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Late Quaternary terraces and their cover beds, north-western Wairarapa, New Zealand, and provisional correlations with oxygen isotope stages

P. Vella*, Worakoon Kaewyana and C. G. Vucetich†**

All the known alluvial aggradation terraces and their cover beds in the Eketahuna-Pahiatua districts are described. Each terrace and its corresponding gravel formation and coeval loess formation, if all are still preserved, form a set of three taking the same name. The Hukanui Terrace, Hukanui Gravel and Hukanui loess are a set that represents the Last Stadial of the Last Glaciation. Pukewhai and Eketahuna sets represent the Second Stadial and First Stadial respectively. Greenhills and Flat Top sets, and Nireaha Terrace and Gravel and Ridge Road 1 loess in order of increasing age, represent the Penultimate Glaciation. Ridge Road 2 loess and Ridge Road 3 loess have no known terrace correlatives in the Eketahuna-Pahiatua area, but probably correspond to terraces mapped in Rangitikei district and are attributed to the Antepenultimate Glaciation. Pahiatua Terrace and Gravel are attributed to the next older glaciation. Strongly developed and coloured paleosols represent the Last Interglacial and Penultimate Interglacial stages, and a white clay on top of Pahiatua Gravel probably represents the Antepenultimate Interglacial Stage. Weak paleosols mark most interstadials. Five silicic tephras are found in the loess paleosol sequence, and two of them, Aokautere Ash (20-21 ka) and Mount Curl Tephra (200-260 ka) provide the chief quantitative age control for correlation. Makakahi Tephric Paleosol, with an andesitic component, forms a prominent horizon between Eketahuna and Pukewhai loesses and is another valuable marker dated at ±60,000 years. The whole sequence is thought to represent approximately the last 300,000 years.

Keywords: Late Quaternary, alluvial terraces, loess, tephra, paleosols, oxygen isotope stages.

INTRODUCTION

Neef (1974, 1984) mapped and named a number of alluvial terraces in the Eketahuna district. Kaewyana (1980) remapped them and extended the mapping northward through the Pahiatua district to the southern side of the Manawatu River (Fig. 1, Fig. 2). He separated and named several terraces that had not been distinguished by Neef, and he described, for the first time, the aeolian cover bed deposits on the terraces, enabling precise correlation with terrace sequences elsewhere in the southern North Island. Our purpose below is to give publication status to new stratigraphic names introduced by Kaewyana and to summarise the evidence for the terrace correlations and ages.

The Mangahao, Mangatainoka and Makakahi Rivers are large tributaries of the Manawatu River, joining it from the south a short distance upstream from the Manawatu Gorge. We assume that the three tributaries were not affected by Quaternary sea-level changes because their effective local base-level (Cotton, 1958) is the head of the Manawatu Gorge which is an ungraded reach of the Manawatu and is remote from the sea. However, that assumption could be incorrect for the time when the Pahiatua Terrace was formed, about 300,000 years ago. Accepting that no alluvial deposition was caused at

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Table 1—Comparison of terrace deposits in Rangitikei and Eketahuna-Pahiatua districts

Rangitikei (Milne and Smalley, 1981; Milne, 1973a)	**Eketahuna-Pahiatua**
Holocene degradation gravel and present day soils	Holocene degradation gravel and present day soils
Ohakea gravel and Ohakea loess with Aokautere Ash	Hukanui Gravel and Hukanui loess with Aokautere Ash
weak paleosol	weak paleosol
Rata gravel and Rata loess	Pukewhai Gravel and Pukewhai loess
andesitic tephra and paleosol	Makakahi Tephric Paleosol (andesitic)
Porewa gravel and Porewa loess	Eketahuna Gravel and Eketahuna loess
Mount Stewart Dune Sand (Last Interglacial high sea-level)	Strong tephric paleosol (Last Interglacial weathering phase)
Marton gravel and Marton loess	Greenhills Gravel and Greenhills loess
	weak paleosol and local peat
Burnand gravel and Burnand loess	Flat Top gravel and Flat Top loess
	weak paleosol
	Nireaha Gravel (lower tread?) and ridge Road 1 loess
Brunswick Dune Sand (Penultimate Interglacial high sea-level)	Strong red tephric paleosol (Penultimate Interglacial weathering phase)
Mount Curl Tephra	Mount Curl Tephra
Aldworth gravel and Aldworth loess	Ridge Road 2 loess
	weak paleosol
Waituna gravel and Waituna loess	Ridge Road 3 loess
	white clay (Antepenultimate Interglacial weathering phase)
	Pahiatua Gravel

any time by rises of sea-level we interpret the sedimentary record in the valleys of the three tributaries as representing chiefly stadials of the last few glacial stages.

Terraces (Table 1, Fig. 1, Fig. 2) were distinguished on three criteria: their relative elevations, their geomorphological forms (degree of dissection) and their cover bed stratigraphy (loess layers, paleosols and tephra). Elevations were determined chiefly from N.Z.M.S. 270 1:25,000 photogrammetric maps, which usually are sufficiently accurate; at a few places relative height differences were measured with a theodolite.

Only pre-Holocene terraces are described in this report. Each represents a former aggraded alluvial flood-plain. Remnants of each former flood-plain are preserved as terrace treads separated from lower treads by sloping risers, because alternations of alluvial aggradation and degradation were superimposed on secular tectonic uplift, and each degradation phase incised and partly destroyed pre-existing aggraded flood-plains. With increasing age the originally flat terrace treads tended to become convex, partly as a result of deposition of aeolian deposits on them and partly because the margins were worn down by erosion.

The alternation of alluvial aggradation and degradation is attributed to climatically controlled variation in the vegetation cover of the catchment, especially the adjacent mountains, which are heavily forested up to an elevation of 1,000 m at the present day. In most of southern North Island palynology has shown that forest was the usual interglacial and interstadial cover, and was replaced by alpine scrub and grass in stadial phases. Preliminary studies by W. McLea (*pers. comm.*, 1986) suggest that the same holds true in the Eketahuna district. It is inferred that slope erosion rates were relatively slow when there was substantial forest cover (during interglacials and interstadials) and the rivers therefore degraded, cutting terraces. Conversely slope erosion rates were high when the forest cover was depleted or absent during stadials, river bed-loads increased, and river flood-plains aggraded (Vella, 1963).

