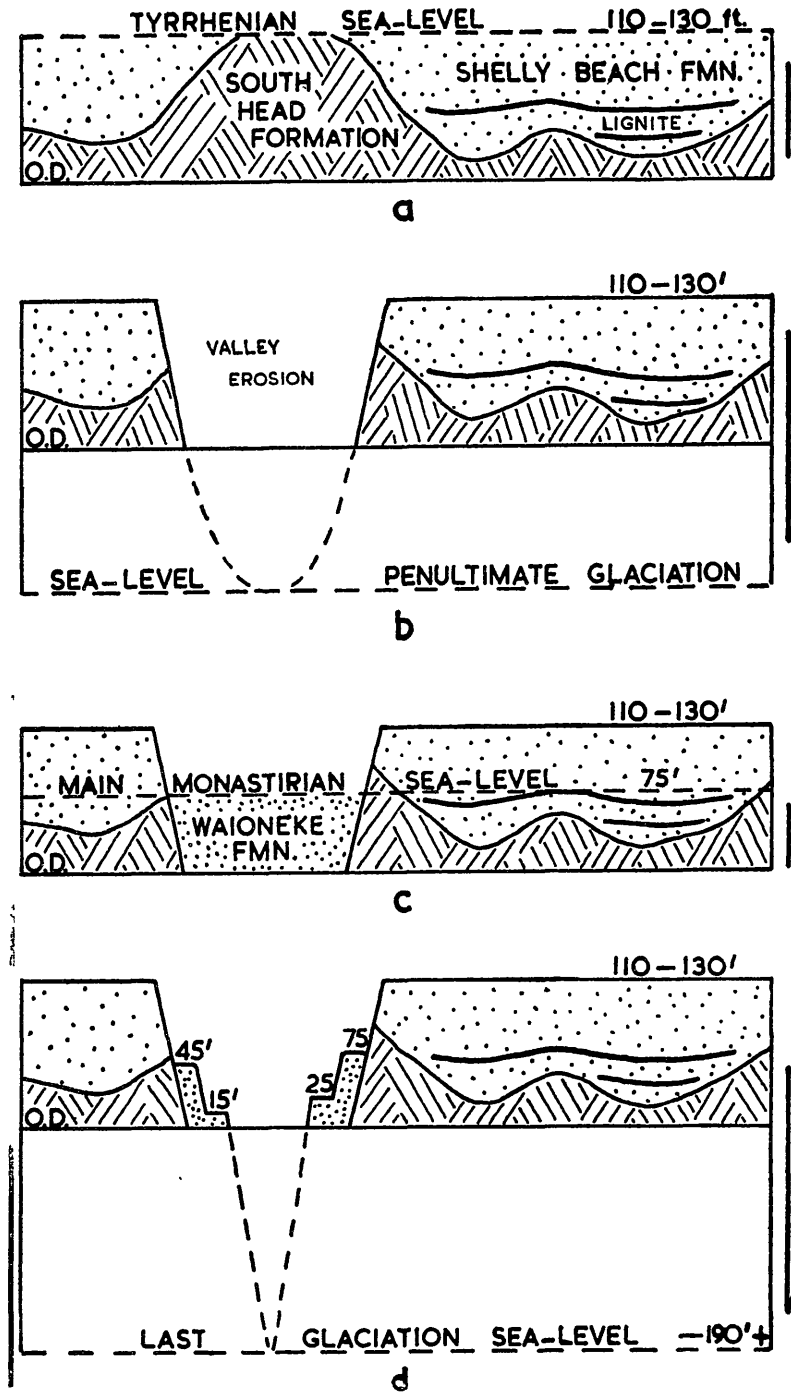


FIG. 4.—Diagrammatic representation of the four sea-level movements in the Shelly Beach-South Head area, prior to Flandrian transgression.

the fact that their origins lie within three periods of rise and fall covering a total vertical distance of at least 1,600ft. Succession of interglacial and glacial periods, as evidenced by the geological processes of deposition and destruction of deposits, has been demonstrated on South Kaipara Peninsula by the alternating events of terrace formation and erosion of valleys across terraces. The oscillations of sea-level have been complementary, the graph (Fig. 5) showing three maxima which may be correlated with interglacial periods. The various surfaces recorded here, with heights between 11ft. and 550ft., have wide areal distribution throughout North Auckland and a complete succession has been recognized as far north as Doubtless Bay (McDonald, 1951).

