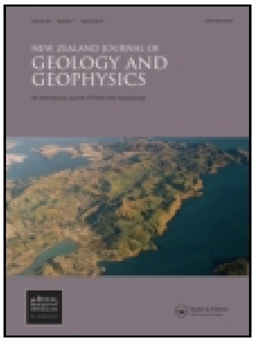

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Inaha Terrace deposits: A late Quaternary terrestrial record in South Taranaki, New Zealand

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Inaha Terrace deposits: a late Quaternary terrestrial record in South Taranaki, New Zealand

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Abstract A 38 m thick stratigraphic section is exposed in cliffs near Inaha on the South Taranaki coastline. At the base, Quaternary deposits overlie a subhorizontal erosional surface which truncates gently dipping Pliocene muddy sandstones about 2 m above present high-water mark (HWM). This erosional surface is interpreted as a wave-cut surface and forms the **Inaha Marine Terrace**; its age is estimated to be c. 100 000 years. Immediately overlying the wave-cut surface are marine and beach sands, formally designated as the **Inaha Formation.** These pass upwards to a thick sequence of volcaniclastic beds with interbedded lignites in which 6 distinct palynological zones (informally named Inaha A–F) are recognised. One of these (Inaha C) contains pollen indicative of a full forest cover dominated by *Dacrycarpus dacrydioides* and *Podocarpus spicatus.* The other lignites contain pollen spectra dominated by grasses and shrubs. The lignite containing the microflora representing Inaha C is formally named the **Manaia Lignite.** It represents a warm interstadial period estimated to be c. 80 000 years old.

Keywords Quaternary; wave-cut platforms; pollen analysis; Otiran Glacial; paleoclimatology; paleobotany; volcanism; Inaha Formation; Inaha Marine Terrace; Taranaki; new stratigraphic names

*Grid references refer to the 1:50 000 grid of the NZMS 260 topographical map series.

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INTRODUCTION

Constant tectonic uplift between Wanganui and Hawera on the southwest coast of North Island, New Zealand, has preserved an excellent record of sea-level fluctuations. Successive interglacial high sea levels have cut broad marine terraces backed by cliffs. These now form a broad flight of uplifted terrace and cliff sequences which have been described by Fleming (1953), Dickson et al. (1974), and Pillans (1981). These interglacial terraces usually carry a marine cover which often passes up into lignites, tephra, and beach-derived sands. West of Hawera, the terraces are overlain by thick volcanic deposits derived from the Taranaki volcanic centres of Egmont, Pouakai, and Kaitake (Neall 1979).

We describe in detail here a section exposed in the present coastal cliff near Hawera. It contains a record of climatic and volcanic events in this area since the cutting of the lowermost marine terrace by a high sea level of the Last Interglacial.

Definitions

In this paper we use the term **marine terrace** to describe a subhorizontal, erosional surface of marine origin. Evidence of marine origin may include boring of marine organisms into underlying strata and/or the presence of marine sediments directly overlying the surface (where such sediments are identified on the basis of sediment character or presence of marine fossils).

A **marine cliff** occurs at the **inland** margin of a marine terrace, and represents the shoreline at the culmination of the marine transgression which cut the marine terrace.

All the sediments (both marine and nonmarine) overlying a marine terrace are referred to as **terrace deposits.**

INAHA SECTION LITHOSTRATIGRAPHY

The section we describe here is exposed in coastal cliffs 10 km west of Hawera, and c. 200 m west of the mouth of Inaha Stream at grid reference Q21/103793* (Fig. 1). A detailed lithostratigraphic column of the section exposed at Inaha is presented in Fig. 2.

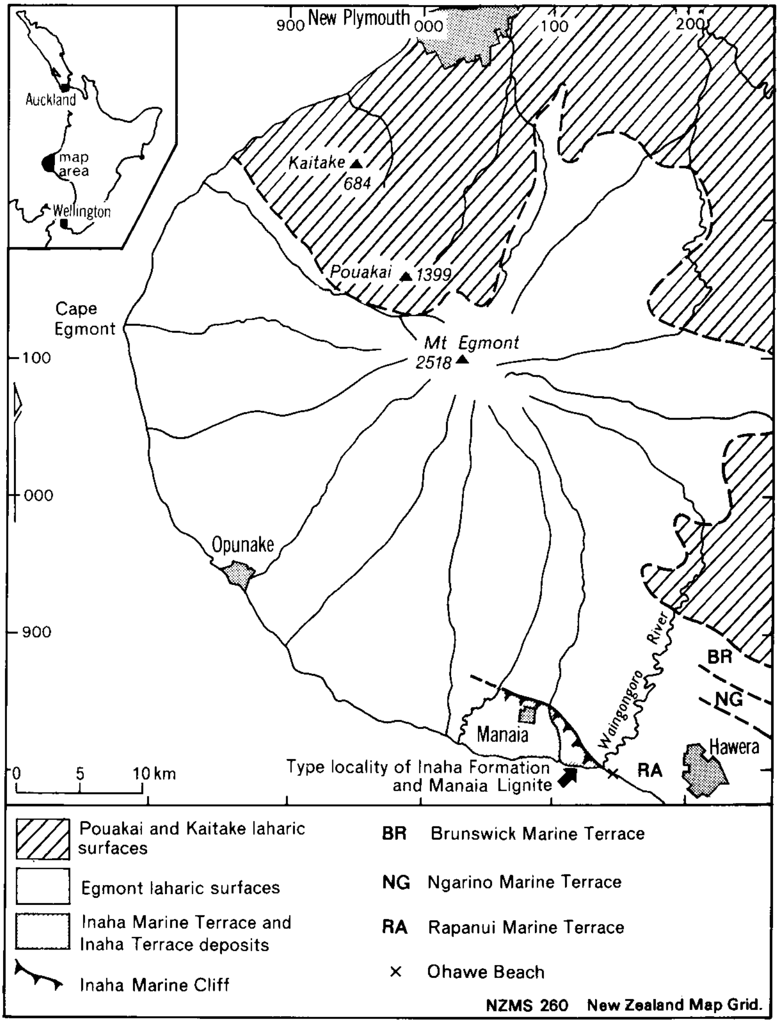
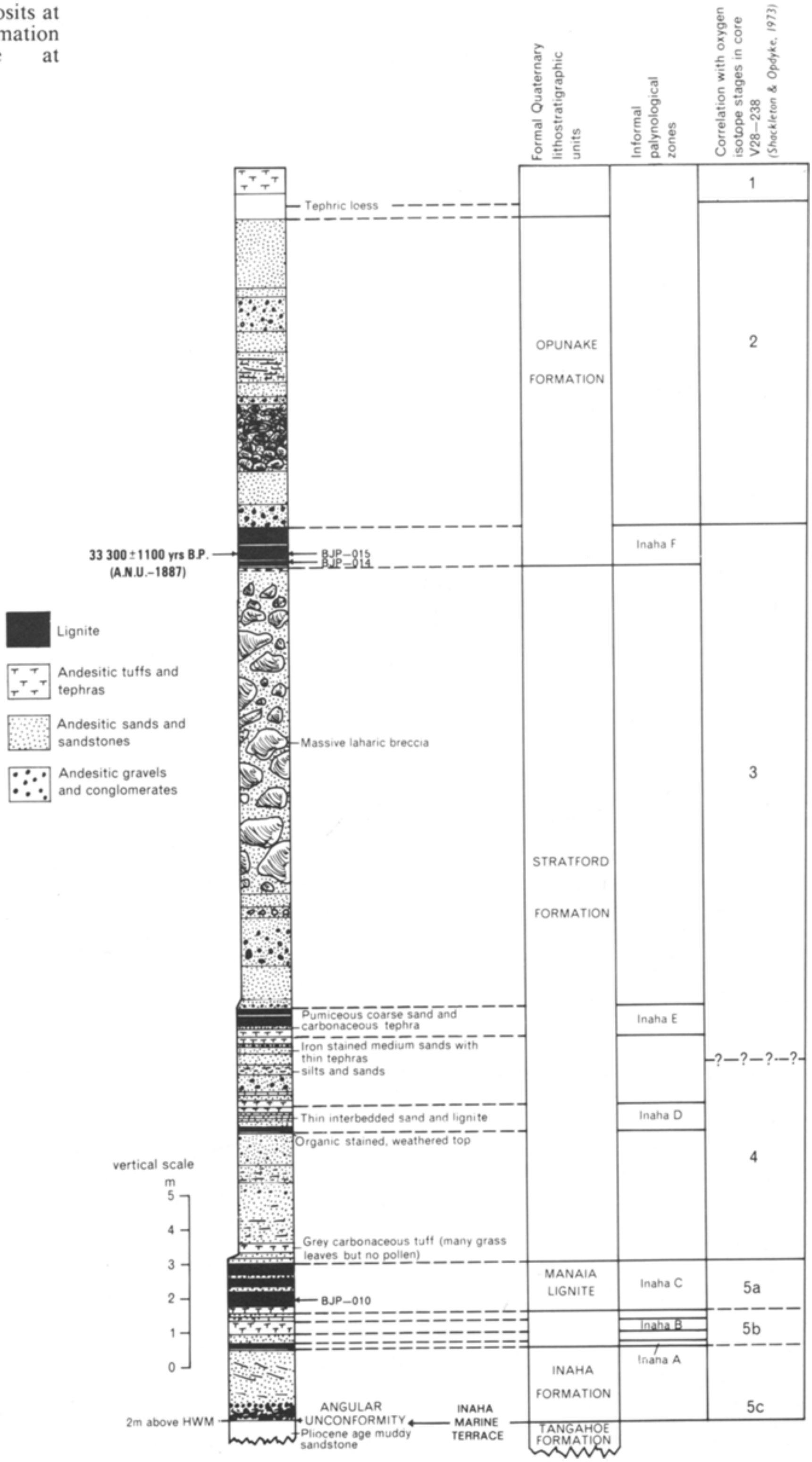