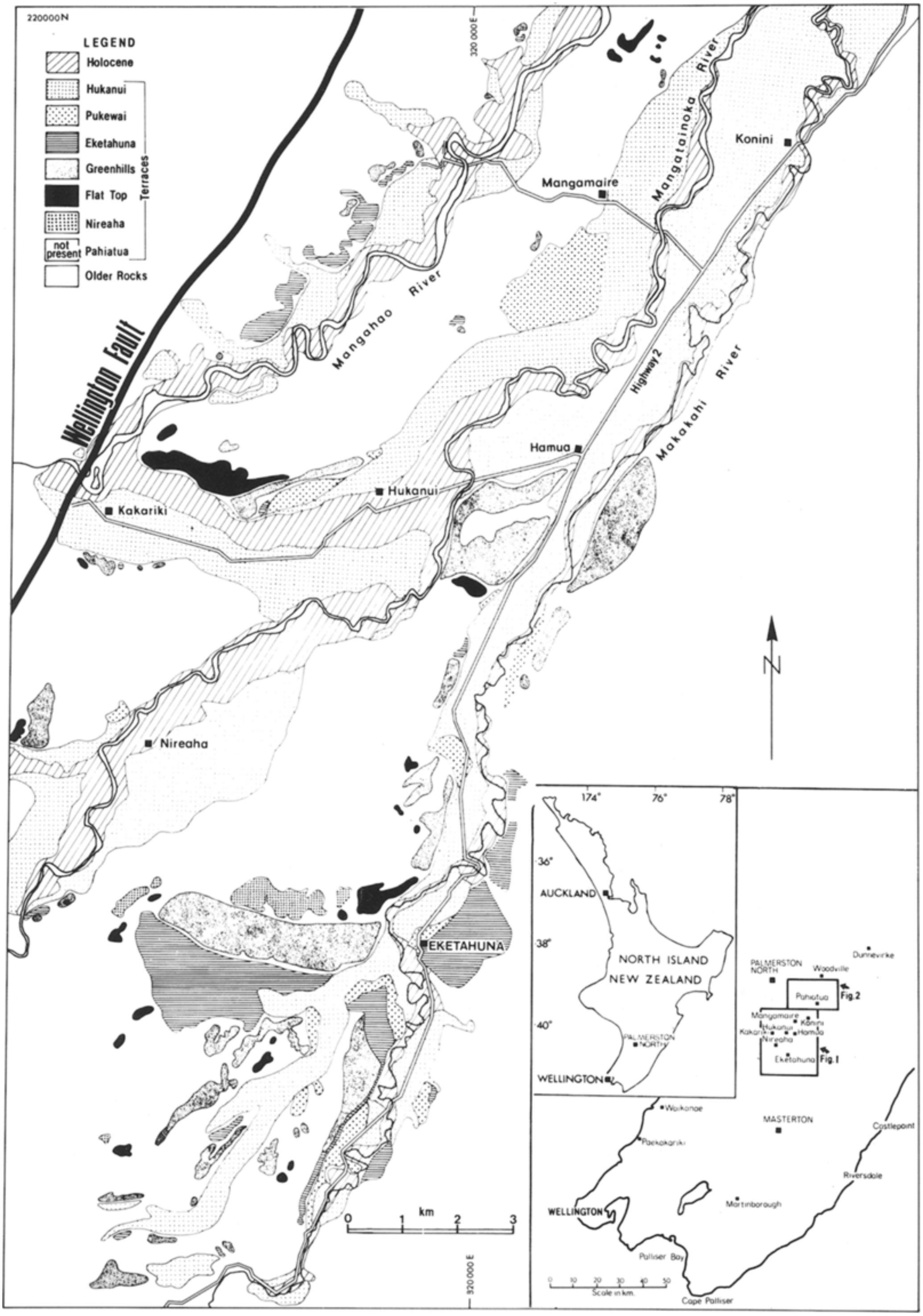

Fig. 1—Map showing terraces along the Mangahao, Mangatainoka and Makakahi valleys, Eketahuna district. Inset, locality map showing areas covered by Fig. 1 and Fig. 2.

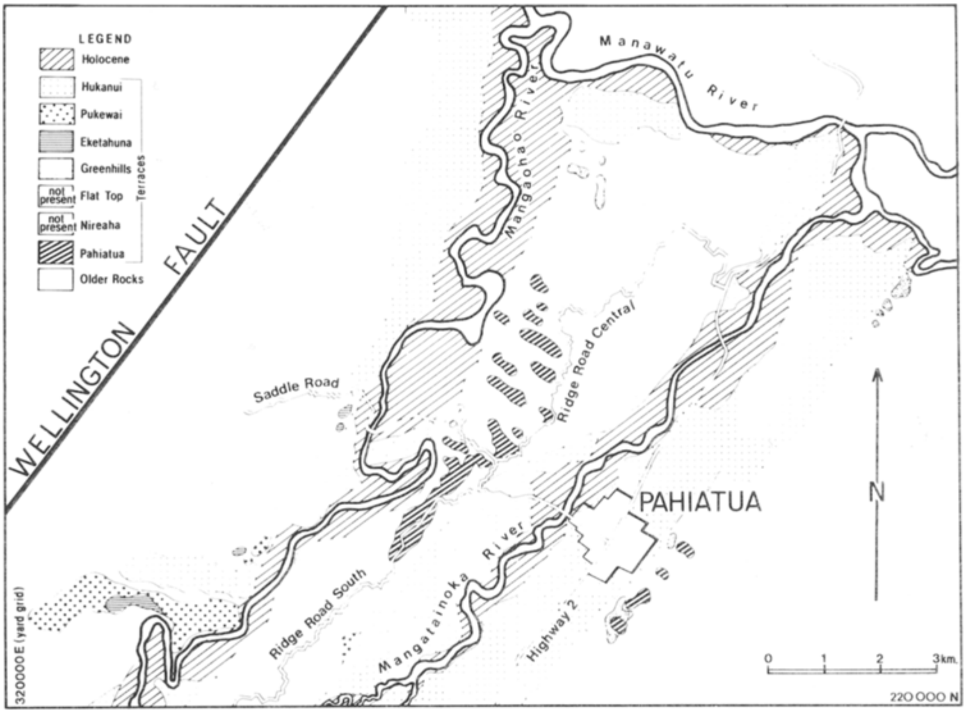

Fig. 2—Map showing terraces along the Mangahao and Mangatainoka-Makakahi valleys, Pahiatua district. For area covered see inset on Fig. 1.

On an aggrading flood-plain the river channel constantly sweeps from one side to the other, destroying any vegetation that temporarily becomes established. The deposits on the flood-plain are poorly sorted, and floods leave large bare areas covered by gravel, sand and mud. The late Quaternary flood-plains represented by the terraces mapped by Kaewyana (Fig. 1, Fig. 2) were much broader than those that exist now in the district. In dry weather wind blew dust (very fine sand, silt and clay) from their surfaces, and higher vegetated surfaces trapped part of the dust to form loess deposits (Cowie, 1964b). The loess tended to be washed off sloping surfaces to form colluvial deposits lower down, but remained on level or nearly level terraces to form a permanent record of successive alluvial aggradation phases (Cowie, 1964a; Milne, 1973a).

Tephras record volcanic activity that presumably was not influenced by climate, but the ones that have been preserved as distinct deposits are mostly those that fell during phases of active loess accumulation (i.e. during stadials). In Eketahuna and Pahiatua districts only paleosols record interglacial and interstadial intervals. The paleosols usually contain severely degraded tephric components. They are thinner than the loess layers, indicating relatively slow deposition, and the tephras that fell while they were forming were decomposed by weathering at or near the ground surface in the relatively warm and humid interglacial or interstadial climates.

