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Pleistocene palynology of the Petone and Seaview drillholes, Petone, Lower Hutt Valley, North Island, New Zealand

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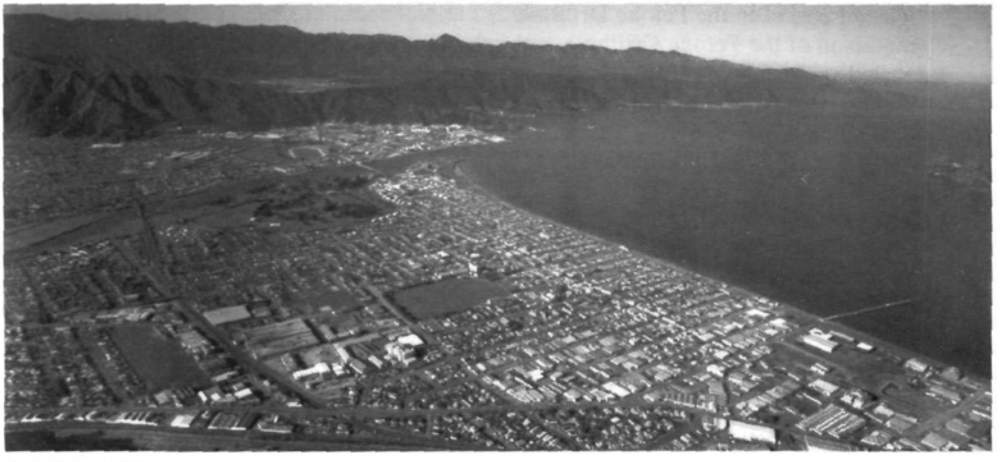

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A mid to late Pleistocene coastal sedimentary sequence drilled to a depth of 311.2 m (299 m of which was composed of Quaternary sediments) at Petone, near Wellington, New Zealand, consists of fossiliferous sands, silts, clays, and occasional peaty and slightly carbonaceous horizons, and provides a discontinuous pollen profile extending from the Postglacial to as far back as about 350,000 years ago. The sequence includes four major cold periods and four major warm periods, although minor fluctuations are recognised within some of these periods. At Seaview, near Petone, another drillhole encountered similar sediments, with 175.3 m of sediment spanning the same period of time and representing a marked eastward thinning from the deeper part of the Lower Hutt/Port Nicholson basin penetrated by the Petone Drillhole.

Large-scale climatic shifts from warm to cool in the Petone area were represented by periods of substantial erosion and/or deposition of coarse gravel resulting in long breaks between pollen-bearing sequences. Nine biozones can be recognised in the pollen profiles; these are related to the lithology, local and regional surface formations and local climatic stages, and tentatively correlated with oxygen isotope stages. Biozone P6 (late Pleistocene Oturi or Kaihinu Interglacial) contains taxa restricted today to the north of North Island, representing the period of maximum warmth recognised in the study, and may correlate with oxygen isotope stage 5. This comparison and the radiocarbon-dated Postglacial (Biozone P9), form the two tie points required for an attempt to correlate the pollen sequence with the oxygen isotope scale. From the top of the sequence, the other biozones are correlated as follows: – Biozone P8 with the peak of the Last Glaciation, Biozone P7 the earlier part of the Last Glaciation (Otira Glacial), Biozone P5 the Waimea Glacial, Biozone P4 the Terangi or Karoro Interglacial, Biozone P3 the Waimaunga Glacial, Biozone P2 the "Normandale" Interglacial and Biozone P1 the Nemona Glacial and older stages.

A discriminant function analysis of the complete sequence, starting with a comparison between the Postglacial and Last Glaciation spore and pollen assemblages, provides a graph indicating relative fluctuations in the vegetation, which bears a close similarity to the oxygen isotope scale for the same period of time. Abrupt changes in climate are indicated between, and occasionally within each glacial and interglacial. These changes are interpreted as representing periods of environmental instability of quite variable length, but possibly as short as 100 years.

Keywords: Palynology, pollen diagrams, vegetation changes, paleoclimate, biozones, oxygen isotopes, radiocarbon dating, stratigraphy, recycling, discriminant function analysis, Petone, Hutt Valley, Petone Drillhole, Seaview Drillhole, Pleistocene, Last Glaciation, Postglacial, Pleistocene climatic stages

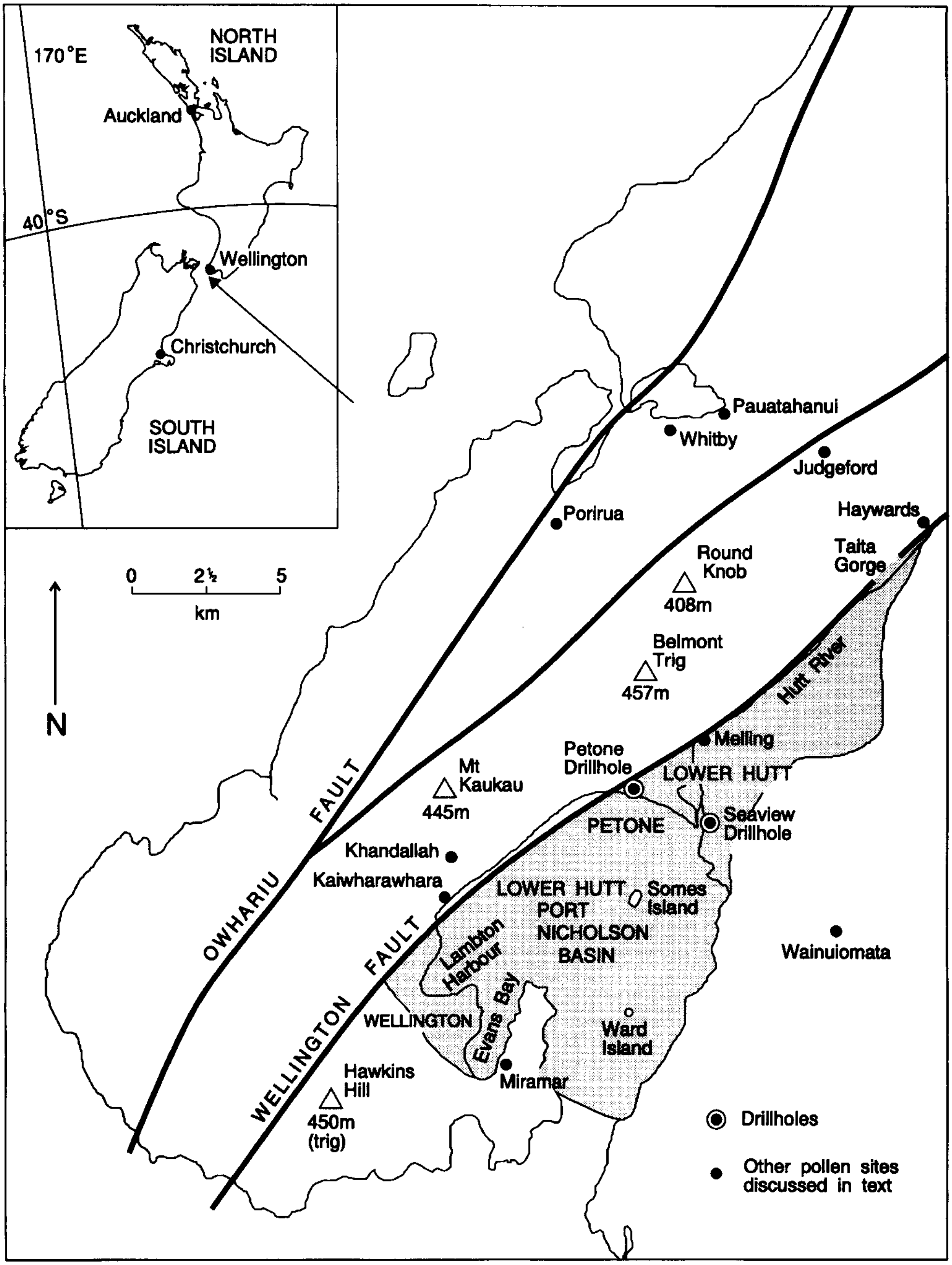

Fig. 1 – Locality diagram. Shaded area outlines the Lower Hutt-Port Nicholson Basin

INTRODUCTION

In 1961 the Hutt Valley Underground Water Authority drilled a deep hole in the grounds of what was then the Gear Meat Company at Petone, on the foreshore of the Hutt River delta near Wellington (Figs 1, 2). The purpose of this drillhole was to explore the underground water resources of the Hutt Valley and to determine the stratigraphy of the aquifers. Later, in

Fig. 2 – Aerial photograph showing the site of the Petone Drillhole (arrow) as it appeared early in the 1990's. Photograph by Lloyd Homer, IGNS

1964, a further drillhole was sunk at Seaview, Petone. In the discussion below these two drillholes are identified as the Petone Drillhole and Seaview Drillhole.

The two drillholes have been mentioned in numerous papers on the middle to late Pleistocene geology of Wellington, e.g., Grant-Taylor & Taylor 1967; Grant-Taylor & Rafter 1971; Harris & Norris 1972; Stevens 1973, 1991; Mildenhall 1973; Grant-Taylor 1974; Harris, Darwin & Newman 1976; Donaldson & Campbell 1977; Mildenhall 1980; Mildenhall & Moore 1983. However, very few primary data relating to the drillholes have been presented, or references to unpublished material documented. This monograph presents and interprets