Fig. 1 Location of Inaha Terrace deposits, Taranaki, North Island, New Zealand.

At the base of the section there is an angular unconformity 2 m above high-water mark (HWM), underlain by the Pliocene Tangahoe Formation, a blue-grey muddy sandstone dipping 5° to the southwest, containing fossil shells including *Nemocardium* sp. The unconformity is sharp and planar with a small angular discordance. The erosion surface dips 3° to the WSW and can be traced several hundred metres westwards before it dips below present sea level. To the east it gradually rises to 8 m above HWM immediately west of the mouth of Waingongoro River (Q21/120792), where it is truncated by fluvial deposits. Overlying the unconformity is a 0.3 m thick gravel unit comprising rounded and subrounded boulders, up to 0.74 m diameter, in a pebble and cobble matrix. The gravels are 90% hard hornblende-augite andesites and 10% much softer sandstones eroded from the Pliocene strata beneath. These sandstones are extensively bored by worms and molluscs and contain fossils, identified by Dr A. G. Beu (pers. comm.), as the date mussel *Lithophaga (Zelithophaga) truncata* (Gray). These have bored by solution into the softer rocks. Samples collected from the matrix around the boulders are devoid of coccoliths because all calcareous material has been removed by the strongly leaching environment. The planar unconformity, and the marine fossils within the overlying bored boulders, confirms a marine origin for this surface. The wave-cut surface is here named the **Inaha Marine Terrace.**

Above the basal gravel unit is 1.87 m of soft, weakly cross-laminated, predominantly andesitic sand with minor granules, pebbles, and cobbles that

Fig. 2 Inaha Terrace deposits at type locality for Inaha Formation and Manaia Lignite at Q21/103793, Taranaki.



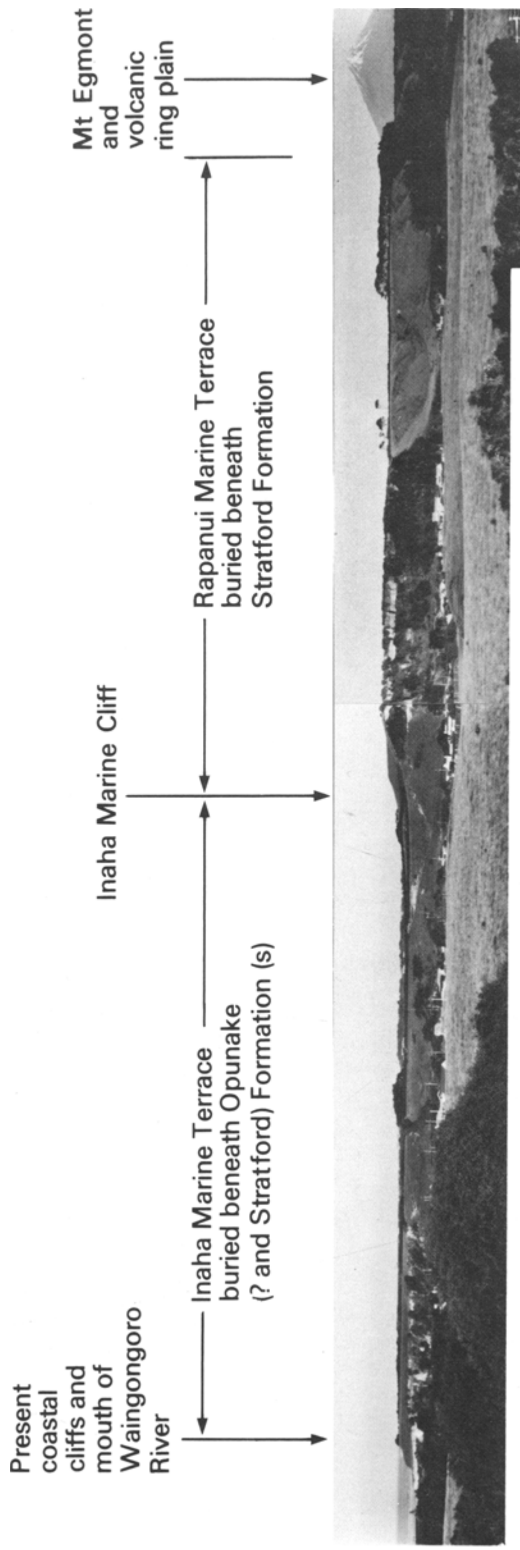


Fig. 3 Surface expression of Inaha Marine cliff, looking west across Waingongoro River, with Mt Egmont in distance to right.

become finer upwards and are extensively weathered and iron stained at the top. A sample sieved for grain-size characteristics is granular medium sand, which is moderately to poorly sorted, with a near-symmetrical leptokurtic grain-size distribution (parameters of Folk & Ward 1957). The gradational nature of the contact between the gravel and sand, and the presence of large bivalve casts in silty sand at the same stratigraphic position 1 km to the east, confirms the monogenetic, near-shore marine and beach origin of this unit. It is here formally defined as the **Inaha Formation**, named after Inaha Stream that flows to the sea 5.2 km southeast of Manaia. The type locality is designated in the South Taranaki coastal cliffs at Q21/103793, 450 m west of the Inaha Stream mouth. The formation is defined as the dominantly andesitic sands and gravels overlying the wave-cut surface exposed to the east and west of the Inaha Stream mouth. Inaha Formation is mapped from near the Waingongoro River mouth in the east to 1 km west of Inaha Stream where the formation dips beneath sea level. The formation is presumed to extend 3–4 km inland to the Inaha Marine Cliff (Fig. 3). The formation is considered younger than the Rapanui Marine Terrace into which marine erosion cut the Inaha Marine Terrace upon which the formation was deposited.

Above Inaha Formation is a black lignite, which is informally designated Inaha palynological zone A. It is overlain by 0.3 m of fine andesitic gravel with sharp upper and lower contacts, passing upwards to 0.4 m of fawn-grey lithified carbonaceous tuff containing many fine plant roots. The tuff is an unusually massive material that breaks into blocks along subconchoidal fractures, rather like chocolate. The tuff yields pollen and has been informally designated Inaha palynological zone B. Green mottles of vivianite are common. Towards the top, thin sand lenses intercalate before passing upwards to a prominent black tephric lignite with occasional wood fragments. Thin wedges of sand, up to 0.14 m thick, are interbedded within the prominent lignite, which exceeds 1 m in thickness. The lignite is coherent and lithified so as to form a distinctive protruding ledge in the near-vertical cliffs, above which softer lithologies erode more readily. This lignite is informally referred to as Inaha palynological zone C. Floristically and lithologically the lignite is so distinctive that it is here given formal lithostratigraphic designation as the **Manaia Lignite** after the South Taranaki township of Manaia. Its type locality is defined in the South Taranaki coastal cliffs at Q21/101794. Although it is exposed for only 2.5 km along the present coastline, it is an important unit as regards the vegetation and climatic history of the Taranaki region.