Assuming that each successive aggraded flood-plain had approximately the same gradient and height above sea-level at any particular place, the average rate of tectonic uplift has been about 0.7 mm/year and nearly uniform along a 10 km transect of the terraces running N.W. to S.E. from the Mangahao River to the Makakahi River, crossing Highway 2 a few kilometres north of Eketahuna (Fig. 3). The terraces are not tilted or only slightly tilted transverse to the north-east structural trend of the area. An estimated uplift rate of 0.1-0.2 mm/year for the Pahiatua Terrace immediately west of Pahiatua Town shows that tectonic uplift has been differential along the north-east trend consistent with a north-eastward regional plunge of structures in the underlying marine sediments

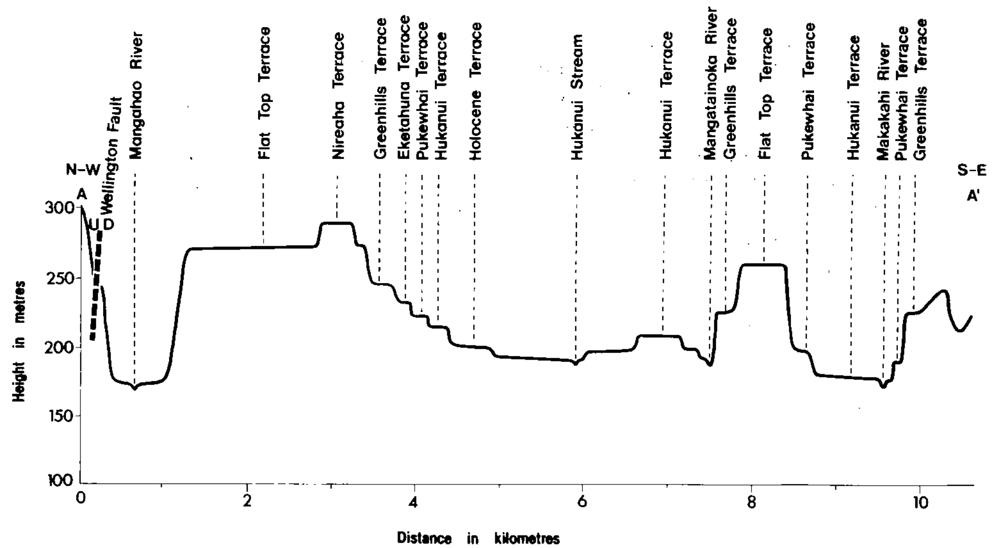

Fig. 3 — North-west to south-east profile of terraces from Mangahao River near Kakariki crossing Highway 2 about 5 km north of Eketahuna. The Profile is transverse to the regional structural trend, and the altitude of each terrace is only slightly different across the entire 10 km of the profile indicating uniform or nearly uniform tectonic uplift.

(Neef, 1974), and of the northern end of the Tararua Range. The uplift rates are slow compared with some other parts of the southern North Island. Continuous slow tectonic uplift accounts for the unusually large number of Quaternary terraces and loess deposits still preserved.

Aggradational terraces are given individual names as geomorphic forms and are treated as stratigraphic entities. Because of the slow rate of tectonic uplift, each aggradation phase is represented by a single tread, not by sets of treads as in Rangitikei (Milne, 1973a). Terrace gravel deposits are treated as formations, and each has the same type locality and takes the same formal stratigraphic name as the terrace it forms.

The loess layer formed on higher ground, mainly from the dust blown off the terrace when it was still an aggrading flood-plain, also takes the same name (Milne, 1973a). The loess is a lateral facies equivalent of its corresponding aggradational gravel formation. The type locality of the gravel (and terrace) is the name-bearer, and loess designated by the same name can not be allocated a separate type locality. Milne's method of naming each loess after its coeval aggradation gravel has proved to be satisfactory and is widely accepted in New Zealand. It has not been addressed in the International Stratigraphic Guide (Hedberg, 1976) or in any national codes of stratigraphic nomenclature. Therefore, when referring to loess formations in the cover-bed sequences below, we use a lower case "l" for loess to indicate informal status. For each loess formation that is named after a terrace, the cover bed sequence at the type locality of the next higher terrace may be considered to be a provisional reference section.

Loess colours are important for identification and were determined in the field using a colour book. They are expressed below in standard Munsell descriptive terminology and number-letter notation.

DESCRIPTIONS

HUKANUI TERRACE (Neef, 1974)

Type Locality: Neef designated Hukanui Settlement. We specify a point 1.5 km W.S.W. from the old Hukanui township centre, where the only relief is occasional shallow braided channels that contain no water. There is no loess and the underlying gravel is exposed only surficially. The gravel is poorly sorted with clast sizes ranging from 0.5 m down through cobble and pebble sizes to sand matrix. The provenance is obviously the Mesozoic rocks of the Tararua Range nearby to the west.

At most places Hukanui Gravel is between 3 m and 5 m thick. An extraordinary thickness of 21 m occurs at Kakariki 5 km west of Hukanui (Neef, 1974). At a few places the gravel is covered by thin loess, never more than 200 mm thick. Large areas of Hukanui Terrace are preserved adjacent to Hukanui Stream and parts of the Mangatainoka and Makakahi Rivers (Fig. 1, Fig. 2). Only small remnants are left along the Mangahao River.

The Aokautere Ash Member of Kawakawa Tephra (Vucetich and Howorth, 1975) was not found anywhere on Hukanui Terrace. Aokautere Ash may be seen at many places on all higher terraces, and the Hukanui Terrace is therefore younger than the ash, *i.e.*, less than 20 ka old. On older terraces the modal thickness of Hukanui Loess is about 1.5 m, and Aokautere Ash is usually about 1 m below the top. Milne (1973a) determined a similar position of Aokautere Ash in Ohakea loess in the Rangitikei district, where the base of the loess is ^{14}C-dated at 25,000 years old, and the top older than 9,450 years (Milne and Smalley, 1981). An age between 10,000 and 12,000 years is here accepted for the top of Ohakean loess. Assuming that loess production and deposition were directly related to alluvial aggradation, Milne (1973a) concluded that Ohakea gravel aggradation ceased at the same time. The similarity of the Hukanui and Ohakea loess stratigraphies supports Milne's conclusion and the Hukanui Terrace is correlated with the youngest Ohakea aggradation tread. The Hukanui Terrace is considered also to be a correlative of the Waiohine Surface (Vella, 1963) in southern Wairarapa Valley.

PUKEWHAI TERRACE (Neef, 1974)

Type Locality: Pukewhai Road, 2.5 km south-east of Mangamaire Township, grid reference N153/212132 (Neef, 1984). The Pukewhai Gravel is not exposed here. Augering proved light olive brown loess to a depth of 1.6 m with Aokautere Ash at 0.95 m, and below the loess, brown grey silt considered to be alluvial, bottomed on Pukewhai Gravel at 4.3 m below the ground surface. Measured using a theodolite the Pukewhai terrace tread (including cover beds) is 6.1 m higher than the adjacent Hukanui tread. The top of Pukewhai Gravel is thus 1.7 m above the Hukanui Tread and the top of the alluvial silt is 4.5 m above it.

Pukewhai Gravel ranges between 3 m and 4.5 m in thickness, is poorly sorted with clasts slightly weathered, ranging from 0.5 m down to sand grade, and including a small amount of yellow-brown clay matrix. It is thought that the clay was introduced by percolating ground water, and possibly was carried down from the cover beds directly overlying the gravel. There is not enough clay to reduce the permeability of the Pukewhai Gravel to any great extent.