Correlation with the relative Pleistocene chronology of Europe seems to be substantiated in two ways. Low curves on the graph, representing regressive sea-levels, indicate glaciations which are identified by working backwards from the Flandrian transgression. Between these recessions the graph shows the positions of high-level terraces formed by return of water to the ocean during warmer interglacial periods. The heights of these terraces, and their particular locations between glaciations, may be correlated directly with the sequence of high sea-levels in Europe and America given by Zeuner (1950, p. 128). To this list have been added glaciations for comparison with data from South Kaipara Peninsula:

Glaciations	*High Sea-levels*	*Average Height*	*Kaipara*
	Sicilian	100 metres	350 ft. (107 m.)
Early Glaciation:			
Antepenultimate Interglacial:	Milazzian	60 metres	220 ft. (67 m.)
Antepenultimate Glaciation:			
Penultimate Interglacial:	Tyrrhenian	32 metres	110 ft. (31 m.)
Penultimate Glaciation:			
Last Interglacial:	Main Monastirian	18 metres	50 ft. (16 m.)
	Late Monastirian	7.5 metres	20 ft. (6 m.)
Last Glaciation:			
	—— Flandrian transgression ——		
Postglacial:			

On South Kaipara Peninsula field evidence for the Early Glaciation is not conclusive and the low curve shown on the graph as following the Sicilian high sea-level is inferred from outcrops near Waimauku. West of Waimauku the terrace at 220ft to 240ft. is floored by pumiceous silts and sands of Kaihu Formation at least 154ft. thick which rest on an irregular basement of Manukau Breccia It is not clear whether this sequence represents glacio-eustatic oscillation of the sea or whether it is an inland exposure of the basal contact of the beds described earlier from the western coast.

Terraces situated at higher levels than the Sicilian shoreline (350ft.) and yet part of the same flight, present problems of age and origin which are not readily solved in the present area. It has been recognized in Europe that gradual withdrawal of the ocean from a position approximately 1,200ft. higher than at present began in late Pliocene time and that the glacial period was entered with the Sicilian shoreline at the 100 metre level (Baulig, 1935; Zeuner, 1950, Figs.