Above the Manaia Lignite are 3.5 m of coarse grey and yellow-brown sands with a 0.3 m carbonaceous tuff that yielded no pollen. Overlying these sands are 1.6 m of bedded tephric lignite, with thin coarse and medium sand lenses, informally referred to as Inaha palynological zone D. A further 1.8 m of laminated silts and sands overlie zone D. Thin allophanic tephras are interbedded and many mottles of green vivianite are present. These lithologies pass upwards to a 0.8 m thick lignite and blocky tuff sequence informally named Inaha palynological zone E. Here, thin pumiceous sands and ash occur as thin interbeds within the lignite.

The section above zone E (14.2 m above HWM) is dominantly volcaniclastic. Soft, grey andesitic sands and gravels, totalling 3.35 m thickness, were deposited as either distal-laharic or fluviatile sediments before they were buried by a massive 10 m thick breccia. This breccia is clearly of laharic origin, as it contains "floating clasts" suspended in a sandy matrix with no evidence of high temperatures. We correlate this laharic breccia, and the underlying sands and gravels which overlie zone E, with the Stratford Formation (Grant-Taylor & Kear 1970), although this unit is poorly defined in the Inaha region. An alternative correlation is that the Inaha breccia unit represents old lahars of the Opunake Formation. However, on the basis of the inferred age of the Inaha Marine Terrace, the former correlation is more likely.

The extent of the Inaha breccia unit along the coastline (which is at right angles to the flow direction), the inferred areal extent (minimum estimate 150 km^2), and the distance which the lahar must have travelled from the nearest known volcanic source vent (in the vicinity of Mt Egmont) all indicate that a massive collapse of a former volcanic cone at the site of the present Mt Egmont occurred. To create such a widespread and thick lahar, a lateral, if not total, collapse of at least 1.5 km^3 of an andesitic stratovolcanic cone must have taken place.

Above the laharic breccia is 1.2 m of black tephric lignite with thin lenses of pumiceous sand. This lignite is informally referred to as Inaha palynological zone F and wood (sample BJP-015) extracted from near the centre has been radiocarbon dated at 33 000 $\pm$ 1100 years B.P. (ANU1887)*. This establishes direct correlation with radiocarbon dates (Grant-Taylor & Rafter 1963; Neall 1979) obtained from the Opunake Formation (Grant-Taylor & Kear 1970), 40 km to the northwest. A thick sequence of andesitic gravel and sandstone overlies zone F, with a total stratigraphic thickness of 9.1 m. Each unit appears channelled in parts and seems to represent highly aqueous distal deposits of lahar flows from Mt Egmont. There are weak cross laminations in some units, but most appear massive, ranging from 0.22 to 2.0 m in thickness. They appear very similar to laharic sandstones and conglomerates visible in the type exposures of the Opunake Formation, and are correlated directly with them. These lahar deposits preceded the 23 000 year old collapse of the former Mt Egmont which produced the Pungarehu Formation of western Taranaki (see Neall 1979, pp. 11–13).

At the very top of the cliff exposure is 1.5 m of tephra and tephric loess correlated with deposits known to have accumulated over the past 20 000 years since deposition of the Aokautere Ash (from the Volcanic Plateau), recently discovered at 14 localities in South Taranaki (Geddes et al. 1981). A direct correlation of the top 1.5 m can be made with the profile exposed at a site of the Egmont loam, 7 km southwest of Hawera (Stewart et al. 1977), where detailed stratigraphic and paleoenvironmental interpretations of post-20 000 year old events have been elucidated.

DISTRIBUTION OF INAHA TERRACE DEPOSITS

The distribution of the Inaha Marine Terrace west of the Waingongoro River mouth is shown in Fig. 1. A marked linear topographic rise extends inland from near the mouth of the river at Q21/124793 (Fig. 3) and may be clearly traced 3 km northwest to Inaha at Q21/103823. Further westwards, the cliff has been partly buried by lahar deposits belonging to Opunake Formation, but can be tentatively traced a further 6 km northwest of Inaha to P21/051849. This topographic rise, which separates 2 subhorizontal land surfaces, is interpreted as the surface expression of a buried sea cliff which separates the Inaha Marine Terrace to the south from the older Rapanui Marine Terrace to the north (Fig. 3). It is here named the **Inaha Marine Cliff**. The cliff, which is oblique to the present coastline (Fig. 1), is inferred to have intersected the present coastline at the mouth of the Waingongoro River, and has since been removed by fluvial incision. Because of this erosion, the relationship between the 2 terraces has been previously poorly understood. East of Waingongoro River, the Inaha Marine Terrace has been removed by marine erosion, and the Rapanui Terrace is exposed in the modern coastal cliff. Immediately east of Waingongoro River, the Rapanui wave-cut surface lies 12 m above HWM and increases in altitude east-

*Laboratory number, Australian National University radiocarbon laboratory. (New Zealand Fossil Record number Q21/f78.)

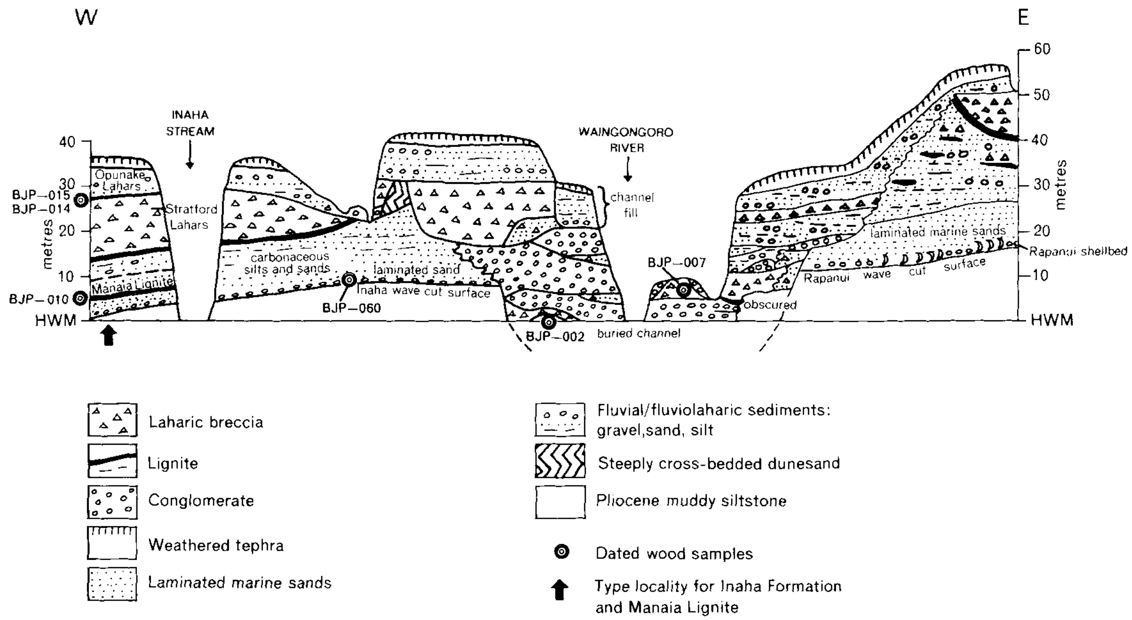


Fig. 4 Inaha to Ohawe Beach coastal section Q21/110793 to Q21/144784 (horizontal distance not to scale).

wards (Fig. 4). The deposits in the Inaha section are therefore inferred to postdate the cutting of the Rapanui Terrace, which is considered to have formed 120–140 000 years ago (Pillans 1981).