At all places where it was examined the Pukewhai Terrace has an aeolian cover, consisting of a single loess layer (Hukanui loess) with Aokautere Ash intercolated typically at its lower two-thirds. The Hukanui loess varies in thickness (Fig. 4) from less than 1 m to greater than 2 m (exceptionally up to 3 m). At all sites on Pukewhai Terrace, except the type locality, described above, the loess rests directly on Pukewhai Gravel. The water-laid silt below the loess at the type locality might have been deposited in a swamp or as overbank silts during the latest stage of Pukewhai aggradation, or during the following interstadial. The Aokautere Ash is typically about 100 mm thick and very similar to the occurrences described by Cowie (1964a) on the Palmerston North side of the Tararua Range. Strictly it is the Aokautere Ash Member of the Kawakawa Tephra, radiocarbon-dated as 20.5 ± 0.5 ka old (Vucetich and Howorth, 1975).

The Hukanui loess layer is inferred to have been deposited during the time when Hukanui Gravel was being deposited on the aggrading flood-plains of the Mangahoa, Mangatainoka and Makakahi rivers during the Last Stadial of the Last Glaciation. In most of the mapped area the loess is light olive brown (2.5Y 5/4) silt loam, moderately hard when dry, soft and friable when wet. In the high rainfall area adjacent to the Tararua Range (c. 2,500 mm/year), chiefly along the Mangahoa River, Hukanui loess is a different

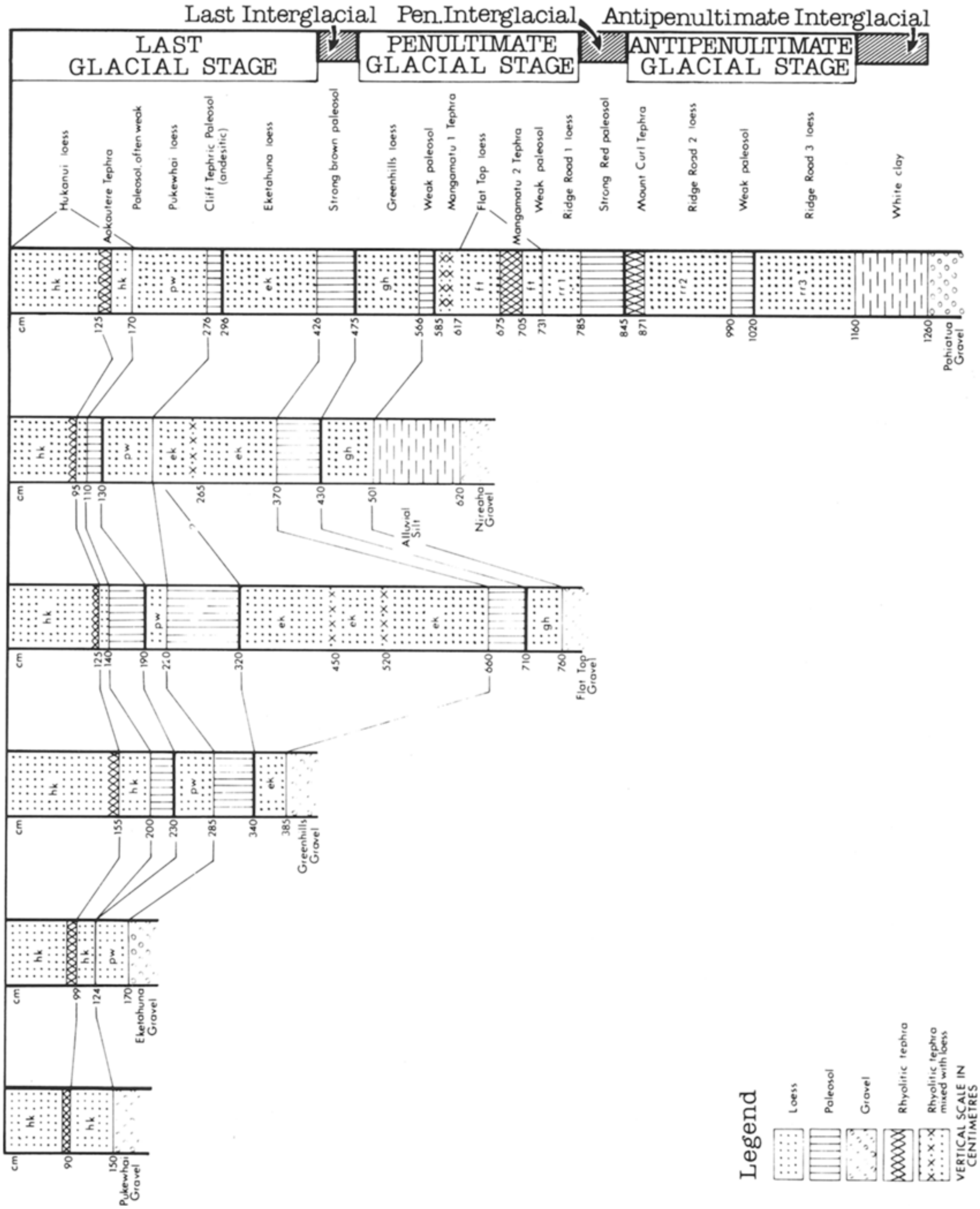

Fig. 4 — Typical cover bed sections on successively older terraces. A: Pukewhai Terrace at cutting on Parkville Central Road, Parkville, Eketahuna, grid reference N153/167982. B: Eketahuna Terrace at cutting on Highway 2, 1.5 km south-west of Eketahuna, N153/182988. C: Greenhills Terrace type locality, 2.5 km west of Eketahuna, N153/165002, augered site. D: Flat Top Terrace type locality, south side of Cliff Road, 2 km north-west of Eketahuna, N153/177012, augered site. E: Nireaha terrace treads, Hansen's farm north side of Nireaha Road, 3 km north-west of Eketahuna, N153/165009, augered site. F: Pahiatua Terrace, Ridge Road Central opposite rubbish tip, N149/298249, partly exposed in cutting partly augured at Pahiatua Terrace type locality 100 m to west (see text).

facies, yellow brown (10 YR 518) in colour, but is still easily identified by the intercolated Aokautere Ash.

Pukewhai Terrace remnants are characteristically small in area compared with the next lower Hukanui and the next higher Eketahuna terraces. They are best represented along the sides of the Mangatainoka and Makakahi valleys, and are rare along the Mangahao (Fig. 1, Fig. 2). Although they are relatively small the remnants nevertheless represent flood-plains that were once as broad as those represented by the Hukanui Terrace. The Pukewhai Terrace tread usually is incised by widely spaced narrow shallow gullies 1 to 2 m deep, about the depth of the loess cover. When observed the bottoms of the gullies were dry, and presumably rain water quickly drains away from them into the underlying Pukewhai Gravel. Between the gullies the tread is nearly flat and level. In contrast the next younger (Hukanui) tread typically has no gullies, and the next older (Eketahuna) tread has deeper and wetter gullies and convex rather than flat interfluves between the gullies.

The Pukewhai Terrace is correlated with the Ramsley Terrace in southern Wairarapa (Vella, 1963) and the Rata Terrace set in Rangitikei district (Te Punga, 1952; Milne, 1973a); all are considered to represent the Second Stadial of the Last Glaciation and to be between 30,000 and 40,000 years old.