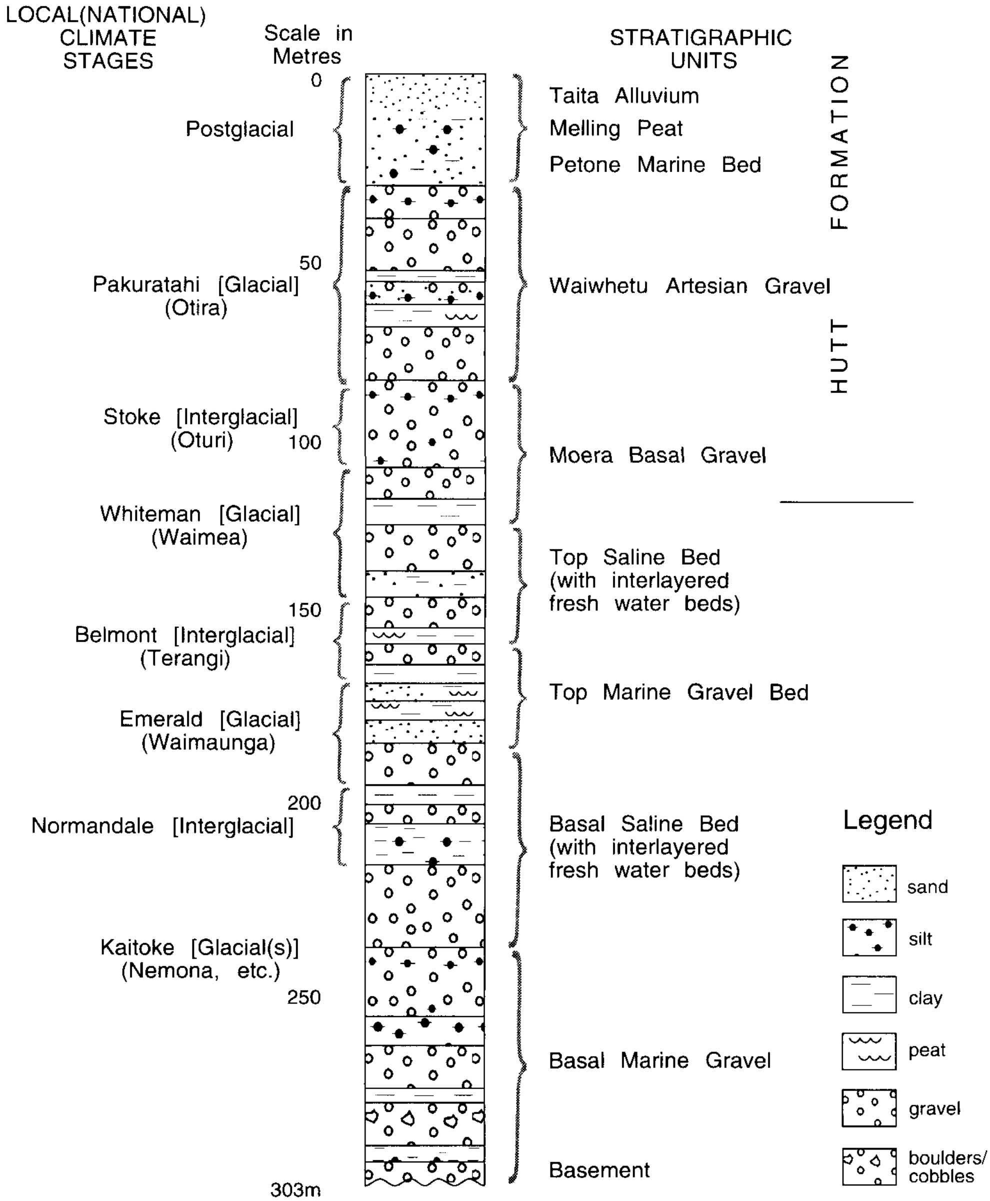

Fig. 3 – Stratigraphy of the Petone Drillhole (after Stevens 1973). The local glacial and interglacial divisions are based on Grant-Taylor (1959). The stratigraphic units to the right of the diagram describe the nature of the aquifers encountered or members of the Hutt Formation (Stevens 1956; Grant-Taylor 1974)

the palynological data obtained from these drillholes, and is based on work done from the late 1960's to mid 1970's.

Initially, the drillholes were logged by P. Hutton and other personnel of the Hutt Valley Underground Water Authority. Subsequently, in the early 1060's the logs were revised by T. L. Grant-Taylor (New Zealand Geological Survey), who also initiated various studies on the sediments, including palynology. Much later, in 1993, a re-interpretation was carried out by J. G. Begg (*pers. comm.* November, 1993).

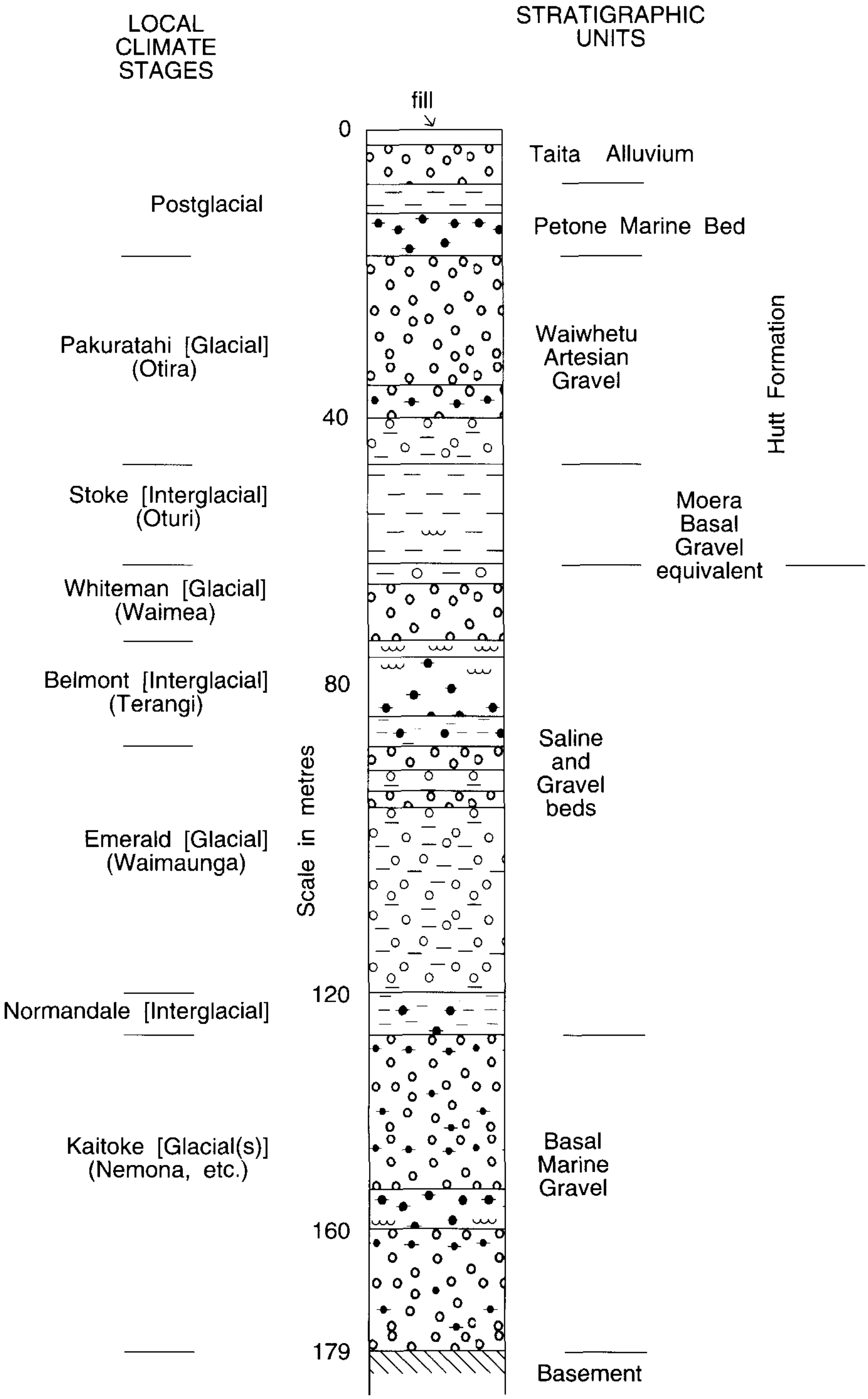

Fig. 4 – Stratigraphy of the Seaview Drillhole based on the original driller's log and sedimentological correlations by John Begg (*pers. comm.*, November 1993). The local glacial and interglacial divisions show the based on Grant-Taylor (1959). The formation names to the right of the diagram show the members of the Hutt Formation (Stevens 1956; Grant-Taylor 1974). For legend see Fig. 3

The stratigraphy of the Petone Drillhole was summarised in publications by Grant-Taylor & Taylor (1967), Harris, Darwin & Newman (1976), & Stevens (1973). This drillhole penetrated 299 m of sediment, predominantly Pleistocene gravel, but also including Postglacial peat, marine sand and silt, alluvium, and some older beds that provided good palynomorph recovery. This monograph follows Edwards et al. (1988) in including the Postglacial (Holocene) in the Pleistocene. The drillhole reached a total depth of 311 m, including, at its base, 12 m of weathered greywacke and black argillite which was encountered before the drillhole reached relatively unweathered, solid, blue-grey greywacke basement. An attempt to relate the sequence to the local surface formations and stages (Fig. 3) developed by Grant-Taylor (1959) was made by Stevens (1973) (see also Fig. 14). The Seaview Drillhole (Fig. 4) penetrated similar sediments and reached a total depth of 181 m, including, at its base, 6 m of what is described on the log as "very weathered light blue rock with hard fragments of rock in it" and which was certainly basement.

Much of the palynological work on the Petone Drillhole was done in the mid 1960's, primarily by Dr. W. F. Harris, but with later contributions by Michele Dickson, Colin Lennie, and Dallas Mildenhall. Originally it was intended that the results would be written up as a separate chapter in a bulletin on the Pleistocene vegetation history of New Zealand to be authored by W. F. Harris, but unfortunately ill health forced him to abandon this project. Although some of the detailed work undertaken for the proposed bulletin has been subsequently published by Mildenhall (1973, 1978, 1986d), and some of the palynological data on the Petone Drillhole, in particular, have been cited in various papers (e.g., Newman et al. 1971; Harris & Norris 1972; Harris, Darwin, & Newman 1976; Mildenhall 1973) there has never been any attempt to construct a general synthesis. Palynological work on the Seaview Drillhole was done in the mid 1970's, primarily by Michele Dickson, but with contributions by Harris and Mildenhall. This work has remained unpublished.

In the presentation of the palynological data from both drillholes in the present study, I have made minimal checks on any of the identifications and have re-examined few of the slides from the 222 samples collected from the Petone Drillhole and the 44 samples collected from the Seaview Drillhole. I have updated the botanical names used by Harris in his unpublished notes and published papers. The summary of results is based on manuscript notes left by W. F. Harris, on an examination of the original logs, and on re-examination of the pollen diagrams and species lists held on file in the Palynology Section of the Institute of Geological and Nuclear Sciences (IGNS).

Geology of the Hutt Valley

The mid to late Pleistocene history of the Wellington – Hutt Valley area is complex because of the frequency of tectonic events, rapid lateral facies changes, periods of deep erosion, the localised nature of many of the Pleistocene deposits, and the lack of widespread and distinctive marker horizons in the Pleistocene sediments. However, localised marker horizons, such as the Petone Marine beds and the Wilford Shellbed, that are present in the stratigraphic sequence underlying the Hutt Valley, enable some correlations to be made over the lower part of the Hutt River delta and extending out into the Lower Hutt-Port Nicholson Basin (Fig. 1).

The surface on top of the greywacke basement rock of the Hutt Valley is classified by Stevens (1956) as part of the downwarped Kaukau Peneplain Surface. This surface may have been formed by a late Cretaceous to late Cenozoic peneplanation phase, but the basement was not exposed until c. 2 million years ago (Stevens 1991). The deeply weathered nature of the greywacke contact encountered at the base of the Petone Drillhole suggests that the downthrown block was exposed for a considerable period before the mid to late Pleistocene sediments were deposited. According to Te Punga (1982, unpublished) the development of the Kaukau Peneplain ceased c. 340,000 years ago, at the same time as the surface began to be disrupted by faulting and deposition of sediment began at the base of the Petone Drillhole. Thus downwarping commenced, possibly in the mid to late Pleistocene, with Somes and

Ward islands remaining exposed as peneplained remnants of high points on downthrown ridges (Stevens 1991). Since the faults bounding Somes and Ward Islands are probably active, the basin may better be regarded as comprising horsts and grabens, rather than as a simple fault-angle depression (J. G. Begg, *pers. comm.*, February 1994).

On the western side of the Hutt Valley the greywacke forms a steep fault-line scarp, and on the western side of the Lower Hutt-Port Nicholson Basin at least 400 m of Pleistocene sediment has been deposited (Hochstein & Davey 1974). On the eastern side of the valley Pleistocene sediments lap against the low dipping slopes (i.e., relative to the fault scarp of the western hills), of the eastern hills. Towards the north, the basement rises towards the Taita Gorge, and in the south it rises again towards Wellington City and the harbour mouth (Fig. 1).

The Petone Drillhole was sited c. 400 m east of the Wellington Fault and, as with the Seaview Drillhole, penetrated sediments laid down in a northeast-striking basin on the east side of the fault. The maximum throw on the fault is c. 1,800 m, displacing the Kaukau Surface, and although there has been substantial uplift to the west, downwarping and buckling to the east has facilitated the preservation of important sedimentary sequences. These provide a record of mid to late Pleistocene tectonic and paleoenvironmental events for the Wellington area.

The Pleistocene geology of the Hutt Valley has been described by Stevens (1956), Grant-Taylor (1959), and most recently by Stevens (1990, 1991). These authors interpreted the sequence of middle to late Pleistocene formations in terms of climatic stages. A summary of the sediments at Petone, and their correlation with the local and national stages, is included in Fig. 3.