POLLEN ANALYSIS: RESULTS AND INTERPRETATIONS

A complete pollen diagram for the 6 Inaha palynological zones is given in Fig. 5. Sampling intervals were at c. 0.1 m where appropriate. Microscopic charcoal particles were abundant in all samples, with the exception of subzones C2 and C3. Interpretation of the zones is given below.

Inaha zone A

Gramineae levels are very high (39–52%) and there is a moderately large shrubland pollen total (40–60%), chiefly Compositae, *Dacrydium bidwillii* type, and *Coprosma*. Tree pollen levels are low (2–3%), mostly of *Nothofagus fusca* type, and there are only a few records of other tree pollen types. Mire herbs are not well represented, Cyperaceae and *Leptocarpus* being the only significant contributors.

The regional vegetation was predominantly grassland, but with a considerable shrub component. Compositae shrubland and grassland were probably the local dominants. There can have been no forest near the site at that time and possibly none in the Taranaki lowlands. The low amount of mire herbs suggests that the local environment of deposition was an accumulating soil, perhaps forming under shrubland, rather than a true mire.

Inaha zone B

Pollen concentration is low and there are high percentages of *Metrosideros* and *Dacrydium cupressinum*, and fern spores. There is obvious corrosion of pollen in these samples (leading to over representation of the more resistant spores), suggesting that the greater part of the tree pollen has either been reworked from older Quaternary sediments, or is the consequence of long-distance dispersal. The most abundant other pollen types are Gramineae, *Leptospermum*, *Myrsine*, Compositae, and *Coprosma*. *Drapetes* attains the exceptionally high level of 2% in 1 sample. Mire herbs are represented by low percentages of Cyperaceae.

This zone is very similar to zone A. Grassland, shrubland, and open ground were dominant, and there was little or no forest in the region.

Inaha zone C

This is the most detailed sequence of the section and is sufficiently complex to require subdivision. Four subzones are recognised and named Inaha C1–C4.

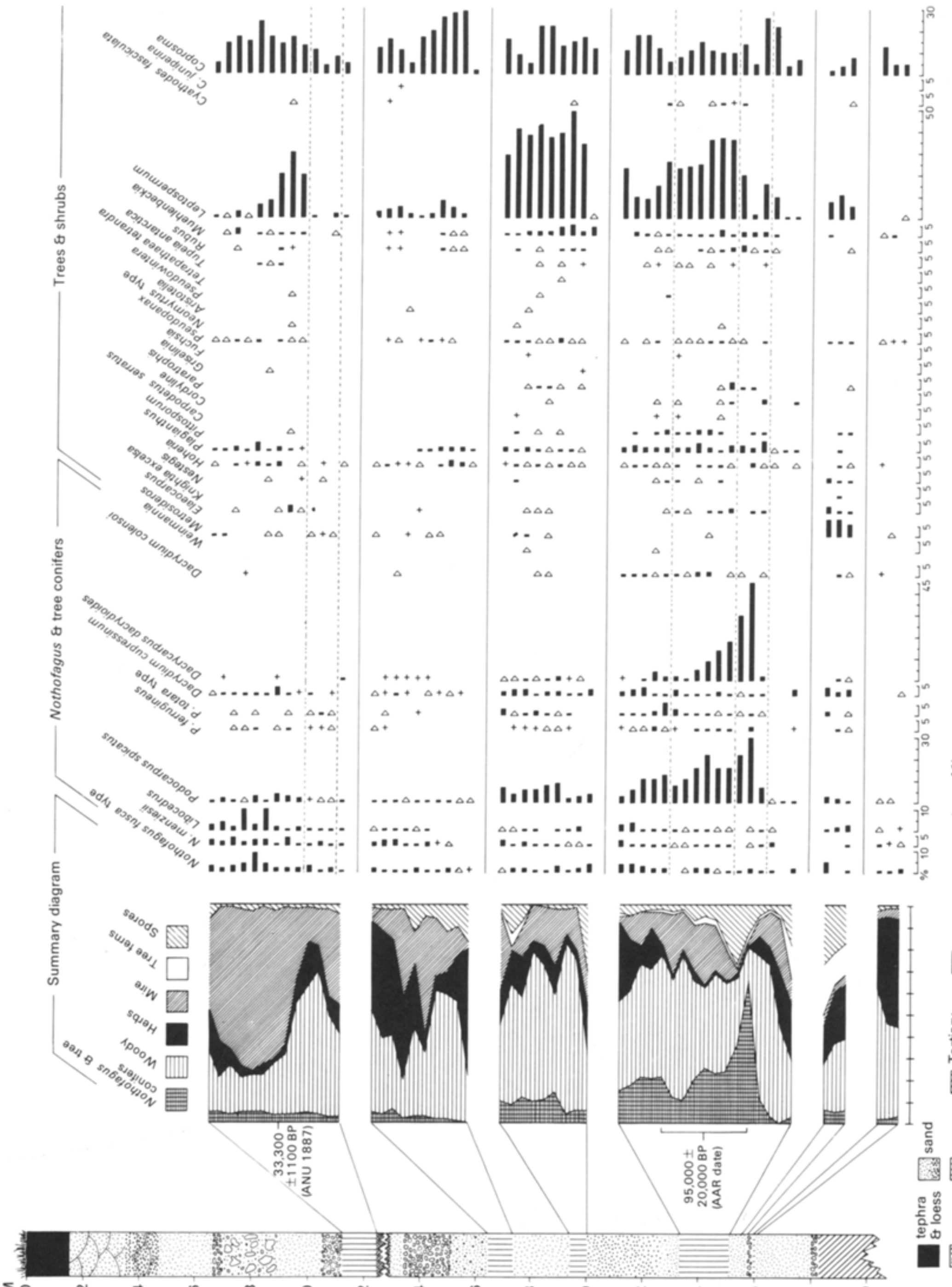


Fig. 5 Pollen diagram of the Inaha Terrace deposits, Taranaki, New Zealand.