EKETAHUNA TERRACE (Neef, 1974)

Type Locality: Neef designated Eketahuna Town. The town extends over three terraces, the lower two are the Hukanui and Pukewhai Terraces. On his map Neef (1974) showed the highest of the three as Eketahuna Terrace and we here specify the type locality as the Alfredton Road on the east edge of the town, grid reference N153/194997. There the tread slopes up at a low (undertermined) angle to the south-east and probably has been titled tectonically (distinct tectonic tilting of the terraces is rare, see Introduction). A railway cutting opposite the Eketahuna Railway Station, 100 m south of the Alfredton Road, exposes 2 m of Eketahuna Gravel, but the base and top are not visible. The gravel consists of poorly sorted subangular to well-rounded clasts ranging from 380 mm down to sand size, with a greater amount of yellow-brown clay matrix than in the Pukewhai Gravel. The cover beds are not exposed, and were not augered at the type locality.

The cover beds are well exposed in a cutting on Highway 2, 1.5 km south-west of Eketahuna (Fig. 4B). They include Hukanui loess and Pukewhai loess. The Hukanui loess is 1.24 m thick light olive brown (2.5Y 5/4) silt loam with Aokautere Ash 60 mm thick, its base at 0.99 m below the ground surface. Pukewhai loess is 0.46 m thick and readily distinguished from Hukanui loess by its yellowish brown (10YR 5/6) colour and more clayey silt loam texture.

Large areas of Eketahuna Terrace remain along the Makakahi Valley (including the type locality at Eketahuna) and along the west side of the Mangahao Valley (Fig. 2A, 2B). Between the Makakahi and Mangatainoka valleys much of the area mapped as Eketahuna Terrace by Neef (1974) is here redesignated as Greenhills Terrace, and true Eketahuna Terrace remnants are smaller and less continuous than shown by Neef's map.

Eketahuna Gravel ranges between 3 m and 5 m in thickness. The clasts are more iron-stained than in the Hukanui and Pukawhai gravels, tend to split more freely along pre-depositional joint plains, and have a smaller average size. The two loess layers are consistently present and are reliable criteria for identifying the terrace. The thickness of Hukanui loess is locally up to 3 m and the thickness of Pukewhai loess is up to 1 m. Aokautere Ash is invariably present in the Hukanui loess.

The tread of the Eketahuna Terrace undulates because of varying thickness of the cover beds and because it has been dissected by gullies, some of which have penetrated through the cover beds into the underlying gravel.

The Eketahuna Terrace is correlated with the Waipoua Terrace in southern Wairarapa (Vella, 1963) and with the Porewa Terrace in Rangitikei district (Te Punga, 1952; Milne, 1973a), and is considered to be about 70,000 years old.

GREENHILLS TERRACE (New name)

Type Locality: West side of Makakahi Valley, 2.5 km west of Eketahuna, at elevation 270 m, grid reference N153/165002. There the Greenhills terrace tread is 25 m higher than the Eketahuna Terrace tread. The Greenhills Gravel is not exposed there or nearby. Augering proved typical Hukanui loess with Aokautere Ash, typical Pukewhai loess, and Eketahuna loess that bottomed on gravel (Fig. 4C). Between the Pukewhai loess and Eketahuna loess is a distinctive paleosol, 0.3 m thick, brown (10YR 4/6), clay loam in texture, and rich in allophane, here formally named Makakahi Tephric Paleosol (type locality the same as for Greenhills Terrace). Makakahi Tephric Paleosol is much darker than the overlying Pukewhai loess and underlying Eketahuna loess. It is considered to be a correlative of the Middle Tongariro Tephras in Rangitikei district, dated at ±60,000 years (Milne, 1973a). Eketahuna loess at the type locality of Greenhills Terrace is 2.0 m thick brownish yellow (10Y 6/6 to 10YR 6/8) silty clay loam with a blocky structure.

Large remnants of Greenhills Terrace are preserved south and west of Eketahuna and near Hamua, 10 km north of Eketahuna, on the west side of Highway 2, (Fig. 1). Many small remnants may be seen along the Makakahi Valley up to 7 km south-west of Eketahuna, and a few small remnants along the Mangatainoka Valley near Nireaha and along the Mangahao and Makakahi valleys as far north as the Manawatu River (Fig. 2).

Greenhills Gravel ranges between 3 m and 5 m in thickness and consists of poorly sorted subrounded to well rounded cobbles and pebbles with a sandy clay matrix. The clasts are more weathered than those in the Hukanui, Pukewhai and Eketahuna Gravels, and break freely along pre-depositional joint surfaces, which are coated with rusty coloured iron oxide. Many clasts have the surfaces softened to a depth of 2 mm or more. The sandy clay matrix contrasts with the much cleaner sand matrix in the Hukanui and Pukewhai Gravels and is more clayey than in the Eketahuna Gravel.

The cover beds range up to nearly 4 m thick and usually comprise the Hukanui Pukewhai and Eketahuna loess formations with intercolated Aokautere Ash and Cliff Tephric Paleosol as at the type locality. Eketahuna loess is generally consistent in colour and lithology. Observed thicknesses range from 0.5 m at one site on Greenhills Terrace (Fig. 4C) to an exceptional 3.4 m at a site on the next higher Flat Top Terrace (Fig. 4D). At the latter site two tephric horizons within the Eketahuna loess were detected by testing for allophane in the field, one 1.3 m below the top, the other 2.0 m below the top, and each was found to contain infrequent silicic volcanic glass shards when examined in the laboratory. The Greenhills Terrace tread undulates with greater relief than that of the Eketahuna Terrace. At places small streams have cut down through the cover beds and gravel into underlying marine sediments. The erosion of the tread is such that complete cover bed sequences are likely to be preserved only near the crests of interfluves.

Greenhills Terrace is correlated with the Marton Terrace in Rangitikei district (in the sense of Milne and Smalley, 1981) and is considered to represent the last stadial of the Penultimate Glaciation (Table 3).

FLAT TOP TERRACE (Neef, 1974)

Type Locality: Neef designated "the high surface" 2 km north-west of Eketahuna. That designation is not clear because Neef did not separate the older and higher Nireaha Terrace set described below. We determine the cover bed sequence by augering on the south side of Cliff Road, 2 km north-west of Eketahuna, grid reference N153/177012, and here specify that as the type locality. The tread of Flat Top Terrace is better defined farther to the east, and we propose a site 1.3 km north-north-west of Eketahuna, grid reference N153/178008, as a standard locality, supplementing the type locality of the terrace.

Four loess layers were proved at the type locality (Fig. 4D), Hukanui loess 1.4 m thick with Aokautere Ash close to the base, Pukewhai loess with an unusually thick paleosol separating it from Hukanui loess, very thick (1 m Makakahi Tephric Paleosol, very thick (3.4 m) Eketahuna loess, and at the base a strongly defined paleosol underlain by lighter-coloured silt loam considered to be Greenhills loess, bottoming on Flat Top Gravel. The Greenhills loess is yellow brown (10YR 5/6) silt loam with minor allophane and is 0.5 m thick. The paleosol between it and Eketahuna loess is dark yellowish brown (10YR 4/4) silty clay loam rich in allophane and is 0.5 m thick. It is a prominent marker horizon (Fig. 4D, E and F) and is considered to represent the Last Interglacial Stage.