Drillhole locations

According to the logs and fossil record forms the Petone Drillhole (also called the Hutt Valley Underground Water Authority Test Bore Number 1, or the Gear Meat Company Borehole) was sited in Petone 2 chains (40.2 metres) north of the Esplanade, and 3 chains (60.4 metres) west of Victoria Street at grid reference N164/423294 (R27/668962)*. The Seaview Drillhole (also called Underground Water Authority Test Bore Number 3) was sited 3 km to the east of the Petone Drillhole, at "Seaview: roadside, beside stream, outside Hutt Park" on Parkside Road at grid reference N164/455282 (R27/697951), near the outlet of the Hutt River. Both sites are a metre or so above mean sealevel.

Both drillholes were deep test wells bored to assist in the understanding of the artesian fresh water system that is utilised by the Wellington Regional Council as a major component of its water supply for the Lower Hutt/Petone area.

Preparation techniques

The materials examined were mostly samples that appear to be cuttings, with multiple sampling of mixed lithologies at some horizons (see Appendix). Standard palynological techniques of the time (Lennie 1968) were used. This involved treatment with hydrofluoric and hydrochloric acids, acetylation, oxidation, ultrasonic irradiation, flotation, and mounting in glycerine jelly on glass slides. All slides, residues, rock samples, and fossil record forms containing full lists of identified taxa are held in the Palynology Section, Institute of Geological and Nuclear Sciences, Lower Hutt. All preparations are registered in the Palynology Section catalogue and are identified by an L number. The sample number and stratigraphic position of each sample is given in the pollen diagrams (Figs 5–10, 12, 13). The appendix lists additional details for each sample, including lithological description where given, as summarised on the fossil record forms. It also provides more detailed stratigraphic information

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*The yard grid reference (N164) is from the national thousand-yard grid of the 1:63,360 topographical map series (NZMS 1), and the metric grid reference (R27) is from the 1:50,000 topographical map series (INFOMAP 260).

than could be placed on the pollen diagrams, since a number of samples were collected from the same, or very close, stratigraphic intervals. The fossil record numbers (R27/f8595 – Seaview and R27/f8696 – Petone) are registered in the New Zealand Fossil Record File which is based on the metric 1:50,000 topographical map series INFOMAP 260.

PETONE DRILLHOLE

Stratigraphic and paleontological zonation

The approximate boundaries and thicknesses of the stratigraphic zones, as originally determined by T. L. Grant-Taylor (*pers. comm.* to W. F. Harris c. 1968), and based on changes in the nature of sedimentation, are given in Table 1.

The symbols in Table 1 indicate the stratigraphic sequence of the biozones that were recognised by W. F. Harris in the Petone Drillhole (as zones 1–9 in Harris, Darwin, & Newman 1976). Because the zone boundaries developed by Harris, and emended in this paper, do not quite coincide with the lithological boundaries, the zones are adjusted as given in Table 2. This is to allow the following discussion to be based on the palynologically determined climatic boundaries, not on the lithologically determined climatic boundaries.

The only significant difference between the lithological and palynological zonation is that two biozones (P7, P8) are recognised in the youngest cold zone, correlated with the last (Otira) glacial deposits. Other apparent discrepancies result from the biozone boundaries being placed in unfossiliferous parts of the sequence, from selection of fewer samples for

Table 1 – Approximate boundaries and thicknesses of stratigraphic zones in the Petone Drillhole as determined by T. L. Grant-Taylor (*pers. comm.* to W. F. Harris in 1968)

Symbol	Cold climate boundaries	Thickness	Warm climate boundaries	Thickness	Correlation
P9			28–0 m	28 m	Postglacial
P8, P7	82–28 m	54 m			Last Glaciation
P6			106–82 m	24 m	Last Interglacial
P5	136–106 m	30 m			
P4			161–136 m	25 m	
P3	184–161 m	23 m			
P2			205–184 m	21 m	
P1	299–205 m	99 m			

Table 2 – Boundaries of biozones developed by W. F. Harris for the Petone Drillhole. The P stands for Petone and has been added to the numbers used by Harris

Biozone	Cold climate boundaries	Thickness	Warm climate boundaries	Thickness	Lithostratigraphic equivalents
P9			31–0 m	31 m	P9
P8	46–31 m	15 m			P8 only
P7	81–46 m	35 m			P7 only
P6			106–81 m	23 m	P6
P5	127–106 m	21 m			P5
P4			163–127 m	36 m	P4
P3	183–163 m	20 m			P3
P2			215–183 m	32 m	P2
P1*	257–215 m	42 m			P1

*Below 257 m there is a single poorly fossiliferous sample (213) dominated by *Nothofagus fusca* type pollen at 278.5 m. This has also been included in biozone P1 in Figs 5 and 14.

pollen examination than was the case for the top 70 m of the drillhole, and from the inclusion in sample groupings only those samples which yielded adequate spores and pollen. A zonal scheme based on pollen dominants is more complex, and would to some extent reflect local as well as regional influences. The figures here for each biozone include the whole sequence and therefore do not match those listed below under each biozone where the unfossiliferous horizons at the boundaries are not zoned.

Palynology

Of the 222 samples submitted for palynological analysis from the Petone Drillhole, 158 yielded pollen data. When possible, counting was continued until 100 specimens of a selected "dominant" had been recorded, such being referred to as "normal" counts. In some cases, when a particular pollen type was especially abundant, counting was continued in order to get a better representation of types other than the dominant (Harris, Darwin, & Newman 1976). Since 91% of all pollen types identified from the drillhole are classified under just 15 different names, Harris decided in 1968 to present the data in the form of a series of summary pollen diagrams, concentrating on these 15 or so forms. About 100 further taxa form the additional 9% of the total pollen identified. Most samples contain abundant fern spores, particularly of *Cyathea* species and smooth, unidentifiable monolete fern spores from a number of parent sources.

In each drillhole the palynology is described upwards from the base so that the vegetational changes towards the present-day can be described in sequence. A series of pollen diagrams (Figs 5–10) illustrates in summary form the vegetational changes exhibited in the Petone Drillhole. Fig. 11 shows the results of two computerised studies of the Petone Drillhole based on a discriminant function analysis and an assemblage analysis as described in Harris, Darwin & Newman (1976) and Harris & Norris (1972), respectively. Although full palynological lists are not presented in this work, they are available on request.

Zonation

Biozone P1 – 299–215 m (Fig. 5)

Lithology: Black argillites and weathered greywacke (samples unproductive); blue silty clay; weathered muddy gravel with finer, occasionally carbonaceous horizons; peaty, woody silt (no pollen sample); weathered sand; muddy gravel (also no pollen sample).

Palynology: The basal productive sample in the drillhole (sample 213 at 278.5 m) is dominated by *Nothofagus fusca* type* pollen (southern beech) in a low count of only 79 grains. A further nine samples collected from below this point either lack spores and pollen, or contain only sparse palynomorphs. Of these six (samples 217–222; 302.7–310.7 m) are regarded as being from the weathered greywacke basement and are not included in Fig. 5. Two of the other three samples (216 and 215 at 297.5 m and 295.7 m respectively) contain enough spores and pollen to indicate the existence of a shrub/grassland environment when sedimentation began. Both samples also contain very rare dinoflagellate fragments that may be either Pleistocene in age, or recycled. One fragment was identified as similar to Pleistocene to Recent species of *Cleistosphaeridium* (G. J. Wilson, *pers. comm.* 1992). The lower of these two samples also contain extinct species, including *Nothofagidites cranwelliae* (Couper) Mildenhall and Pocknall, *Haloragacidites harrisii* (Couper) Harris, and *Proteacidites minimus* Couper, all of which are probably recycled, but may also indicate an age older than 1 million years. This part of the sequence from 299–257 m has been included in biozone P1 in Fig. 5, but was excluded from the biozones set up by Harris (unpublished notes; also see section on stratigraphic and paleontological zonation above). Many of the other samples described in

*The term *Nothofagus fusca* type here, and elsewhere, refers to the pollen from *Nothofagus fusca* (red beech), *N. truncata* (hard beech), *N. solandri* var. *solandri* (black beech), and *N. solandri* var. *cliffortioides* (mountain beech), which are indistinguishable from each other.

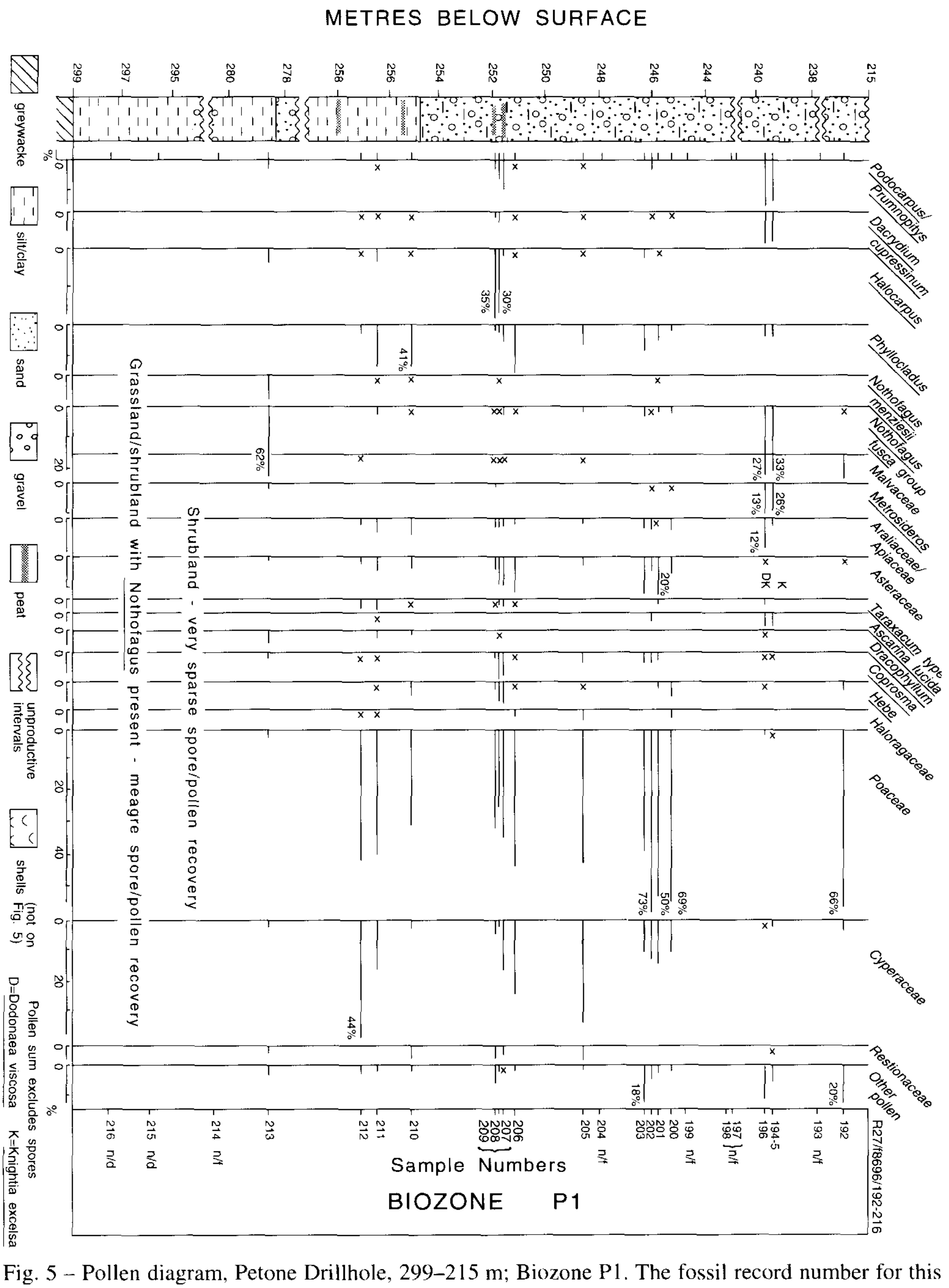

Fig. 5 – Pollen diagram, Petone Drillhole, 299–215 m; Biozone P1. The fossil record number for this and succeeding pollen diagrams is given at the head of the right-hand column. The basal 30.5 m (pollen samples 214–222) did not contain any fossiliferous material. n/d = too few spores and pollen to count; n/f = no flora; X = < 1%. The main peaks in the pollen diagram for "other pollen" represent abundant *Gentiana* (sample 203) and *Geranium* plus unidentified tricolpate grains (sample 192).