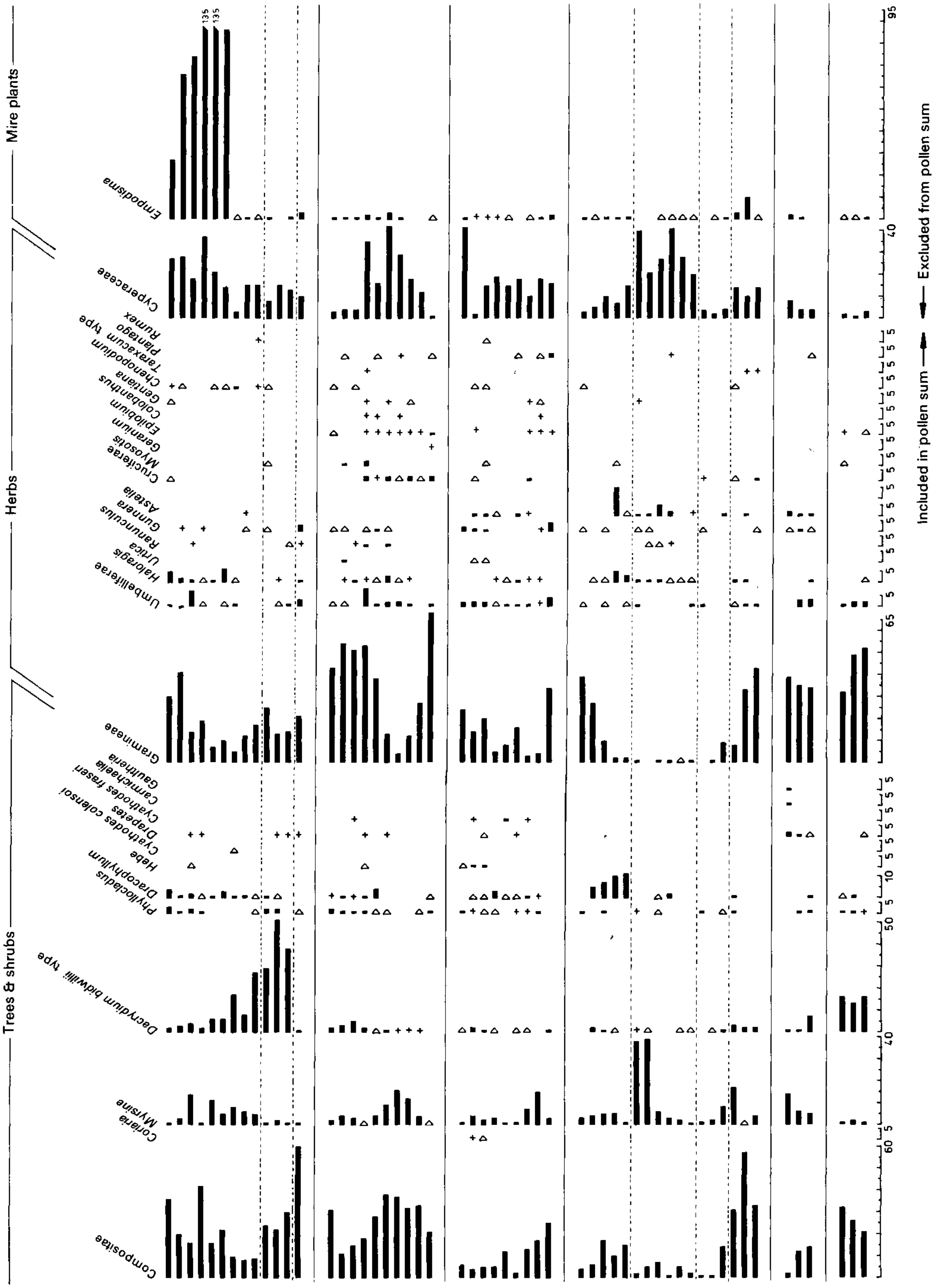


Fig. 5 *(continued).*

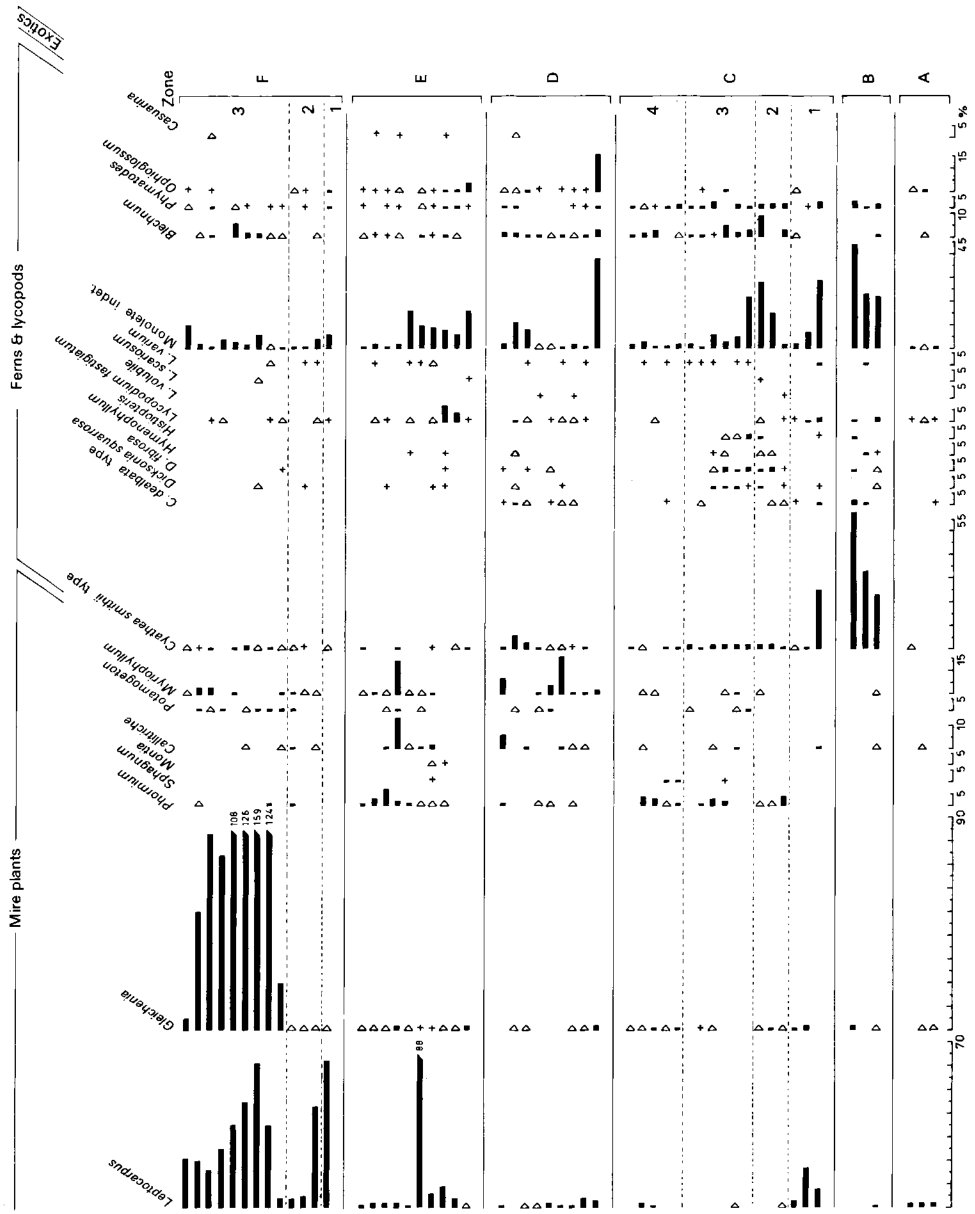


Fig. 5 (continued).

Inaha C1: The first sample of this subzone has a high level of spores and an anomalously high *Dacrydium cupressinum* percentage. It is likely that, as in zone B, enhancement of spore percentages by differential corrosion has occurred, again suggesting reworking of older pollen. This subzone is defined by initially high, but rapidly dropping, Gramineae percentages, and by very low levels of tree pollen. Compositae are well represented and the other main shrubland types, *Leptospermum, Coprosma*, and *Myrsine*, increase as Gramineae decline. Mire plant pollen, especially that of Cyperaceae, *Leptocarpus*, and *Empodisma*, is present in moderate quantities.

Inaha C2: Through this subzone there is an increase in the amount of tree pollen from the previous level of about 3% to over 60%. At the same time, Gramineae percentages fall from c. 10% to negligible levels. *Dacrycarpus dacrydioides, Podocarpus spicatus*, and to a much lesser extent, *Plagianthus* cf. *betulinus*, are the main tree types. Pollen of *Dacrydium cupressinum, Elaeocarpus, Nothofagus*, and *Libocedrus* is regularly encountered, but none of these reach levels of more than a few percent. The same shrubland types as in subzone C2 are present, but the total amount of shrubland pollen is much reduced. During the peak of this tree-dominated phase, only low percentages of mire herbs are recorded. A large number of uncorroded monolete and tree fern spores is present.

Inaha C3: *Dacrycarpus* undergoes a steady decline, and in the last few samples drops to percentages of 1–2%. *Podocarpus spicatus* falls from the peak values of subzone C2, but maintains relatively high levels. *Plagianthus* and *Dacrydium cupressinum* are unchanged, and *Libocedrus* and *Nothofagus menziesii* are consistently present. Gramineae percentages do not rise above 1% in this subzone. Shrubland pollen levels rise from the low of the last subzone. Mire herb pollen (most from Cyperaceae) recovers its former levels and is abundant throughout the zone.

Inaha C4: Gramineae begin to increase and by the end of the subzone make up nearly 40% of total pollen. *Podocarpus spicatus* drops steadily from 13% to 3%. *Dacrycarpus*, after a slight recovery from the low values at the end of subzone C3, falls to trace levels. *Plagianthus* is unaffected, but there are increases in the latter half of the subzone in *Libocedrus, Dacrydium cupressinum*, and *Nothofagus*; none of these types exceed percentages of 4%. Total shrubland pollen percentage does not change much, but Compositae increase markedly, as do *Coprosma* and *Dracophyllum*. Cyperaceae become less abundant, but there is no increase in the other mire herbs.