The Flat Top flood-plain must once have been very broad, but only scattered small patches still remain (Fig. 1). The largest remnant is an east-west flattish-topped ridge 4.0 km long by 0.5 km wide, on the north side of Hukanui Valley, no doubt deposited by the river that is now the upper Mangahao but was then a tributary of the Mangatainoka River (Vella *et al.*, 1987). The Mangatainoka itself was evidently a tributary of the Makakahi and the Flat Top flood-plain extended west to east across what is now the dividing ridge between the Mangatainoka and Makakahi valleys (Fig. 1).

Flat Top Gravel is exposed rarely, only along secondary roads and farm tracks, and its thickness is not known. It is poorly sorted subrounded to well rounded cobbles and pebbles with a firmly compacted sandy clay matrix. The degree of weathering of the clasts is similar to that in the Greenhills Gravel.

The Flat Top Terrace tread undulates with a greater relief than that of the Greenhills Terrace. From a distance the remnants seem to be continuous flat and nearly level surfaces, but that is an illusion caused by summit height accordances. At close quarters they resemble downlands rather than terrace treads. Even the smallest of streams have formed broad valleys across them and the interfluves are nearly invariably convex. The likely sites for loess sequences that are complete and not modified by colluvial deposition are rare.

The Flat Top Terrace is correlated with the Burnand Terrace of Rangitikei (Milne and Smalley, 1981) and in this account is considered to be about 160,000 years old.

NIREAHA TERRACE SET (new name)

Type Locality: North-west side of Mr Drysdall's farm road, 0.8 km east of Nireaha Road, about 4 km north-west of Eketahuna, grid reference N153/152009. The site is 25 m higher than the adjacent Flat Top Terrace and 50 m higher than nearby Greenhills Terrace. It is on the lower of two terraces that are too indistinct to map separately. In a cutting beside the farm road at the type locality 0.5 m of Nireaha Gravel is exposed, and consists of weathered poorly sorted subrounded to well rounded small cobbles and pebbles in compact sandy clay matrix, indistinguishable from Flat Top Gravel. It is exposed at few other places, and its thickness is not known; the maximum seen was 1 m. The maximum clast size measured was 250 × 60 × 40 mm. From field observations the maximum and mean clast sizes appear to be smaller than in most younger gravel formations.

The largest known area of Nireaha Terrace set is an east-west trending ridge 2.0 km long by about 0.5 km wide between Nireaha and Eketahuna. The type locality is at the west end of the ridge. The ridge is the so-called high surface mentioned by Neef (1974) in his designation of the type locality of the Flat Top Terrace, but on a true north-west bearing from Eketahuna the Nireaha Terrace treads are further from Eketahuna than the 2 km specified by Neef.

Because the Nireaha Terrace treads form the top of the ridge they are not deeply dissected by streams. They have a surface relief of up to 10 m, consisting of broad dome-shaped mounds. Augering of a depression between mounds proved 1.3 m of Hukanui loess containing Aokautere Ash at 0.8 m below the ground surface, and resting on Nireaha Gravel. Augering on the top of a mound 500 m to the west of the depression, at grid reference N153/165009, proved 6.2 m of cover beds overlying the gravel (Fig. 4E). The relief evidently is the result, partly of the different heights of the original gravel treads, and partly of the large variation in the thickness of the cover beds.

In the mound the sequence of cover beds is nearly complete down to the Greenhills loess, in comparison with those on the younger terraces (Fig. 4E). The only unit missing is the Makakahi Tephric Paleosol. Nireaha Terrace has been elevated for a long time, is now about 280 m above sea level, not sheltered by any nearby higher ground, and very exposed to severe weather. It is surprising, not that cover beds were eroded from the depressions, but that they have been preserved so well in the mound that was augered. We conjecture that islands of thick vegetation need to persist on the cover bed mounds, entrapping aeolian deposits during stadial intervals and protecting them against erosion during most interstadial intervals. Similarly a full complement of cover beds was proved by drilling at a mound crest on the Pahiatua Terrace described below.

The Greenhills loess in the augered mound is underlain by orange-mottled yellow grey silt, considered to be water-laid. There is no clearly defined aeolian deposit that could represent Flat Top loess. The Nireaha Terrace treads are treated as older than Flat Top Terrace, solely because of their higher elevation. It is uncertain whether the higher Nireaha tread is significantly older than the lower one.

PAHIATUA TERRACE (new name)

Type Locality: We designate a site at which we augered 8.5 m of aeolian cover beds (not reaching the bottom) on a mound crest of the ridge adjacent to Ridge Road Central, 140 m south-west of the Pahiatua refuse tip, grid reference N149/298249. A cutting on the west side of Ridge Road Central adjacent to the rubbish tip is designated as a standard locality supplementing the type locality. In 1980 the cutting exposed the 7.35 m of cover beds immediately overlying the Pahiatua Gravel, and five loess layers and three silicic tephra layers were distinguished in it. The cutting is not a satisfactory site for a type locality because the upper part of the cover bed sequence (estimated to be 5.25 m) is not represented, and the cutting collapses from time to time obscuring parts of the sequence.

Deeply dissected remnants of the Pahiatua Terrace are preserved in small areas on the two sides of the Mangatainoka-Makakahi valley to the west and north-west and east and south-east of Pahiatua Town (Fig. 2). The thickness of Pahiatua Gravel is uncertain. Exposures on Saddle Road between Pahiatua and Palmerston North show at least 5 m of poorly sorted subrounded to well rounded small cobbles and pebbles in a firm matrix of orange-brown sandy clay. The provenance is the indurated Mesozoic rocks of the nearby Tararua Range; clast sizes are similar to those in Nireaha Gravel, and the clasts are strongly weathered.

The 8.5 m of cover beds sampled at the type locality were drilled using a trailer-mounted motorized auger. The lowest bed reached was Mount Curl Tephra. The auger could not penetrate a hard silicified pan at the base of the tephra, and the lower part of the cover bed section (Fig. 4F) was determined from the exposure in the road cutting by the Refuse tip on Ridge Road Central. The composite section is 12.6 m thick and contains eight loess layers, at least five paleosols, three distinct tephras and two richly tephric horizons. A possible sixth paleosol is represented by white clay at the base of the cover beds, directly overlying Pahiatua Gravel. The youngest and oldest tephras are the well known and dated Aokautere Ash and Mount Curl Tephra.

The four youngest loess layers are the Hukanui, Pukewhai, Eketahuna and Greenhills loesses described above, each with typical colour and texture and nearly modal thickness (Fig. 4F). Of them, only the base of Eketahuna loess, the Greenhills loess and the intervening strong brown Last Interglacial paleosol are exposed in the rubbish tip road cutting section. The stratigraphic position of Aokoutere Ash is typical within the lower part of Hukanui loess. Makakahi Tephric Paleosol, about 0.2 m thick, is well defined between Pukewhai and Eketahuna loesses, and the Last Interglacial paleosol is 0.5 m thick and strongly differentiated from the enclosing loesses by its strong colour and clayey texture.