Fig. 5, from above 257 m, also contain sparse palynomorphs, and the recorded counts often total less than 200 grains.

From 257 m to c. 216 m the pollen samples are all dominated by *Phyllocladus* (celery pine), almost certainly *P. alpinus* (mountain toatoa) judging by the associated pollen types, Poaceae (grass), and Cyperaceae (sedge), except for two samples between 239 m and 240 m which are dominated by *Nothofagus fusca* type pollen and *Metrosideros* (rata). These latter samples have a high percentage of *Ascarina lucida* (hutu) pollen, indicating that the climate was probably free of severe frosts for this period (McGlone & Moar 1977). *Dodonaea viscosa* (akeake) and *Knightia excelsa* (rewarewa) pollen are also present, further indicating a (?short) period of warm, equitable climate (Macphail & McQueen 1983). The on-site vegetation at this time was a beech/broadleaved forest. It is possible that a considerable period of time, but of unknown duration, is missing or unrepresented by fossiliferous material from either immediately above or below this interval, or both. Generally the assemblages, together with the presence of *Bulbinella* (Maori onion), *Claytonia australasica, Gaimardia, Gentiana, Geranium*, and *Halocarpus* (probably *H. bidwillii* (bog pine; typical of waterlogged soils) or *H. biformis* (pink pine; typical of high rainfall sites)), taxa typical of alpine and subalpine grasslands and swamps (Allan 1961; Macphail & McQueen 1983), indicate a downward shift of the vegetation belts of at least 1,000 m of altitude relative to the present-day.

Many of the samples contain abundant spores of *Gleichenia circinata* (umbrella fern). This, and associated spores and pollen, indicate that the depositional environment was an acid peat swamp, but with an abundance of dryland pollen derived from nearby well drained grasslands. Other samples contain abundant spores of *Cyathea* (tree ferns) or abundant smooth, monolete spores of the *Blechnum* type, but which have lost their perispores. A possibly extinct bryophyte spore, *Bryosporis problematicus* (Couper) Mildenhall, was identified from samples 206 (251.2 m) and 211 (256.3 m). Although this taxon was regarded by Bussell & Mildenhall (1990) as becoming extinct in the mid Pleistocene, it is now known to occur in the Postglacial at Miramar, Wellington (Mildenhall 1992).

Pollen from woody plants consists primarily of *Phyllocladus, Halocarpus*, and Asteraceae (composites). These plants may have been growing on the swamp or very close to it. Spores of hornworts, liverworts, and lycopods are frequent, indicating the presence of damp, protected, open, muddy ground (like the banks of streams) (Allan 1961; Campbell 1981, 1982, 1984). Pollen from canopy trees, such as *Nothofagus fusca* type and the tree podocarps, are present, but only rarely indicate the presence of any substantial forest near the deposition site. Two intervals, one at the base (278.5 m) and the other at the top (239.5 m), show evidence of nearby beech forest, presumably on the protected and sunny slopes of the eastern (?and western) hills (McGlone 1988).

Climatic assessment: The climate was cool to cold, frosty, and possibly windy and wet enough to produce swamplands, interspersed with relatively short periods of less intense frosts, or frost-free, and mild conditions.

Biozone P2 – 215–183 m (Fig. 6)

Lithology: Grey-brown silt with sand and organic matter; grey-blue gravel and sand (no pollen samples); brown, sandy silty clay.

Palynology: This part of the sequence is divided into two phases. The first represents a podocarp/broadleaved forest in which the dominant species were *Dacrydium cupressinum* (rimu), *Ascarina lucida, Metrosideros*, and various other podocarps. The climate was probably warm, nearly frost-free, and moist. This warm phase appears to have ceased abruptly at 205.4 m followed by a wide sample gap up to 196 m in unfossiliferous gravel. The second represents a short period of time when *Nothofagus fusca* type dominated the pollen rain. This change from *Dacrydium cupressinum* to beech represents cooling and possibly also a decrease in rainfall, but the presence of *Knightia excelsa* in sample 183 (194.8 m) indicates that

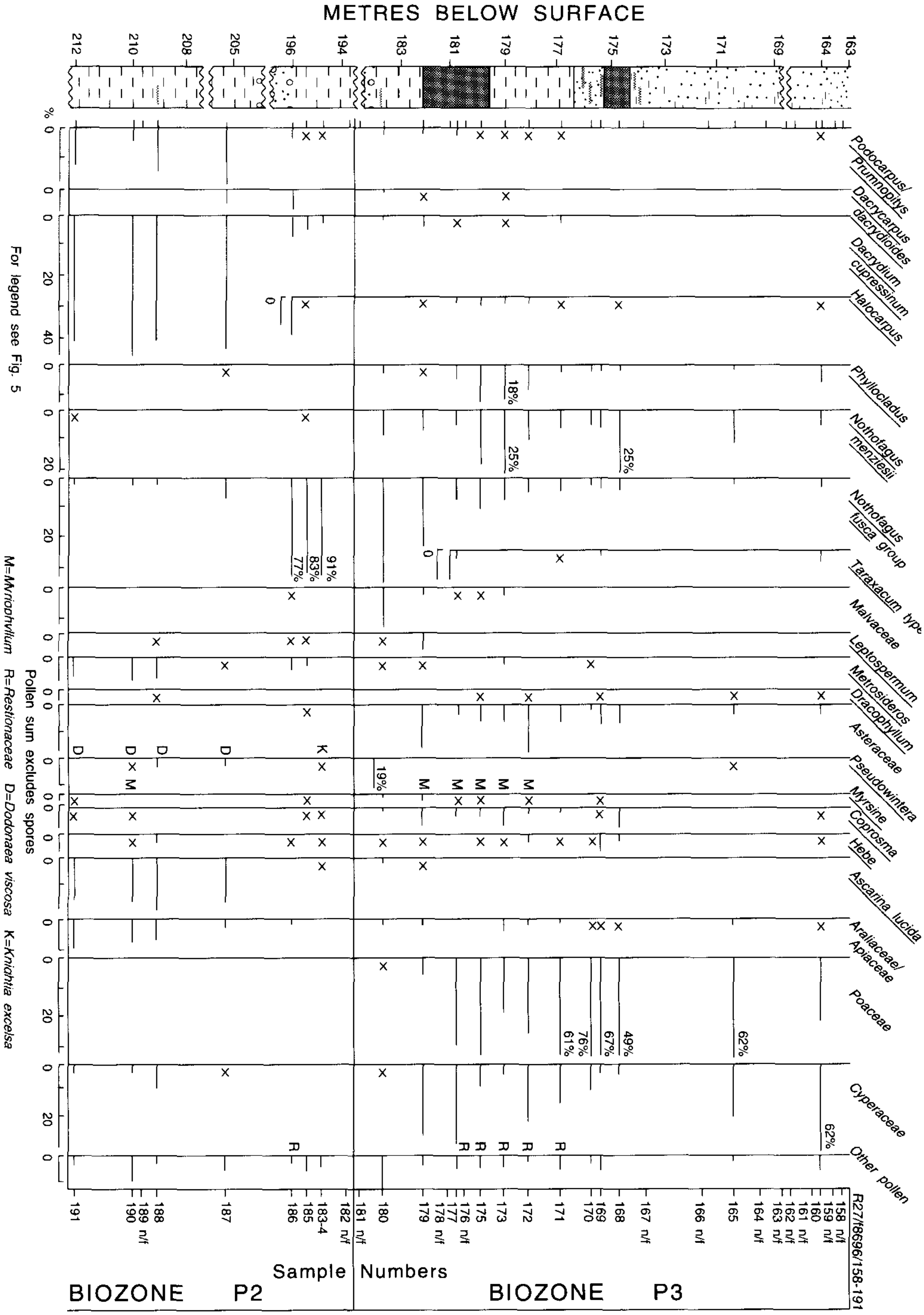

Fig. 6 – Pollen diagram, Petone Drillhole, 212–163 m; biozones P2 and P3. n/f = no flora; X = < 1%. The large peak in the pollen diagram for "other pollen" (sample 180) represents abundant unidentified 3–4 porate pollen types (?*Plagianthus*). Note that sample 174 does not exist.

temperatures and conditions were probably similar to the present-day, as the modern distribution of *K. excelsa* is Marlborough Sounds and North Island (Allan 1961; Macphail & McQueen 1983). During this cooling, represented by four samples in the interval 196.0–194.5 m, both the floor and the valley sides of the Hutt Valley were likely to have been forested.

The lowest sample in this biozone (191; 212.2 m) contains numerous dinoflagellate cysts indicating marine or estuarine deposition. Throughout the *Dacrydium cupressinum* part of the biozone, dinoflagellates were recorded spasmodically (samples 188, 187; 209.1 m, 205.4 m), plus shell fragments on the logs. Many of the samples are dominated by *Cyathea* spores and the preservation shows evidence of water sorting and concentration of robust spores and pollen. The four pollen counts of the *Nothofagus* phase total < 150 pollen grains of which *Nothofagus* comprises 100 or more. Species diversity during this time appears to have been very low.

An interval of c. 15 m follows in which the sediments were unsuitable for pollen preservation.

Climatic assessment: Warm, virtually frost-free, moist (humid).

Biozone P3 – 183–163 m (Fig. 6)

Lithology: Sandy gravel; blue-grey silty-sand with thick peat; peaty, weathered sandy gravel. Harris, Darwin & Newman (1976) recognised an unconformity at 165 m, near the top of this zone.

Palynology: From 183.5–163.9 m all pollen samples are dominated by Poaceae pollen. During this interval the main pollen types from woody plants were *Nothofagus fusca* type, *N. menziesii* (silver beech), *Phyllocladus*, almost certainly *P. alpinus* judged by the associated pollen types, *Coprosma*, and Asteraceae. The prominence of pollen of dryland grasses suggests that the climate was cold and probably relatively dry. The grass pollen may have come from nearby well drained areas, rather than representing low precipitation sites since *N. menziesii*, typical of high precipitation sites, is common. The presence of Restionaceae (jointed rushes) and *Myriophyllum* (water milfoil), taxa of aquatic and wetland environments (Macphail & McQueen 1983), indicate that enough water was available to provide a depositional Cyperaceae swamp setting, possibly as a result of poor drainage. Most of the floor of the Hutt Valley was probably grassed, with the woody vegetation occupying protected and better drained parts plus the sheltered and sunny slopes of the eastern (?and western) hills. *Phyllocladus* and Asteraceae, which were particularly prevalent during the earliest part of this zone, probably grew on the surfaces of the swamps. Fern spores were generally far fewer in numbers than in the previous zone, probably reflecting the cold and drier conditions. However, spores of hornworts and liverworts were more abundant because of the frequency of open, muddy environments around the depositional site.