The first subzone, C1, differs little from the shrub and grass-dominated zones A and B. Subzone C2 records a rapid transition from open shrubland to forest. *Dacrycarpus* swamp forest occupied the site, while the surrounding landscape had a cover of *Podocarpus spicatus/Plagianthus* forest. Only small numbers of other forest trees and tree ferns were present. Subzone C3 saw the decline of *Dacrycarpus*, as shrubs (mainly *Leptospermum* and *Coprosma*) and sedges replaced it as the local dominant. This appears to have been the consequence of spread of the mire. *Podocarpus spicatus* continued to dominate. During subzone C4, although *Podocarpus spicatus* remained abundant, *Dacrydium cupressinum* increased, while grassland spread. *Dracophyllum*, rare elsewhere in the Inaha section, was abundant on the site at this time. It appears that during subzone C4, forest became restricted.

Inaha zone D

Although there are major changes in some of the more important pollen curves throughout this zone, the complexity is not such as to demand subdivision.

Podocarpus spicatus averages about 7% for most of the zone, and *Dacrydium cupressinum, Nothofagus menziesii*, and *N. fusca* types are relatively well represented. *Plagianthus, Hoheria, Pittosporum, Elaeocarpus*, and *Paratrophis* are present. Gramineae percentages are erratic, rising as high as 16% and falling as low as 3% in the middle portion of the zone. The first sample and the last 3 are, however, high in Gramineae. *Leptospermum* dominates the shrub pollen and, with the exception of the first sample of the zone which has only a trace amount, averages almost 40% of terrestrial pollen. *Coprosma*, Compositae, and *Myrsine* are the only other shrub types of importance. Herbs of open places, such as *Epilobium, Chenopodium* and *Plantago*, are frequent. Cyperaceae are the major mire herbs, but *Leptocarpus* is common in the first 2 samples of the zone. *Myriophyllum* is found throughout and reaches 16% of the pollen sum in 1 sample. Tree fern and monolete fern levels are low except in the first and the last 3 samples; in both, enhancement of spore percentages by corrosion of susceptible pollen types is likely to be the cause.

Zone D bears a strong resemblance to subzone C4. The main vegetation was shrubland, with fluctuating amounts of grass. The relatively high *Podocarpus spicatus* percentages indicate that there was some forest, most likely in the hilly interior of the region, which may have also had small patches of *Nothofagus* and *Dacrydium cupressinum* trees. The site itself was a wet sedge mire, with a thick *Leptospermum* overstorey.

Inaha zone E

Podocarpus spicatus and other podocarps are at levels of 1% or less for the entire zone, and there are only small amounts of other tree types. Gramineae percentages are high, especially in the first sample, but fall rapidly to a low 4% and then climb as rapidly back to an average of 50% for the last part of the zone. Compositae, *Coprosma*, and *Myrsine* are the shrubland dominants. *Dacrydium bidwillii* type becomes more common in the top half of the diagram, the first substantial record of this taxon since subzone C1. Cyperaceae and *Leptocarpus*, the latter reaching an exceptional figure of 88% of terrestrial pollen, are the mire herb dominants for the lower three-quarters of the zone; the upper portion has *Phormium*, *Leptocarpus*, and Cyperaceae as the most common mire herbs. There are fluctuating amounts of *Callitriche*, *Potamogeton*, and *Myriophyllum*. Tree fern spores are rare; monolete fern spores are quite abundant.

There was no podocarp-hardwood forest near the site at this time. There may have been some pockets of *Nothofagus menziesii*, but no other form of tree vegetation is likely to have existed in the region. Grassland and shrubland completely dominated the landscape, Compositae shrubland being especially prominent. The site itself was a wet sedge swamp at first, but later became a *Phormium*-sedge mire.

Inaha zone F

This sequence is subdivided into 3 subzones.

Inaha F1: This subzone consists of 1 sample only. It has moderately high Gramineae (21%), high Compositae (60%), and very low tree pollen levels. *Leptocarpus* completely dominates the mire herb assemblage.

Inaha F2: This subzone is characterised by very high percentages of *Dacrydium bidwillii* type; *Coprosma* and Compositae are the only other significant contributors to the shrub total. Gramineae percentages are moderate, but tree pollen frequencies are extremely low and mainly of *Nothofagus* and *Libocedrus*. Cyperaceae is present in some quantity while *Leptocarpus* falls from 60% to 4%.

Inaha F3: *Libocedrus*, *Nothofagus fusca* type, *N. menziesii*, *Podocarpus spicatus*, and *Dacrydium cupressinum* are relatively common; the first 3 attain their peak abundances for the whole sequence. *Dacrydium bidwillii* type drops to an average of 4% after the first few samples, while *Leptospermum* peaks early at 30% and then drops to low frequencies. The remainder of the shrub pollen is derived mostly from Compositae, *Coprosma*, and *Myrsine*. Gramineae percentages generally remain high but are depressed somewhat in the middle of the subzone. In the last sample of the subzone they recover to a level of 30%. *Gleichenia* and *Empodisma* make a dramatic appearance through the subzone, rising quickly to extremely high levels. Both these plants are uncommon in earlier zones of the Inaha sequence. *Leptocarpus* and Cyperaceae remain abundant.

Subzone F1 is typical of the other shrubland/grassland zones in the Inaha Terrace deposits. Subzone F2 is distinguished by the occurrence of *Dacrydium bidwillii* group shrubs on the site. Wood from this level has been identified (R. N. Patel, Botany Division, DSIR) as belonging to this group, most probably being of *D. biforme*. The landscape remained treeless and dominated by shrubland/grassland. During subzone F3, *Dacrydium bidwillii* group shrubs may have been excluded from the local vegetation by what appears to be the development of the mire into an extensive, raised bog in which *Gleichenia* and *Empodisma* were the major peat formers. Although the immediate area was still dominated by shrubland/grassland, there was a noticeable increase in trees, mainly *Nothofagus menziesii*, *Libocedrus* and, to a limited extent, *Podocarpus spicatus* and *Dacrydium cupressinum*. These trees may have grown in small groves in sheltered areas in the ranges.

DATING THE INAHA TERRACE DEPOSITS

Three wood samples were submitted for radiocarbon dating (cellulose fraction). At the Inaha section, wood sample BJP-015 from the centre of unit Inaha F was radiocarbon dated at 33 300 $\pm$ 1100 years B.P. (ANU1887). At the eastern end of the Inaha Marine Terrace, near the mouth of Waingongoro River, the terrace deposits have been truncated by fluvial incision. However, intercalated within the terrace deposits, but stratigraphically overlying the marine sand of the Inaha Formation, are fluvial gravels (Fig. 4). These gravels contain wood (BJP-002) which was submitted for radiocarbon dating (ANU1881) and for which the sample was beyond the radiocarbon detection limit of c. 52 000 years B.P., and is reported as "background ^{14}C count". The first sample (BJP-007) also from these gravels yielded a date of > 35 200 years B.P. (ANU1885).

Four samples including one of the above (BJP-015) from the Inaha Marine Terrace deposits were also dated using the extent of isoleucine epimerisation (see Schroeder & Bada (1976) for review of amino acid racemisation dating methods). Samples were calibrated against 4 wood samples which closely underlie a rhyolitic tephra, fission-track dated at 370 000 ± 50 000 years at Q21/346806 some 15 km northeast of Hawera (Pillans 1981; Pillans & Kohn 1981). Results are summarised in Table 1 and support our interpretation that the Inaha Marine Terrace is younger than the c. 120–140 000 year age of the Rapanui Marine Terrace (Pillans 1981). Unfortunately, in such young samples, the extent of isoleucine epimerisation is small, and the dating method loses sensitivity. However, simply on a "count-forward-from-120 000 year" basis, the Inaha Marine Terrace is likely to have been cut by a widely identified high sea level c. 100 000 years ago (Pillans 1981). On this basis, and in conjunction with the racemisation age determinations, we assign an age of c. 100 000 years to Inaha Formation and an age of c. 80 000 years to the Manaia Lignite.