The following descriptions down to the Mount Curl Tephra are based partly on the augered section and partly on the road cutting section. Greenhills loess is underlain by a weakly developed brown (7.5 YR 5/6) paleosol 0.2 m thick. A loess and tephric loess layer 1.46 m thick below the paleosol is taken to be the Flat Top loess because of its stratigraphic position below Greenhills loess. The top 0.3 m of the Flat Top loess contains abundant silicic glass, which is here named Mangamutu 1 Tephra and is a yellowish brown (10 YR 5/6) fine sandy silt loam. Within Flat Top loess 0.6 m below Mangamutu 1 Tephra is another, more distinct, silicic tephra layer 0.3 m thick with little or no intermixed non-volcanogenic sediment, here named Mangamutu 2 Tephra. It is similar in colour and texture to the Mangamutu 1 Tephra. The enclosing Flat Top loess contains no detected volcanogenic component, and is a yellow brown (10 YR 5/8) silty clay loam with many small manganese nodules.

A loess layer 0.54 m thick, consisting of yellow brown (10 YR 5/6) silty clay, directly underlies Flat Top loess. It has no distinct paleosol at the top, but its whole thickness is highly weathered and contains a higher proportion of clay than any younger loess deposit. It is here named Ridge Road 1 loess, but its stratigraphic position suggests that it corresponds in age to the Nireaha Terrace set. No corresponding terrace or loess is recognised in Rangitikei district (Table 1).

A bright pink to red paleosol 0.6 m thick underlies Ridge Road 1 loess, and immediately under the paleosol is the silicic glass Mount Curl Tephra, 0.25 m thick, the age and correlation of which are discussed in the section on tephras below. At the road cutting by the rubbish tip, two loess layers underlie the Mount Curl Tephra, and are here named Ridge Road 2 loess (upper) and Ridge Road 3 loess (lower). Ridge Road 2 loess is a 1.2 m thick strong brown (7.5 YR 5/8) silty clay loam with a silicified hard pan at the top directly underlying Mount Curl Tephra. No paleosol was detected, and it is inferred that the tephra was deposited before the Ridge Road 2 phase of loess deposition was completed, but very close to its end, consistent with the correlation by Froggatt *et al.* (1986) of Mount Curl Tephra with the latest part of oxygen isotope stage 8 (Table 3, below). Under Ridge Road 2 loess is a paleosol 0.3 m thick, consisting of brown (7.5 YR 5/4) silty clay loam with abundant small manganese nodules. Below the paleosol Ridge Road 3 loess is darker brown than Ridge Road 2 loess (7.5 YR 5/6) silty clay 1.6 m thick. Below Ridge Road 3 loess is a layer of white clay 1.0 m thick resting on Pahiatua Gravel.

Neither Ridge Road 2 loess nor Ridge Road 3 loess can be correlated with any known terrace in the Pahiatua or Eketahuna districts. Accepting that loess deposits were derived mainly from alluvial flood-plains (see above and Cowie, 1964a), the Ridge Road 2 and 3 loesses represent terraces that either have not been recognised or have been totally destroyed by erosion. The small remnants of Nireaha Terrace are approaching that total destruction now. The small remaining parts of the Pahiatua Terrace owe their preservation to the local unusually slow rate of tectonic uplife (0.1-0.2 mm/year, see Introduction above).

SUMMARY OF TEPHRAS AND TEPHRIC HORIZONS

A Tephra is taken to be a primary airfall volcanic deposit without a significant intermixed non-volcanogenic component; a tephric horizon a paleosol or loess in which a significant volcanogenic component can be recognised by microscopic examination of the sand fraction. The tephric horizons listed below were initially detected by field allophane tests (Fields and Perrott, 1966), which are most useful where volcanic glass and feldspar have been weathered in a humid environment with active silica leaching. Tephras and tephric horizons are treated in order of increasing age.

1. *Aokautere Ash*: Cowie (1964a) described the silicic Aokautere Ash at sites in Manawatu district with a type locality near the township of Aokautere east of Palmerston North, and on the opposite side of the Tararua Range from Eketahuna and Pahiatua districts, where the field characteristics are very like those described by Cowie. A reference section for the district is designated as a cutting on the west side of Mangamaire Road 3 km south-south-west from Mangamaire, grid reference N153/219133. The sequence through the ash is as follows:

yellow (10YR 7/6) fine ash grading up to overlying Hukanui Loess, grading down to	60 mm
brownish yellow (10YR 6/6) medium-grained ash grading down to	50 mm
brownish yellow (10YR 6/6) coarse-grained ash, sharp contact at base	20 mm
pale yellow (2.5YR 8/4) fine-grained ash, sharp undulating contact with Hukanui loess at base	20 mm
Total thickness	150 mm

The basal fine ash and overlying coarse to fine normally graded ash are diagnostic features throughout the district. Aokautere Ash was identified at 72 sites.

2. *Makakahi Tephric Paleosol*: The type locality is designated as the augered site on Flat Top Terrace at Mr Kon Kroot's farm alongside Cliff Road, 2 km north-west of Eketahuna, grid reference N153/177012. There it is 1 m thick and its top is 2.2 m below the ground surface, with Hukanui and Pukewhai loess above it (Fig. 4D). It is brown (7.5YR 4/6) silt loam, and its minor sand grade component includes quartz, feldspar, and euhedral hornblende, hypersthene and magnetite or other iron oxide. The mafic minerals are much more abundant than in the enclosing (Eketahuna and Pukewhai) loesses. No glass was found. Field tests for allophane were strongly positive, and we conclude that the Makakahi Tephric Paleosol contains a large component of degraded andesitic volcanic detritus, and is a correlative of the Middle Tongariro Tephras between the Porewan and Ratan Terraces in Rangitikei district whose estimated age is ±60,000 years (Milne, 1973a). It is also considered to be a correlative of the Kimbolton Paleosol in Rangitikei district (Leamy *et al.*, 1973), and is a persistent and valuable marker bed in the Eketahuna-Pahiatua district.

3. *Mangamutu 1 Tephra*: The type locality is designated as the Ridge Road Central cutting opposite the Pahiatua rubbish tip, grid reference N149/298249. At the type locality the Mangamutu 1 Tephra is not easy to distinguish from the underlying Flat Top loess (Fig. 4F), because it is mixed with non-volcanogenic sediment. Nevertheless it has been detected at the top of Flat Top loess at two other localities on the Pahiatua Terrace west of Pahiatua; on Ridge Road South, grid reference N149/273224, and on Saddle Road, grid reference N149/287256. At both sites it has similar thickness and characteristics to those at the type locality. Its stratigraphic position immediately below the paleosol between Flat Top and Greenhills loess suggests that the intermixing of non-volcanogenic sediment may have been caused by bioturbation during an interval of slow loess deposition. From its stratigraphic position, the age of Mangamutu 1 Tephra is estimated to be ±140,000 years (Table 3).

4. *Mangamutu 2 Tephra*: The type locality here designated is the same as for Mangamutu 1 Tephra. Mangamutu 2 Tephra is within Flat Top loess (Fig. 4F); its top is 0.58 m below the base of Mangamutu 1 Tephra. It is a poorly defined layer, 0.3 m thick, of brown (10YR 4/6) sandy clay loam with glass shards visible under a magnifying glass, distinguished from the loess by its darker colour and coarser texture. Strong reaction with sodium fluoride shows a substantial allophane content. No layering was seen within the tephra. The sand fraction contains feldspar, hornblende, hypersthene, opaque minerals, rare euhedral quartz and (about 5%) clear volcanic glass shards. From its stratigraphic position Mangamutu 2 Tephra has an estimated age of ±150,000 years (Table 3). Either it or Mangamutu 1 Tephra might be the distal airfall equivalent of the Kaingaroa Ignimbrite, which is thought to be approximately 180,000 years old (Froggatt, 1983).