The basal sample (180; 183.5 m) in this zone contains abundant pollen of *Pseudowintera* (horopito or pepper tree), Malvaceae (both *Hoheria* and *Plagianthus*; lacebark and ribbonwood respectively), and rarer pollen of *Libocedrus* (New Zealand cedar). These pollen types usually indicate marginal forest or disturbance in the vegetation caused, for example, by climate change, fire, or wind throw (Clayton-Greene 1977; McGlone et al. 1984). Charcoal is quite common in the sample, and fire may have been a factor, but the prime cause is probably climate change since the sample is intermediate between the change from *Nothofagus fusca* type forest and subsequent grassland and shrubland. The original pollen count included 28 pollen types identified as unknown 3–4 pored grains. Re-examination of the slides suggests that these are pollen grains of *Plagianthus* that have lost their spines. In Fig. 6 they are included under "other pollen".

A single marine dinoflagellate cyst was identified from sample 170 (175.6 m, fine sand immediately below a peat) and, if *in situ*, may indicate an estuarine or brackish water environment.

Climatic assessment: Cold, but probably with relatively high rainfall to enable the continuing presence of *Nothofagus menziesii* forest.

Biozone P4 – 163–128 m (Fig. 7)

Lithology: Silt-sand; peat, shelly sand with carbonaceous horizons; gravel (no pollen samples); marine silt with shells; silt-sand.

Palynology: A short phase of dominance by *Dacrydium cupressinum* from 163.0–161.5 m may represent all of the fossiliferous material collected from the peak of a warm period when the vegetation appears to have been very similar to that of Biozone P2, although *Dacrydium cupressinum* is consistently more abundant and *Metrosideros* pollen is less common. *Ascarina lucida*, *Dodonaea viscosa*, *Pseudowintera*, *Fuchsia* (probably tree fuchsia), numerous other broadleaf taxa, and a variety of lycopod and fern taxa together indicate warm, moist climatic conditions (Macphail & McQueen 1983). The palynological samples are overwhelmingly dominated by spores of *Cyathea*, in a ratio of between 6–8 to each *Dacrydium cupressinum* pollen grain. The floor of the valley and the surrounding hills were all clothed with podocarp forest at this time. As *Nothofagus* pollen never exceeds 10% of the total, it was probably a very minor element in the forest, and likely to have been either restricted to higher points (?skeletal soils) on the surrounding hills or have come from some distance from the deposition site. This phase is followed by a break of unfossiliferous material (a number of samples collected, none of which contained a palynoflora) for the next 8 m.

Between 153.6–128.3 m the vegetation was relatively unstable, although the pollen rain was usually dominated by *Nothofagus fusca* type pollen. Occasional incursions of *Nothofagus menziesii*, *Dacrydium cupressinum*, and *Podocarpus/Prumnopitys* species (totara/matai type) occurred, suggesting periodic changes in either climate or, more likely, the local depositional environment. Disturbance to the vegetation is indicated by the presence of *Pseudowintera* and *Libocedrus* pollen types, two taxa that appear very quickly after catastrophic damage events. These taxa are particularly abundant and frequent within the peats towards the base of this phase. Sediments included peat, gravel, silt, and marine silty sands in this part of the sequence.

The basal part of this phase, 153.6–151.4 m, contains abundant spores of *Sphagnum* (peat moss), and pollen of Centrolepidaceae (*Gaimardia*), Restionaceae (*Leptocarpus* and *Empodisma*), *Myriophyllum*, and other pollen and spore types from aquatic and semi-aquatic plants (Allan 1961). *Cyathea* (*dealbata*, *medullaris*, and *smithii*) and *Gleichenia circinata* spores were extremely abundant, occasionally reaching counts of over 1000, or numbers estimated, before a reasonable number of pollen grains were counted. Species diversity of both spores and pollen is high. The sediments were peats with silty or sandy lenses which provided occasional unfossiliferous samples. Sediments either side of the peat contain shells, but there is no evidence of marine conditions within the peat. The depositional environment was an acid *Sphagnum* swamp with the surrounding valley and hills occupied by a beech/podocarp forest consisting primarily of *Nothofagus fusca* type, *Prumnopitys ferruginea* (miro), and *P. taxifolia* (matai). The temperature ranges were similar to the present-day with the same or slightly higher rainfall. *Ascarina lucida* and *Dodonaea viscosa* pollen are present in trace amounts. Conditions were probably slightly cooler and drier than the *Dacrydium cupressinum* phase it succeeded, since this taxon only forms a minor role in the vegetation at this time. This phase is separated from the next interval by a c. 3 m thick unfossiliferous gravel.

At 148.4 m and between 140.2–138.4 m *Nothofagus fusca* type pollen dominates the samples, and this taxon appears to have been growing on or very close to the deposition site. The absence of *Ascarina lucida* suggests that conditions during this time may have been much cooler than the time period it succeeded. *Dacrydium cupressinum* is still abundant and rainfall would have been relatively high, but species diversity is much lower suggesting less than optimal conditions. *Gleichenia* spores are less abundant and less frequent, but *Cyathea* spores are still abundant indicating that plenty of moisture was still available. One sample

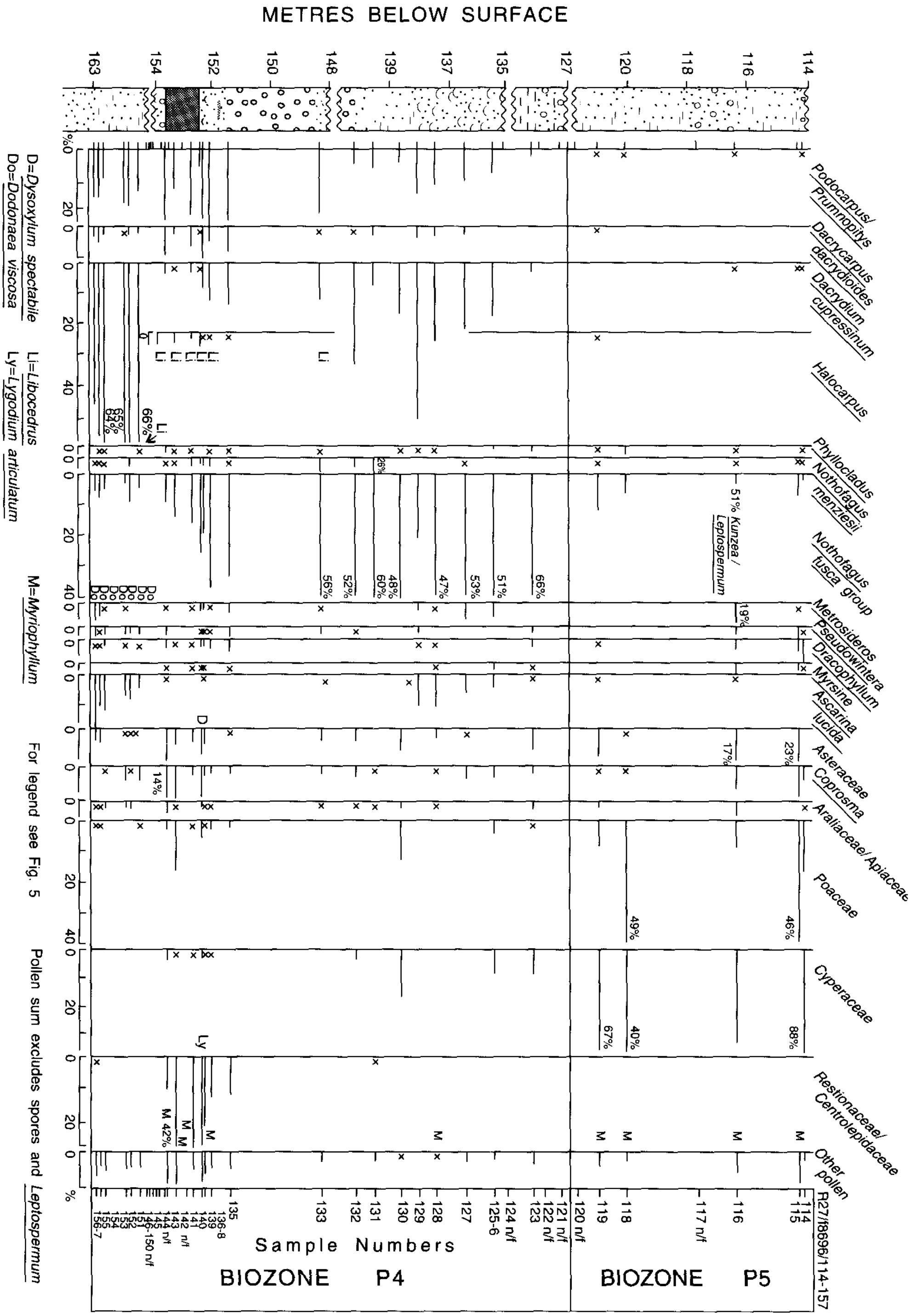

Fig. 7 – Pollen diagram, Petone Drillhole, 165–114.0 m; biozones P4 and P5. n/f = no flora; X = < 1%. The large peaks in the pollen diagram for "other pollen" include for samples 156–7 (*Lophomyrtus*, *Fuchsia*, and *Dodonaea*), 145 (*Myriophyllum* and *Hebe*), 143, 140 (*Libocedrus* and *Myriophyllum*), 139 (*Myriophyllum* and *Phormium*), 116 (Malvaceae), and 115 (*Hebe*). Note that sample 134 does not exist. A massive influx of *Kunzea* and/or *Leptospermum* (51%) is noted on the pollen diagram, but is excluded from the pollen sum.

(131; 139.3–139.9 m) contains an unusually high percentage of *Nothofagus menziesii* pollen (26%). Its abundance and frequency indicates cooler conditions, since it is a hardy species forming the treeline in areas of relatively high precipitation, and, taking into consideration its poor dispersal capability (McKellar 1973), was presumably present nearby.

The presence of abundant *Ascarina lucida* pollen in the uppermost part of Biozone P4, between 128.2–138.1 m, suggests the return of a period of relative warmth, during which frosts were rare or not very intense. There is a 7 m interval of unfossiliferous and unsampled sediment within this part of the sequence which consists primarily of shelly sands, silts, and sandy silts. *Nothofagus fusca* type and *Dacrydium cupressinum* are the most abundant pollen types, and both were probably growing close to the deposition site. It is likely that beech was growing on the less fertile soils of the nearby hills, with *Dacrydium cupressinum* on the more fertile soils of the valley floor. *Cyathea* spores are still abundant. None of the pollen samples indicate marine conditions in spite of the prevalence of marine shells in the sediment.

There is a break of 11 m of unsampled and unfossiliferous sediment before the basal sample of the next biozone is reached.

Discriminant function analysis by Harris, Darwin & Newman (1976), described below, supports the idea of a warm period (*Dacrydium cupressinum*) followed by a gradual cooling (*Nothofagus fusca* type). A solitary grain of *Lygodium articulatum* (mingimingi), a climbing fern found today no further south than 38°S, c. 350 km north of the deposition site (Allan 1961), was found in this zone.

Climatic assessment: In the stratigraphic interval between 163.0 and 161.5 m : warm, moist and relatively frost-free. Between 153.6 and 151.4 m : cooling but moist. Between 148.4 and 138.4 m : cool, frosty but moist. Between 128.2 and 138.1 m : warm and moist.

Biozone P5 – 128–114 m (Fig. 7)

Lithology: Silt-sand with gravel horizons. Sparsely sampled.