DISCUSSION

The interpretation of the Inaha sequence depends to a large degree on the status of the polliniferous lignite beds. Are they a portion of the vegetation history record randomly preserved by shifting patterns of aggradation, or do they represent discrete periods of relatively benign climate, separated by episodes characterised by sparse vegetation and unstable landscapes? The lower 2 palynological zones, A and B, are almost certainly preserved organic layers that reflect the climatic conditions during phases of active sedimentation. Zone C clearly represents a major climatic amelioration. Zones D, E, and F are somewhat problematical as they indicate partially forested landscapes. However, each sequence begins with a grassland phase which is followed by a period of relative shrubland dominance during which grass pollen levels are low and, in zones D and F, tree types are relatively common. Towards the top of each horizon, grass pollen levels increase. This movement from open grassland through to almost closed shrubland, and then back to grassland, suggests that these peat horizons record a climatically determined cycle.

At least 4 of the 6 zones preserved in the Inaha Terrace deposits can be regarded as being primarily the consequence of a period of relatively mild climate leading to more complete vegetative cover and less erosion. However, given the active erosion/deposition regime throughout much of the sequence, there is no guarantee that all significant interstadial episodes are recorded here. Nevertheless, nearly 2 m of lignites in the Inaha Terrace deposits represent many thousands of years of organic accumulation and a significant proportion of the total time represented in the Inaha section.

Vegetation and climate

Zones A and B and subzone C1 represent periods characterised by treeless landscapes with an incomplete vegetation cover of low-growing shrubland/grassland. These indicate a cool, dry, unpredictable

Table 1 Radiocarbon and racemisation dates relating to Inaha Terrace deposits. (For stratigraphic positions see Fig. 4.)

Sample no.	Location With metric 1:50 000 grid references (NZMS 260) map series	^{14}C age (years B.P.)	Racemisation age* (years B.P.)
BJP-002	Q21/124792: Fluvial deposit incised within Inaha Marine Terrace (100 m west of Waingongoro River.)	"Background" (ANU-1881)	—
BJP-010	Q21/104794: Manaia Lignite, Inaha section	—	95 000 ± 20 000
BJP-014	Q21/104794: Opunake Formation, Inaha section	—	30 000 ± 20 000
BJP-015	Q21/104794: Opunake Formation, Inaha section	33 300 ± 1100 (ANU-1887)	25 000 ± 20 000
BJP-060	Q21/111793: Inaha Formation to east of Inaha section	—	80 000 ± 20 000
BJP-007	Q21/126791: Lahar in valley fill, Ohawe Beach	> 35 200 (ANU-1885)	—

*Calibrated to Meremere Lignite (400 000 years B.P.) — see Pillans & Kohn (1981) for details climate which led to sparse woody vegetation and widespread erosion.

Subzones C2 and C3 represent the only periods during which forest completely occupied the Taranaki lowlands. Modern pollen spectra from the drier parts of New Zealand, especially the east coast of both islands, resemble those of zone C quite closely. As the region, until recently, had dense *Dacrydium cupressinum*-dominated forests, rainfall was probably much lower during zone C times then the present-day average of 1200 mm, and it may have been as low as 600–800 mm with frequent droughts. Lower rainfall may not have been the only reason for the dominance of *Podocarpus spicatus* and *Dacrycarpus* relative to *Dacrydium cupressinum*; fresh, alluvial soils favour these species and stands of *Dacrycarpus* are often found on river terraces (Wardle 1974). Recent deposits of volcanic ash can also support dense forests of *Podocarpus spicatus* (McKelvey 1963). It is difficult to give any estimate of the temperatures prevailing during this interval. Forests, much like that represented by zone C, extend from lowland areas into the montane zone, and occur from the far north to the south of South Island.

Zone C reflects a major climatic event, during which forest almost certainly covered the northern and central areas of North Island, and possibly areas further south. Holocene pollen diagrams from the Taranaki region do not closely resemble that of zone C, and therefore it is unlikely that it was an interglacial, but was rather a major interstadial.

Zone D is the only other zone to record appreciable amounts of forest, but it was some distance from the site and restricted in extent. This is true of zone E as well, but trees must have been even rarer in the Taranaki region. *Leptospermum* shrubland pollen is less common in zone E than in zones C and D, and this may reflect an increasingly severe climate. Although these periods with open shrubland and grassland were characterised by climates unsuitable for forest, there is no reason for supposing that they were particularly cold. Many of the plants recorded do not grow above the regional tree limit at present, and 1 of the common mire plants recorded, *Leptocarpus*, does not occur above 600 m in the central North Island (McGlone et al. 1978).

Zone F is very different from the other zones dominated by shrubland and grassland. *Dacrydium biforme* was abundant and *Nothofagus menziesii* and *Libocedrus* were more common than at any other point in the development of the Inaha Terrace deposits. These trees are generally moisture loving, and rainfall would have been moderate and well distributed. It is possible that a raised bog developed at around this time, and this also suggests frequent rainfall.

There is evidence from elsewhere in New Zealand that the period around 30 000 years ago was one of the warmest and wettest of the late Otiran. In Auckland (Searle 1964), Gisborne, and Bay of Plenty there are records of conifer-hardwood forests at this time (McGlone 1980).

The rarity of forest in the South Taranaki lowlands for much of the Otiran is part of the wider problem of why forest trees, and in particular hardy *Nothofagus* spp., were generally excluded from similar lowland areas throughout New Zealand. Lower temperatures would be an obvious explanation, but this is unlikely. Many of the plants that were abundant during the Otiran do not exceed the present-day regional tree limit, and near the top end of their altitudinal range they are often restricted in distribution (e.g., *Leptospermum*). Sites from the upland Ruapehu area that cover the same time range as zone F show a very similar vegetation pattern of shrubland and grassland, with many of the same plants involved, despite their average altitude being some 600 m higher (McGlone & Topping 1983). If temperatures in Inaha during the treeless shrub-dominant phases were equivalent to those prevailing at treeline at present, the sites on Ruapehu should have been above the limit for wood vegetation.

Although low temperatures played a role in maintaining a treeless landscape in southern Taranaki for the greater part of the Otiran, other factors must have been important. Wind, frost, and drought, combined with generally lower temperatures, may have acted to exclude forest from most sites. Also, because nearly all the pollen spectra, with the exception of those in zones C2 and C3, are associated with abundant microscopic charcoal fragments, it seems likely that fire was important, probably as a consequence of volcanic activity and wind, lower rainfall, and frequent drought.

Recovery of low subalpine forest after fire is slow. Calder & Wardle (1969) estimate that it can take up to 200 years before such species as *Dracophyllum longifolium, Dacrydium biforme*, and *Libocedrus bidwillii* reach maturity. In subalpine shrubland, the early dominants after fire are scrubby composites such as *Senecio bennettii* and *Cassinia fulvida*, and various *Hebe* species, but it takes at least 75 years before *Dracophyllum longifolium* and *Phyllocladus alpinus* regain their original dominance. Calder & Wardle also found that although *Nothofagus solandri* var. *cliffortioides* often regenerated rapidly after fire, there was little tendency for it to invade shrubland and grassland beyond the original forest boundaries. Burrows (1977) has shown that there are severe limitations to the establishment of *Nothofagus* seedlings in the montane grasslands of the Cass Basin, Central Canterbury. Grasses compete strongly against the seedlings, and, in many years, the summers are too hot and dry and the winters too cold to permit survival. Only in shrubland, and especially *Leptospermum* shrubland marginal to forest, is seedling establishment successful.

Even relatively infrequent fires could eliminate or severely reduce the amount of *Nothofagus* forest and restrict the taller, slower-growing shrub and small-tree species such as *Dacrydium biforme* and *Phyllocladus alpinus*. However, fire would encourage shrubs such as *Hebe*, *Leptospermum*, and *Coprosma* as well as woody and herbaceous composites, herbs, and grasses. There would tend to be a mosaic of vegetation types produced, with taller shrubland in areas sheltered from fire, or not recently burnt, and open grass and shrub-dominated vegetation elsewhere.