5. *Mount Curl Tephra*: The unpublished name Pahiatua Tephra (Roberston, MS, 1976) is a synonym that was introduced as a measure of caution even though identity with the Mount Curl Tephra (Milne, 1973b) was considered likely from the time that the exposures near Pahiatua were first discovered. The stratigraphic position, field characteristics, mineralogy, and glass chemistry (Froggatt, 1983) of the so-called Pahiatua Tephra now leave no doubt that it is the Mount Curl Tephra.

Table 2 — Estimates of the age of Mount Curl tephra

Milne (1973b):	fission-track, glass, 230±30 ka. K-Ar, glass, 250±120 ka.
Seward (1979):	fission-track, glass, 230±40 ka. fission-track, zircon, 230±60 ka.
Pillans and Kohn (1981):	fission-track, glass, 230±50 ka. fission-track, zircon, 240±50 ka.
Froggatt *et al.* (1986):	from oxygen isotope stratigraphy, DSDP site 594, 254±2 ka.

Mount Curl Tephra is exposed at several sites on the Pahiatua Terrace. We are satisfied that a complete sequence of the overlying loess layers was determined from the augered section at the type locality of the Pahiatua Terrace and the nearby rubbish tip road cutting on Ridge Road Central (Table 1, Fig. 4F). The tephra directly underlies the pink to red strongly developed Penultimate Interglacial paleosol, and directly overlies Ridge Road 2 loess. The paleosol is correlated with the Brunswick Dune Sand in Rangitikei-Wanganui districts, considered to have been deposited during the high sea-level interval representing the Terangian Interglacial Stage (Fleming, 1953).

Milne (1973a, 1973b) established the importance of Mount Curl Tephra as a dated marker bed in the late quaternary sequences of New Zealand, giving two radiometric age estimates based on the glass (Table 2); one was a K/Ar age determined by C. Adams at the Institute of Nuclear Sciences, 250 ± 120 ka, the other a fission-track age determination by D. Seward at Victoria University of Wellington, 230 ± 30 ka. Several later attempts have been made to refine the dating (Table 2) because the importance of the tephra as a marker bed has steadily increased as finds have been reported over an increasing area, including some in offshore marine deposits. The most recent estimate is 254 ± 2 ka, based not on any radiometric method, but on oceanic oxygen isotope stratigraphy in core taken at Deep Sea Drilling Program site 594 on the Campbell Plateau west of the South Island (Froggatt *et al.*, 1986). This date is within the error limits of all the previous radiometric estimates, but its small error limit is deceptive because the age determination was influenced by the assumed frequencies of the earth's orbital perturbations (precession and changes of obliquity and ellipticity) used to calculate the ages of the oxygen isotope fluctuations. We provisionally accept that the Mount Curl Tephra was deposited at or near the end of the time represented by oxygen isotope Stage 8, and is approximately 254,000 years old (Table 3).

Table 3—Correlation of terraces and cover beds, Eketahuna and Pahiatua districts

Terraces and loesses	Paleosols	Dated Tephra*	Climatic stages	Dalta^{18}O stages	Age** ka
	(modern soil)		Holocene	1	12
Hukanui		AA	Last Stadial	2	23
Pukewhai			Second Stadial	3	
	andesitic	MTP	First Interstadial		56
Eketahuna			First Stadial	4	68
	strong brown		Last Interglacial	5	128
Greenhills			stadial		
	weak		interstadial		
Flat Top			stadial	6	
	— —		interstadial		
Nireaha and Ridge Rd 1			stadial		174
	strong red		Penultimate Interglacial	7	247
Ridge Rd 2		MCT	stadial		
	weak		interstadial	8	
Ridge Rd 3			stadial		297
	white clay		Antepenultimate Interglacial?	9	339
Pahiatua Terrace			stadial?	10	

* Dated tephras: AA, Aokautere Ash, 20 ± 0.5 ka; MTP, Makakahi Tephric Paleosol, ± 60 ka; MCT, Mount Curl Tephra, age shown is approximately 54 ka from oxygen isotope stratigraphy DSDP Site 594 (Froggatt *et al.*, 1986), but see Table 2.

** Ages of oxygen isotope stage boundaries given by Froggatt *et al.* (1986).

Oxygen isotope stages 1 to 10 after Emiliani (1966), Hays *et al.* (1976) and Gardner (1982).

CONCLUSIONS

The principle established by Cowie (1964a) and Milne (1973a), that each phase of alluvial aggradation caused by deterioration of the climate in Manawatu and Rangitikei districts was accompanied by deposition of loess over all pre-existing terraces, is the key to determining relative ages of terraces. The principle appears to apply as well in the Eketahuna and Pahiatua districts. Each successively younger terrace or terrace set has one less loess layer in the cover than the previous one, until at the end, on the Ohakea Terrace (Hukanui Terrace at Eketahuna-Pahiatua) there is little or no loess cover. Downcutting treads on the Ohakea Terrace set in Rangitikei Valley tend to have a variable but thin loess cover, always lacking Aokautere Ash (Milne, 1973a). Hukanui Terrace has no such downcutting treads, and has only a few localised patches of loess, the maximum known thickness of which is 200 mm.

Cover bed sequences in the Eketahuna-Pahiatua district (Fig. 4) closely resemble those in Rangitikei, enabling unambiguous correlation of most of the terraces of the two regions (Table 1) even though they are on opposite sides of the axial mountain ranges. One major difference is that no dune sands represent interglacial stages at Eketahuna and Pahiatua. Dune sands in the Rangitikei sequence were blown inland from the Wanganui coast by the prevailing westerly-north-westerly wind during interglacial high sea-level phases. Eketahuna and Pahiatua were always remote from the sea, there was no source of sand, and interglacial stages there are represented solely by strongly developed paleosols. Another major difference is the more complete preservation of the cover bed sequence in the Pahiatua district, where tectonic uplift has been slow. Because of the slow rate of uplift the relief of the Pahiatua Terrace is still low, erosion of the terrace has been slow, and deposition of modal thicknesses of loess layers continued until the end of the last (Hukanui) phase.

The silicic Aokautere Ash (member of Kawakawa Tephra, 20 ± 0.5 ka B.P.) and Mount Curl Tephra (*c*. 254 ka B.P.), and the andesitic Makakahi Tephric Paleosol (± 60,000 ka B.P.), are especially useful parts of the cover bed sequence because they confirm the correlations with the terraces in Rangitikei district (Table 1) and also they provide a quantitative framework with which to make international correlations (Table 3). Assumptions made in the correlations shown in Table 3 are that each loess formation and corresponding aggradation gravel represent a climatic stadial, strongly developed paleosols represent interglacial stages, and weakly developed paleosols or loess contacts without detectable paleosols represent interstadial intervals. The Makakahi Tephric Paleosol is anomalous because it represents an interstadial but is nearly as prominant in colour and thickness as the presumed interglacial paleosols. The unusually large component of andesitic tephra is the cause of the anomaly.

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