Palynology: The 121.0–114.1 m fossiliferous part of this interval, which follows 11 m of unfossiliferous sediment, has a palynoflora dominated by Poaceae pollen. Pollen from woody plants was principally Asteraceae, with occasional influxes of *Leptospermum* and/or *Kunzea* (manuka and/or kanuka; 51% in sample 116; 116.4 m), *Dracophyllum* (grass tree), *Metrosideros*, and *Coprosma*. Pollen from emergent trees such as *Nothofagus fusca* type and *Phyllocladus* form < 10% of the total pollen and are indicative of trees growing some distance away from the deposition site, possibly in sheltered areas on the eastern and/or western hills of Wellington. This interval represents a time of large-scale deforestation. Conditions were cool and probably relatively dry, since the pollen rain is dominated more by dryland Poaceae pollen (i.e., it was too dry and cold to allow the growth of hardy montane trees like *Nothofagus menziesii*) than by wetland sedges and rushes, which, however, still form a sizeable percentage of the total palynoflora. Fern spores are not as common as in the previous biozone and further indicate less available moisture. The spores consist primarily of *Dicksonia squarrosa* (wheki), smooth, unidentifiable monolete spores, and in one sample (116; 116.4 m), *Cyathea*. Spores of hornworts are common, indicating open, moist, muddy, protected environments (e.g., Campbell 1981, 1982, 1984). *Pseudowintera*, often found at forest margins and in wetter areas, is again frequent, and indicates periodic disturbance in the vegetation (Macphail & McQueen 1983). The interval is the basis of Biozone P5 and contains the only known pollen grain of *Drosera* (sundew), an insectivorous herb, from the sequence. *Drosera* grows mainly in exposed subalpine and montane bogs (Allan 1961). Two samples (114, 118; 114.1 m, 120.1 m) contain spores of the possibly extinct bryophyte *Bryosporis problematicus* (Bussell & Mildenhall 1990).

An unsampled interval of almost 9 m exists between 114.1 m and the basal sample (113) of the overlying biozone at 105.4 m. The sediments in this interval consist predominantly of weathered and sandy gravel indicating a break in sedimentation, possibly at c. 106 m, to allow enough time for the underlying gravel to be thoroughly oxidised.

Climatic assessment: Cool or cold and relatively dry.

Biozone P6 – 105.4–82.0 m (Fig. 8)

Lithology: Marine shelly gravel; shelly sand with occasional sand, mud, and gravel horizons. Sparsely sampled.

Palynology: This whole phase of deposition represents a stable period of warm and moist conditions during which a podocarp forest, dominated by *Dacrydium cupressinum*, probably clothed the alluvial flats and surrounding hills of the Hutt Valley and Wellington. *Dacrydium cupressinum* pollen averages c. 50% of the total pollen recovered from each fossiliferous sample. Pollen of *Nothofagus fusca* type was rare and the parent trees could not have existed anywhere near the deposition site, unless as scattered individuals in less sheltered sites or on less fertile soils. *Ascarina lucida* pollen was abundant and attests to moist, relatively frost-free, and warm conditions. Other frequent pollen types in this part of the profile include Myrtaceae (*Leptospermum/Kunzea* and *Metrosideros*), *Podocarpus/Prumnopitys* species, and *Dacrycarpus dacrydioides* (kahikatea; at the top and base of the sequence only). The abundance of *Cyathea* spores, averaging c. 900–1,000 per count, and the frequency of *Fuchsia* pollen, probably from *F. excorticata* (kotukutuku or tree fuchsia), a plant very commonly found growing in shaded situations beside running water, also reflects a moist, warm climate. The total count of pollen grains in each sample from this part of the sequence only rarely totalled more than 200 out of total spore and pollen counts often reaching over 900, such was the dominance of fern spores. Spores of ground ferns, lycopods, and bryophytes are rare, reflecting the lack of open spaces in a closed canopy forest.

The zone contains the pollen type *Ixerba brexioides* (tawari), which today is distributed in the lowland and lower montane forest of the North Island from lat. 35° 30′S to a little south of 38°S (Allan 1961), c. 300 km north of the deposition site. One spore of the northern North Island fern, *Lygodium articulatum*, was also located. This zone, containing the maximum floral diversity in terms of the number of different taxa identified, provides an unequivocal indication of optimal growing conditions. In terms of the overall floral sequence from the drillhole, it represents the warmest phase documented and possibly the warmest time during the whole of the middle to late Pleistocene.

Sea levels were high during this period, as indicated by the sediment of this biozone consisting predominantly of marine sands, commonly containing shells. Dinoflagellate cysts were frequently encountered on the palynological slides between 92.9–82.0 m, indicating nearshore marine or estuarine conditions.

There is an unsampled interval of c. 6 m between the uppermost sample (90) in this biozone at 81.6–81.8 m and the basal sample (89) of the overlying biozone at 75.8–76.0 m.

Climatic assessment: Warm, moist, and humid.

Biozone P7 – 76.0–49.4 m (Fig. 9)

Lithology: Gravel with occasional silt and woody horizons; silt-sand (both sparsely sampled); peat (densely sampled); gravel (not sampled).

Palynology: Sampling throughout this biozone was generally more intensive than elsewhere and the samples provided adequate counts of over 200 pollen grains per count.

This biozone began with a period (75.6–66.0 m) in which pollen of *Nothofagus fusca* type was abundant enough to indicate that the parent plants were close to the deposition site. However, *Dacrydium cupressinum* seems also to have been locally present right through this biozone, a contrast with biozones P3 and P5, which represent previous glacial periods. The basal sample (89; 75.8–76.0) contains abundant pollen of *Myrsine* and Malvaceae (both *Plagianthus* and *Hoheria*) and these probably grew on-site as well. *Cyathea* spores are abundant, forming between 54% and 94% of the total spore and pollen count. The abundance and variety of lycopod and fern spores indicates a moist environment. No bryophyte spores

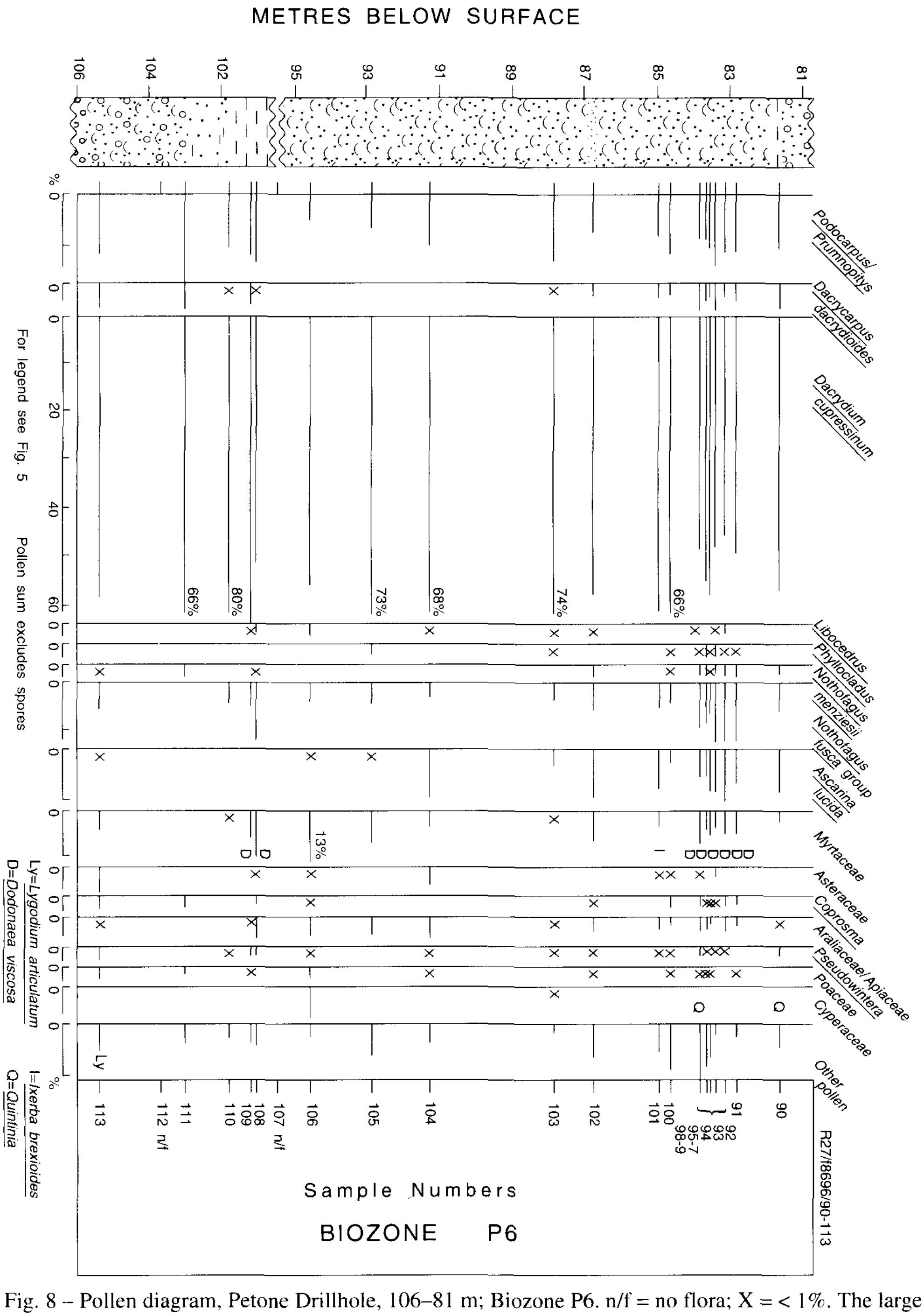

Fig. 8 – Pollen diagram, Petone Drillhole, 106–81 m; Biozone P6. n/f = no flora; X = < 1%. The large peaks in the pollen diagram for "other pollen" reflect the large number of taxa present in low numbers, including *Myrsine*, *Loranthus micranthus*, *Muehlenbeckia*, Malvaceae, *Cordyline*, *Rhopalostylis sapida*, and *Fuchsia*.

were identified, suggesting that open, moist, muddy, sheltered sites were at a premium. Climate would have been the same as the present-day or a little cooler.

From 64.3 m to c. 61.5 m a gradual increase in pollen of *Dacrydium cupressinum*, the appearance of *Ascarina lucida* and *Quintinia*, plus an increase in diversity, suggests increased rainfall and a gradual warming. Frosts would not have been common, unless the infrequent *A. lucida* pollen came from rare trees growing on sheltered sites. Other pollen types which are prominent in the pollen diagram in the interval 64.3–53.4 m are, in upward succession, (1) Myrtaceae (*Metrosideros*) (64.3–61.8 m); (2) Poaceae, with *Coprosma*, *Nothofagus fusca* type, *Dacrydium cupressinum*, *Podocarpus/Prumnopitys*, *Dacrycarpus dacrydioides*, *Nothofagus menziesii*, and *Metrosideros* (61.6 m); (3) *Nothofagus fusca* and *menziesii* types (58.3 m); (4) *Nothofagus* and podocarps (58.2–57.5 m); and (5) Malvaceae (mainly *Plagianthus*), *Coprosma*, *Myrsine*, *Nothofagus fusca* type, and podocarps (53.4 m). Overall the vegetation represents a rata/beech/podocarp swamp forest, particularly at and immediately above 62 m where a small bed of peat developed on alluvial flats with constantly changing sediment supply providing alternate stable (peats and silts) and unstable (sands and gravel) environments.

This dynamic succession represents an overall cooling, which caused *Ascarina lucida*, *Knightia excelsa* (which appears only in this interval in Biozone P7), and *Quintinia* to disappear. *Knightia excelsa* shows a marked preference for warmer, lowland and lower montane sites (Allan 1961). Malvaceae pollen in the fossil record tends to appear most commonly in sediments deposited during periods of cooler climate. There are still high to very high percentages and diverse types of lycopod and fern spores, especially *Cyathea*, *Dicksonia*, and smooth monolete grains, indicating that Biozone P7 was not as cold as the succeeding Biozone P8. Bryophyte spores are absent, indicating a lack of moist, bare, sheltered ground in the vicinity of the deposition site – that is, the area was well vegetated.