Volcanic history

The presence of well-rounded andesitic boulders in the Inaha Formation is indicative of the presence of a distant andesitic volcano that was almost certainly to the north c. 100 000 years ago. This may have been the Pouakai volcano or any early cone at the Egmont centre. From evidence at the Inaha section it appears that about 60–70 000 years ago volcanic activity increased markedly, consistent with previous evidence from tephra accumulation rates in North Taranaki (Neall 1979). Fluvial and laharic sand and gravel deposits were overlain about 45 000 years ago by a massive lahar from the Egmont centre that is tentatively correlated with the Stratford Formation. A type locality has never been designated for this formation and in this paper it is recognised as all those deposits underlying the Opunake Formation and overlying the Manaia Lignite. A period of quiescence and peat formation ensued from which wood has been dated around 33 000 years old. This peat was then buried by a second period of active lahar aggradation, the deposits of which are correlated with the Opunake Formation. This formation was deposited prior to a massive collapse of the former cone at Egmont centre (deposits of which are mapped further to the west of the Inaha section), about 23 000 years ago. No laharic deposits of the post-20 000 year period are in the Inaha section.

Correlation of the Inaha sequence

At present there is no good dating control between 40 000 and 100 000 years B.P. so that only tentative correlations can be made.

The high sea level that cut the Inaha Marine Terrace around 100 000 years ago presumably represents an episode within the Last Interglacial. This high sea level stand was followed by a period of cool climate and a treeless landscape in South Taranaki (Inaha zones A and B). Later, about 80 000 years ago, the Manaia Lignite (Inaha zone C) records a warming, during which forest dominated the region. After this there was an onset of cool climate which was interrupted by 2 minor climatic ameliorations. During the first amelioration, which is undated, shrubland and grassland were dominant, but podocarp forest was still important in some areas, and the climate was cool and probably somewhat dry (Inaha zone D). During the second amelioration, between 40 and 30 000 years ago, the climate was cool, but with seemingly high effective precipitation (Inaha zone F).

The section records 2 phases of very active lahar aggradation in South Taranaki, tentatively correlated with the Stratford and Opunake Formations. Suggested ages on the basis of dates and accumulation rates are: Opunake Formation 23 000–40 000 years old; Stratford Formation 40 000–80 000 years old.

The Manaia Lignite occupies an important stratigraphic position with respect to the chronostratigraphy of the late Quaternary in New Zealand. Its forest-dominated floral assemblage may represent conditions either at the end of the Last Interglacial (Oturian Stage) or of an early interstadial of the Last Glaciation (Otiran Stage). Although Pillans (1981) has advocated placing the boundary between the Oturian and Otiran Stages at the top of the Manaia Lignite, assignment of the Manaia Lignite to the early Otiran cannot be excluded on present evidence.

A number of climatic events represented in the Inaha section may be tentatively matched with those inferred from oxygen isotope stratigraphy in core V28-238 from the west Pacific Ocean (Shackleton & Opdyke 1973) and New Guinea coral reefs (Chappell 1974). For example, the cutting of the Inaha Marine Terrace, followed by the forest phase recorded in the Manaia Lignite, are correlated with oxygen isotope stages 5c and 5a, respectively dated at around 100 000 and 80 000 years old. Similarly, the c. 33 000 year old lignite records a partly forested phase during the latter stages of oxygen isotope stage 3. Well-dated coral reefs in New Guinea that record relative high sea level stands at c. 100 000, 80 000, and 30 000 years ago (Chappell 1974) may correlate with the Inaha Formation, Manaia Lignite (zone C), and the basal lignite of the Opunake Formation (zone F), respectively, in the Inaha section.

Although not providing a continuous record of climatic change, the Inaha section is one of the most complete for this age range in North Island. In conjunction with other sections exposed along the South Taranaki coast, it provides one of the best opportunities for more detailed reconstructions of the tempo of climatic and volcanic events in western North Island, New Zealand.

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REFERENCES

Burrows, C. J. 1977: Forest vegetation. Pp. 233–257 *in:* Burrows, C. J. *ed.* Cass. History and science in the Cass District, Canterbury, New Zealand. University of Canterbury.

Calder, J. S.; Wardle, P. 1969: Succession of subalpine vegetation at Arthur's Pass, New Zealand. *Proceedings of the New Zealand Ecological Society 16*: 35–47.

Chappell, J. 1974: Geology of coral terraces, Huon Peninsula, New Guinea: a study of the Quaternary tectonic movements and sea level changes. *Bulletin of the Geological Society of America 85*: 553–570.

Dickson, M.; Fleming, C. A.; Grant-Taylor, T. L. 1974: Ngarino Terrace: an addition to the Late Pleistocene standard sequence in the Wanganui-Taranaki District. *New Zealand journal of geology and geophysics 17*: 789–798.

Fleming, C. A. 1953: The geology of Wanganui Subdivision. *New Zealand Geological Survey bulletin 52*: 362 p.

Folk, R. L.; Ward, W. C. 1957: Brazos River bar: a study in the significance of grain-size parameters. *Journal of sedimentary petrology 27*: 3–26.

Geddes, A. M.; Neall, V. E.; Stewart, R. B. 1981: Recent discovery of the westernmost occurrences of Aokautere Ash and implications for the Late Quaternary in Taranaki. *In:* Howorth, R.; Froggatt, P.; Vucetich, C. G.; Collen, J. D. *ed.* Proceedings of tephra workshop, June 30th – July 1st 1980, Victoria University of Wellington. *Publication of Geology Department, Victoria University of Wellington no. 20*: 29–32.

Grant-Taylor, T. L.; Kear, D. 1970: Geology. Pp. 20–33 *in:* Land inventory survey, Waimate West County. Wellington, Department of Lands and Survey.

Grant-Taylor, T. L.; Rafter, T. A. 1963: New Zealand natural radiocarbon measurements I–V. *Radiocarbon 5*: 118–162.

McGlone, M. S. 1980: Late Quaternary vegetation history of central North Island, New Zealand. Unpublished Ph.D thesis lodged in the Library, Canterbury University, Christchurch, New Zealand.

McGlone, M. S.; Topping, W. W. 1983: Late Quaternary vegetation, Tongariro region, central North Island, New Zealand. *New Zealand journal of botany 21*: 53–76.

McGlone, M. S.; Nelson, C. S.; Hume, T. M. 1978: Palynology, age and environmental significance of some peat beds in the Upper Pleistocene Hinuera Formation, South Auckland, New Zealand. *Journal of the Royal Society of New Zealand 8*: 385–393.

McKelvey, P. J. 1963: The synecology of the West Taupo indigenous forest. Wellington, Government Printer, 127 p.

Neall, V. E. 1979: Sheets P19, P20, & P21—New Plymouth, Egmont and Manaia. Geological map of New Zealand 1:50 000. 3 maps and notes, 36 p. Wellington, New Zealand. Department of Scientific and Industrial Research.

Pillans, B. J. 1981: Upper Quaternary landscape evolution in South Taranaki, New Zealand. Unpublished Ph.D thesis, Australian National University.

Pillans, B. J.; Kohn, B. P. 1981: Rangitawa Pumice: a widespread(?) Quaternary marker bed in Taranaki–Wanganui. *In:* Howorth, R.; Froggatt, P.; Vucetich, C. G.; Collen, J. D. *ed.* Proccedings of tephra workshop June 30th – July 1st 1980, Victoria University of Wellington. *Publication of Geology Department, Victoria University of Wellington no. 20*: 94–104.

Schroeder, R. A.; Bada, J. L. 1976: A review of the geochemical applications of the amino acid racemization reaction. *Earth science reviews 12*: 347–391.

Searle, E. J. 1964: City of volcanoes. Auckland, Pauls Book Arcade, 112 p.

Shackleton, M. J.; Opdyke, N. D. 1973: Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V28-238: oxygen isotope temperature and ice volumes on a 10^5 and 10^6 year scale. *Quaternary research 3*: 39–55.

Stewart, R. B.; Neall, V. E.; Pollok, J. A.; Syers, J. K. 1977: Parent material stratigraphy of an Egmont loam profile, Taranaki, New Zealand. *Australian journal of soil research 15*: 177–190.

Wardle, P. 1974: The Kahikatea (*Dacrycarpus dacrydioides*) forest of South Westland. *Proceedings of the New Zealand Ecological Society 21*: 62–71.