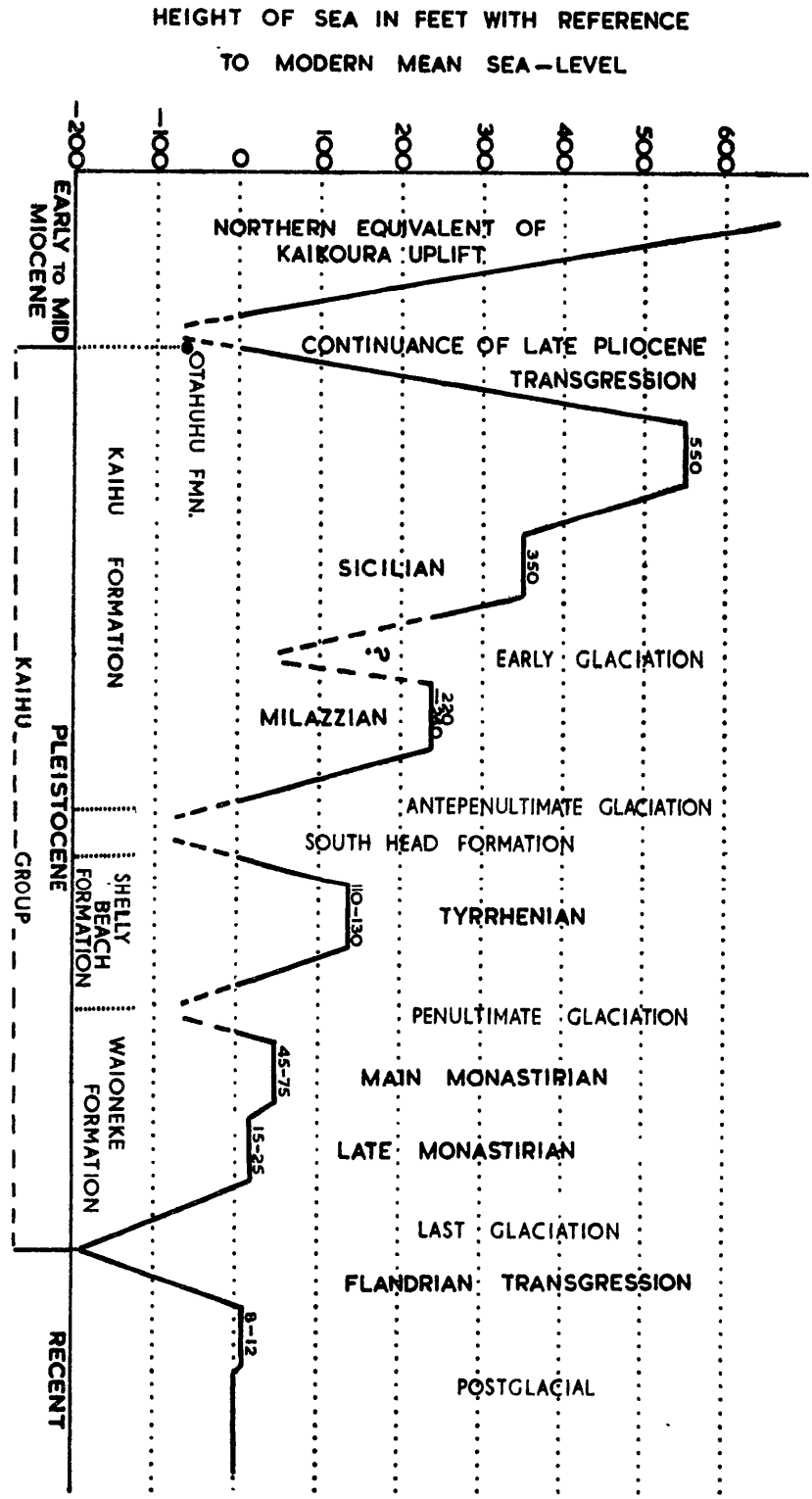


FIG. 5.—Graph of late Tertiary and Quaternary sea-level movements in the South Kaipara district. The equivalent Pleistocene chronology of Europe and the sedimentary succession in Kaihu Group are shown.

46, 50). The lowest late Pliocene surface of Baulig at 180 metres (585ft.) may be correlated with the 550ft. Kaipara plateau, and this would suggest a possible position for the Pliocene-Pleistocene boundary. The age of this Kaipara surface and the underlying unfossiliferous beds is, however, by no means fixed by such a correlation since Movius (1949) has shown that the Villafranchian of Europe should be considered basal Pleistocene rather than Pliocene. Movius does not give details of high-level terraces apart from indicating (Fig 4, p. 386) a surface on the Villafranchian at 250–280 metres, but it seems probable that the age of the terraces discussed by Baulig (1935) will be revised. Nevertheless, Stearns (1945, p. 1074) in describing surfaces at 560ft., 260ft., 215ft., 150ft, 100ft., 45ft., 25ft and 5ft. above modern mean sea-level in the New Hebrides group, pointed out that on paleontological evidence the age of the 560ft. and higher terraces may well be late Pliocene.

In a recent summary of literature Fleming (1953, pp. 77–79) has shown that much of the North Island of New Zealand was in a zone of periglacial climate during the Pleistocene glaciations. From a study of river terraces in Wanganui Subdivision Fleming (p. 80) has adopted a provisional classification of glacial and interglacial phases within which it is possible to recognize correlatives of Zeuner's (1950) Antepenultimate, Penultimate and Last Glaciations. However, the amount of post-Tertiary differential warping that has occurred in the Wanganui area does not allow such correlation any degree of certainty, as emphasized by Fleming (1953, p. 81).

In addition to the striking similarity between the chronology of sea-level movements in the Kaipara district and that in Europe, there are broader features of the Pliocene-Pleistocene history in North Auckland that are matched elsewhere in the world. The abandonment of higher shorelines shows the Pleistocene was a period of discontinuous major retreat of sea-level upon which was superposed the effects of glacial eustasy, with successively lower sea-levels appearing in each interglacial phase. The individual oscillations of sea-level recorded here as due to the alternation of glaciations and interglacials appear small in their range when compared with the total regression of the Pleistocene sea from the 550ft level to the present position Only a part of the water that has " disappeared " can be accounted for by ice-caps now formed at the poles, and some effect other than glacial eustasy is necessary to explain the continued regression throughout the Pleistocene. As a solution to a similar problem in Europe Baulig (1935) expanded the theory of deformational, or diastrophic, eustatism and concluded that there possibly had been simultaneous re-arrangement of large segments of the earth's crust without any evidence in the emergent stable (i.e., non-faulted and non-folded) regions of warped terrace surfaces or tilted sedimentary layers. Some such mechanism of crustal relief is essential in order to allow world correlation of terraces on landmasses that have undergone extensive emergence during the Quaternary.

If any credence is found in the control of landmass emergence by diastrophic eustatism, then an explanation may be given for one problem in the Kaipara district. That is, the 550ft. " late Pliocene transgression " referred to in this text (Fig. 5) may never have occurred as such; it may have been a marine transgression which never reached great heights above present sea-level, but the scale of transgression has been falsely accentuated by diastrophic regression of the ocean during the Pleistocene.

Note on Terrace Heights

Where there is a seaward slope on the Kaipara terraces, particularly those at 110ft. to 130ft. and 220ft. to 240ft. which slope eastward towards Kaipara Harbour, the heights at the lower margins have been used for comparison with the European levels. Without doubt there has been retreat of the scarps forming the lower margins of these terraces and measurements made at North Kaipara Peninsula show that less dissected surfaces extend down to 100ft. and 205ft. respectively. In the case of the two groups of terraces carried by Waioneke Formation between 15ft. to 25ft. and 45ft. to 75ft., the height of the commonest level has been taken in each group.

A consistent difference of 5ft. to 10ft. was noted between the heights of the lower terraces at Kaipara Harbour and the corresponding ones measured by Turner and Bartrum (1929) in the Takapuna-Silverdale area Since the height of the 5ft. post-Flandrian surface recorded by Turner and Bartrum seems to have been measured above high tide mark, this difference may be due to the use of mean sea-level as datum in the present study.

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