From 53 m upwards there are marked changes in the dominance and co-dominance of several pollen types deposited at the site, recorded in a closely sampled sequence. In the interval 52.1–53.4 m (note change of scale in Fig. 9 in the 1 m interval between 52–53 m) Poaceae (66; 53 m), *Halocarpus* (60; 52.7 m), Poaceae and *Halocarpus* type (59; 52.6 m), *Podocarpus/Prumnopitys* (60; 52.7), *Nothofagus menziesii* (59; 52.6 m), Poaceae (59–57; 52.6–52.3 m), and *Nothofagus fusca* type (53; 49.5 m) are the most abundant types. This cyclical change probably reflects continuation of an unstable local environment, rather than dramatic climate changes, although a cooling to the next biozone at c. 46 m is indicated by the abundance of grass and shrub pollen. Alternatively, this change could be a short, cool interstadial with *Nothofagus menziesii* and *Podocarpus/Prumnopitys* forest at its peak. This interval also records the last appearance of *Libocedrus* pollen in the area. Pollen of *Montia fontana* was found only in this biozone at 52.4 m. This taxon occupies a wide range of habitats from the coast to subalpine streams (Allan 1961), but its pollen appears mainly in cold climate sediments. The peat, from which most of the samples came, represents deposition in a wet Cyperaceae swamp around which *Halocarpus* (*H. bidwillii* or *H. biformis*) was common. The abundance of pollen from the semi-aquatic plant *Myriophyllum* indicates the presence of running water. The abundance and diversity of spores shows a marked decline in samples from the peat, among which *Gleichenia circinata* is the most frequent and abundant

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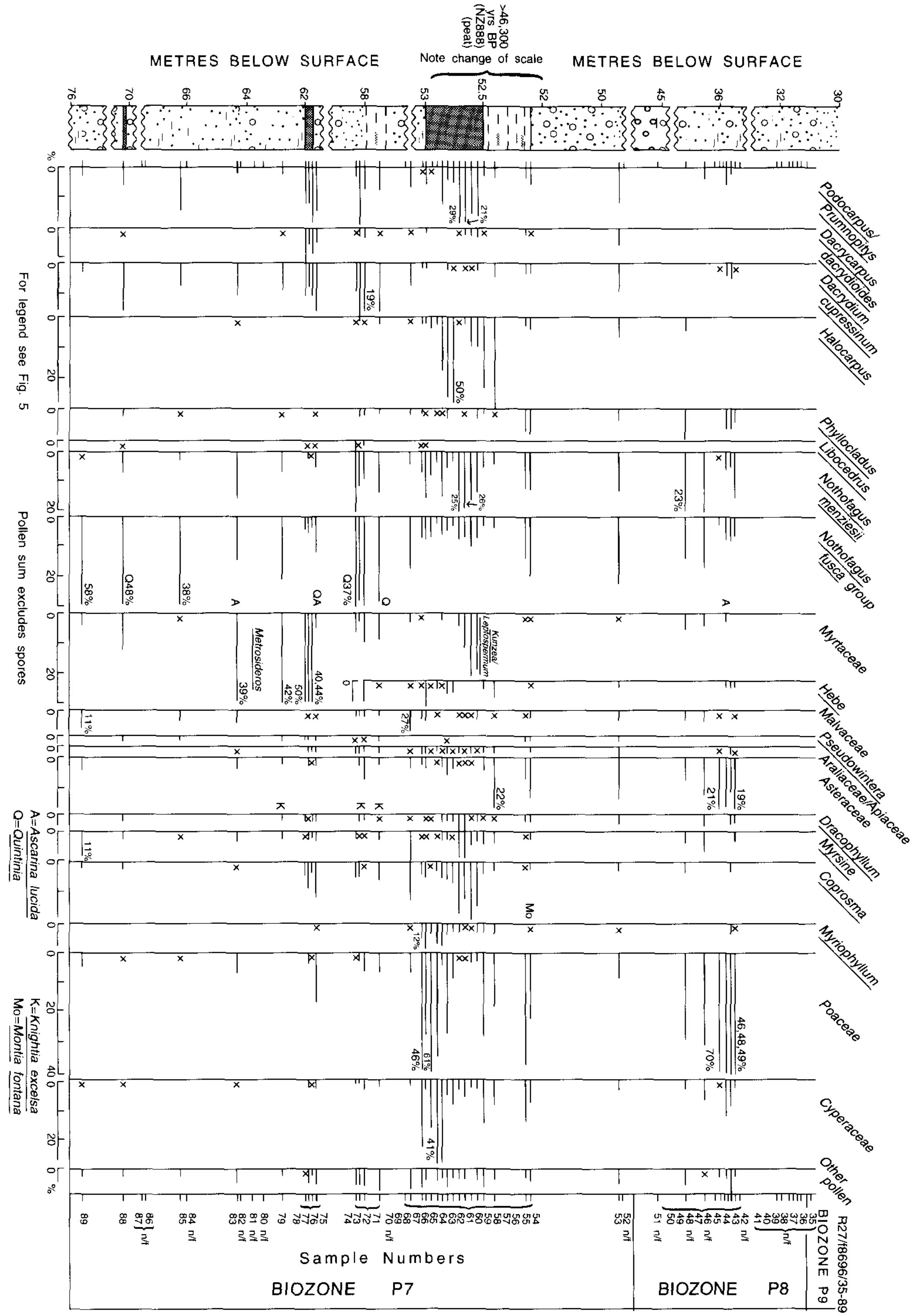
Fig. 9 – Pollen diagram, Petone Drillhole, 76–30 m; biozones P7-P9. n/f = no flora; X = < 1%. The large peaks in the pollen diagram for "other pollen" are for a variety of pollen types in a very low count (samples 42, 50), Restionaceae (57), and *Phormium tenax*, *Astelia*, and a number of unidentified tricolporate grains (71). Note change of scale between 52–53 m. Within this interval a peat was sampled at very closely spaced intervals, some samples registered on the fossil record forms and in the drillhole logs as being from the same depth. These could not be placed accurately on the pollen diagram where they are evenly spaced. There are discrepancies between the fossil record forms and the logs as to the order of these samples and since this could not be resolved they are listed in order of fossil record number. This involves samples 56–67 covering an interval of 0.4 m. ➤


METRES BELOW SURFACE
Note change of scale
METRES BELOW SURFACE
>46,300 yrs BP (NZ888) (peat)
Podocarpus/Prumnopitys
Dacrycarpus dacrydioides
Dacrydium cupressinum
Halocarpus
Phyllocladus
Libocedrus
Nothofagus menziesii
Nothofagus fusca group
Myrtaceae
Metrosideros
Kunzea/Leptospermum
Hebe
Malvaceae
Pseudowintera
Araliaceae/Apiaceae
Asteraceae
Dracophyllum
Myrsine
Coprosma
Myriophyllum
Poaceae
Cyperaceae
Other pollen
For legend see Fig. 5
Pollen sum excludes spores
A=Ascarina lucida
Q=Quintinia
K=Knightia excelsa
Mo=Montia fontana
Sample Numbers
BIOZONE P7
BIOZONE P8
BIOZONE P9
R27/f8696/35-89

type, indicating, in its association with Restionaceae, an acid swamp as the depositional environment. Many of the other fern, lycopod, and bryophyte spores like *Ophioglossum* (adder's tongue), *Pilularia*, and *Sphagnum* are types associated with swampy environments. Swamp forest probably grew in or near the deposition site, while the regional pollen rain consisted of beech and podocarp pollen from trees growing in sheltered areas. The abundance of Poaceae pollen indicates that substantial shrub/grassland associations were nearby at the time.

The samples from immediately above the peat show a return to diverse spore palynofloras dominated by *Cyathea* and smooth monolete spores, but with the types mentioned above still prevalent. This represents an encroachment of forest near the deposition site, and the presence of tree ferns and ground ferns shedding spores into streams entering the deposition site. The abundance of Poaceae and Cyperaceae pollen indicates that a shrub/grassland still covered much of the valley floor, with stands of trees growing in sheltered areas. The increase of pollen of *Nothofagus fusca* type at the expense of *Nothofagus menziesii*, which tended to be more common within the peat, may indicate a slight climatic amelioration, and a slight decrease in precipitation, but *N. fusca* type includes *N. solandri* var. *cliffortioides* which is just as hardy as *N. menziesii*.

Radiocarbon dating: One radiocarbon date from this sequence was listed by Grant-Taylor & Rafter (1971). An age of >46,300 (NZ888) was obtained from peat within "a slightly milder phase" of the Last Glaciation (Grant-Taylor & Rafter 1971). This was listed by Harris, Darwin, & Newman (1976) as PEAT 4630, a typographical error in quoting the radiocarbon date in their figure 2. Grant-Taylor and Rafter listed the fossil record number as N164/594/172 (N164/594 = R27/f8696) and the depth as 172–173 1/2 ft (see Table 3). The final figure, 172, represents the depth in feet from which the sample came, not a fossil record or sample number. The sample number on the fossil record form is given as 290, but this sample number is not recorded at all on the logs let alone from around 172–174 ft. The exact fossil record number is not known, because no sample is recorded as having been collected from precisely 172 ft, but the peat bed sampled for dating is obvious (Fig. 9), although the palynology of the peat does not indicate a "milder phase" of climate. On the contrary, the climate at 172 ft (52.4 m) appears to have deteriorated from a previously milder phase. In his manuscript notes Harris places this sample at 53 m.

Climatic assessment: The floral record at the base of the biozone indicates warming, followed by a cool period represented by samples from the most carbonaceous part of the sequence. A slight improvement in the climate, perhaps to cool temperate, is suggested for the top of Biozone P7.

Biozone P8 – 44.0–31.2 m (Fig. 9)

Lithology: Gravel (not sampled); sandy, gravelly mud (sampled); gravelly sand (sampled but unfossiliferous).

Palynology: The biozone as defined here is slightly different from that of Harris (see table above). The biozone is represented by only a few fossiliferous samples between 49.4 and 30.0 m, of which only one contains a full count (sample 43; 35.6–35.7 m). Other samples are included in the pollen diagram, but the total pollen count in these was very low. These include (depth and total pollen count in brackets) samples 44 (35.8 m; 102), 45 (35.9 m; 41), 47 (36.1–36.2 m; 143 grains of which 100 are of Poaceae), 49 (36.4–36.6 m; 64), and 50 (36.6–37.4 m; 48). In spite of the low counts the results appear consistent and therefore are included in Fig. 9. A further 10 samples were unfossiliferous.

There is a 12.3 m gap of unfossiliferous and unsampled sediment between the last sample in Biozone P7 (sample 52 at 49.5 m) and the first fossiliferous sample at the base of Biozone P8 (sample 50 at 37.2).

These samples are all dominated by Poaceae pollen (27–70%) and represent the peak of the Last Glaciation deforestation. The deposition site itself was a dry and well drained grassland, but a few pollen types present in the samples indicate occasional stream or wet patches supporting semi-aquatic plants like *Myriophyllum* and *Gonocarpus*. *Nothofagus menziesii* is relatively abundant and is characteristic of areas of high precipitation, suggesting that conditions were probably cold, bleak, windy, and relatively moist. As *Nothofagus menziesii* and N. *fusca* type pollen are the most abundant representatives of woody plants in the basal two fossiliferous samples, both taxa were probably growing in the region of the deposition site. *N. menziesii* has poor pollen distribution (McKellar 1973), so may have been growing nearby, possibly forming forest groves. The deposition site had *Phyllocladus*, Asteraceae, *Coprosma*, *Hebe*, *Myrsine*, and *Dracophyllum* growing on it, but apart from the Asteraceae these shrubs would have been sparse. Pollen from the other podocarps are rare but include *Dacrydium cupressinum*, which occupies moist situations in low rainfall and well drained areas (Franklin 1968).

Samples 49 (36.4–36.6 m) and 50 (36.6–37.4 m) both contain abundant fern and lycopod spores. The lycopods are especially abundant, with *Lycopodium fastigiatum*, *L. scariosum*, *L. varium*, and *L. volubile* forming 8–10% of the total count. This indicates the presence of abundant open spaces, as these species are typical of montane and subalpine grassland, shrublands, and forest margins (Allan 1961). These samples also contain spores of *Dicksonia squarrosa* and *Cyathea dealbata* (ponga), the latter known to live in contemporary montane shrublands (Allan 1961; Macphail & McQueen 1983). *Ophioglossum* and *Dicksonia squarrosa* are the most abundant spores in the other samples. Both *Ophioglossum pedunculosum* and *O. coriaceum* have been identified, forming 27% of the total count in sample 45 (35.9 m). Both of these species are plentiful in grassy situations and at the margins of swampy areas (Allan 1961).

A single dinoflagellate cyst was found in sample 49 (36.4–36.6 m) which, if *in situ*, indicates that the deposition site was at sea level and that the site was estuarine, lagoonal, or brackish water.

Because of the unfossiliferous nature of the samples from the top of the zone the placement of the boundary between biozones P8 and P9 is uncertain. It has been set at 31.2 m on the grounds that sample 35 (31.1 m) contains a few *Dacrydium cupressinum* grains, and little else. Thus the change to warm *Dacrydium cupressinum*-dominant palynofloras in Biozone P9 appears abrupt, and no shrubland or intermediate assemblages were preserved in the sequence. However, such sudden shifts appear to be a feature of the Last Glaciation/Postglacial boundary (Lewis & Mildenhall 1985; Mildenhall 1992, and unpublished IGNS reports) in Wellington.

Climatic assessment: The presence of *Nothofagus menziesii* indicates a cold and moist climate. However, at other times there was some dryness, possibly resulting from the combination of strong westerly and southwesterly winds, the orographic effect of Cook Strait (Harris, Mildenhall & McQueen 1981; McQueen & Mildenhall 1983; McGlone 1985), and lower sea levels. Temperature levels may have been 4–5 degrees colder than the present-day, and the treeline was probably below present sealevel (Mildenhall 1993c). The treeline is defined as the "whole ecotone from the upper limit of closed forest to that of scattered, stunted specimens of tree species" (Wardle 1981). Since this is difficult to determine palynologically because of the upward drift of pollen from trees into shrub/grasslands above the level of the highest trees (trees 1–2 m high within the subalpine zone), the treeline is here restricted to the upper level of closed forest.

Biozone P9 – 31.2–3.0 m (Figs 9, 10)

Lithology: Sand with gravel and wood fragments; marine sand; mud with shells (well sampled to 11 m); marine sand with coarse gravel (sparsely sampled); fill (not sampled).

Palynology: The zone boundaries are slightly different from those defined by Harris in his unpublished notes. The base has been extended downwards slightly (see above) and the upper limit of the biozone has been extended to encompass all sediments below the surface

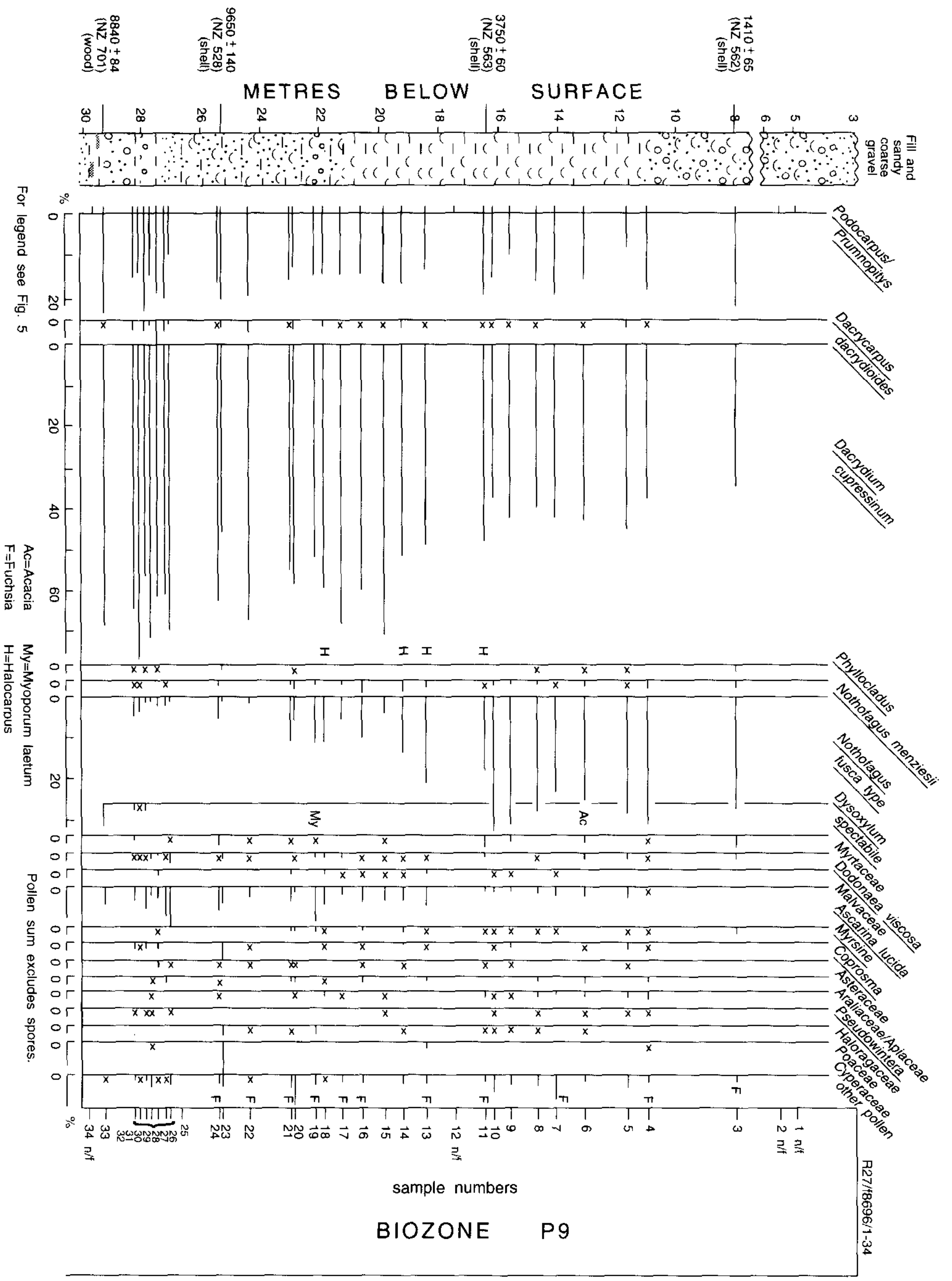


Fig. 10 – Pollen diagram, Petone Drillhole, 30–3 m; Biozone P9. n/f = no flora; X = < 1%. The large peaks in the pollen diagram for "other pollen" are for identified tricolpate and tricolporate pollen types (sample 20) and *Muehlenbeckia* (7).

fill and the sandy, coarse gravel comprising the top 3 m of the sequence. Most of the pollen samples gave good recovery, and 200 pollen grains or more were recorded from most samples.

The Postglacial sequence begins with abundant *Dacrydium cupressinum* pollen, but this is gradually replaced by *Nothofagus fusca* type, indicating a gradual deterioration of conditions. This same climatic deterioration, extending over the last 8,000 years, was evident at Pauatahahui, near Porirua, where it was attributed to increased frostiness and summer droughts becoming more prevalent after 5,000 years BP (Mildenhall 1980). The rise of *Nothofagus fusca* type pollen seems to have extended over a long period of time, possibly since deforestation at the peak of the Last Glaciation and certainly since the peak of the Postglacial warm period at c. 30–27 m, dated here as between 9,000–9,800 years ago. *Nothofagus* was not recorded in the basal Postglacial sample (33; 29.3 m) but its presence in the underlying Last Glaciation and overlying Postglacial sequence suggests that it was within about 25 km of the Petone Drillhole, based on the known distribution characteristics of *Nothofagus fusca* type (Myers 1973). The percentages of *Nothofagus* indicate that it did not reach the vicinity of the deposition site until c. 3,000–4,000 years ago, represented in the sequence by sample 10 at 16.2 m, and then only on the nearby hills. *Nothofagus*, except *N. fusca* (not found south of Waiorongomai River, near the headwaters of the Orongorongo River) and *N. solandri* var. *cliffortioides* (not found south of the Manawatu Gorge, 135 km north of Wellington), currently occupies the eastern hills of Wellington (Druce & Atkinson 1959), but has yet to cross to the western hills south of Haywards Hill.

Dysoxylum spectabile (kohekohe) pollen was identified only during the interval of the peak Postglacial warm period. At present, this species is restricted to north of latitude 41° 30′S, i.e., the northern-most South Island, and the North Island (Allan 1961). Its presence in the core indicates that a range of broadleaved taxa grew in the north Wellington area during the early part of the Postglacial.

The warmth loving plant *Ascarina lucida* slowly declined up the core until at c. 2,000 years (after sample 4 at 11 m) it disappeared, as it has in other parts of New Zealand (McGlone & Moar 1977). The podocarps other than *Dacrydium cupressinum* (i.e., *Podocarpus, Prumnopitys, Dacrycarpus dacrydioides*), remained at constant levels throughout this phase. *Dodonaea viscosa*, another warmth loving plant, often associated with *Ascarina lucida* in declining throughout the late Postglacial, survived here to produce pollen in trace amounts throughout the Postglacial.

Acacia (wattle) pollen is present at 13.1 m (sample 6) and may possibly be a result of sample contamination from contemporary plants, but there have been previous records from the Wellington late Pleistocene (Mildenhall 1972; Lewis & Mildenhall 1985; Bussell & Mildenhall 1990), so it may also represent an extension of its stratigraphic range into the Postglacial.

Pollen of *Knightia excelsa* is absent from the sequence. Its current distribution is Marlborough Sounds and North Island (Allan 1961) and its appearance in the Wellington

Table 3 – Radiocarbon dates from the Petone Drillhole with sample and fossil record numbers as assigned by Grant-Taylor & Rafter (1971)

Old "fossil" record number	New "fossil" record number	Nearest equivalent fossil record number	^{14}C number	Date in years before present
N164/594/25	R27/f8696/56	Above f8696/3	NZ562	1,410 +/–65
N164/594/53	R27/f8696/62	Above f8696/28	NZ563	3,750 +/–60
N164/594/84	R27/f8696/75	Below f8696/24	NZ528	9,650 +/–140
N164/594/96	R27/f8696/85	Between f8696/33 and f8696/34	NZ701	8,840+/–84
N164/594/172	R27/f8696/290	Not determined, ?near f8696/64	NZ888	>46,300

area at c. 3,400 years ago was documented by Mildenhall (1980) in a sequence from Pauatahanui, near Porirua. It has also been recorded in the Melling Peat (Harris 1959), about six kilometres to the north of Petone, and dated as 4,350 ± 100 and 4,275 ± 100 yrs BP (Stevens 1956), and at Wainuiomata, about 7 1/2 kilometres southeast of Petone, at an equivalent or younger time (Mildenhall 1993c). Since this interval is probably represented by just one or two samples at the top of the Petone Drillhole, its absence from the Petone area during this time cannot be substantiated. The taxon still forms a useful biomarker for the late Postglacial.

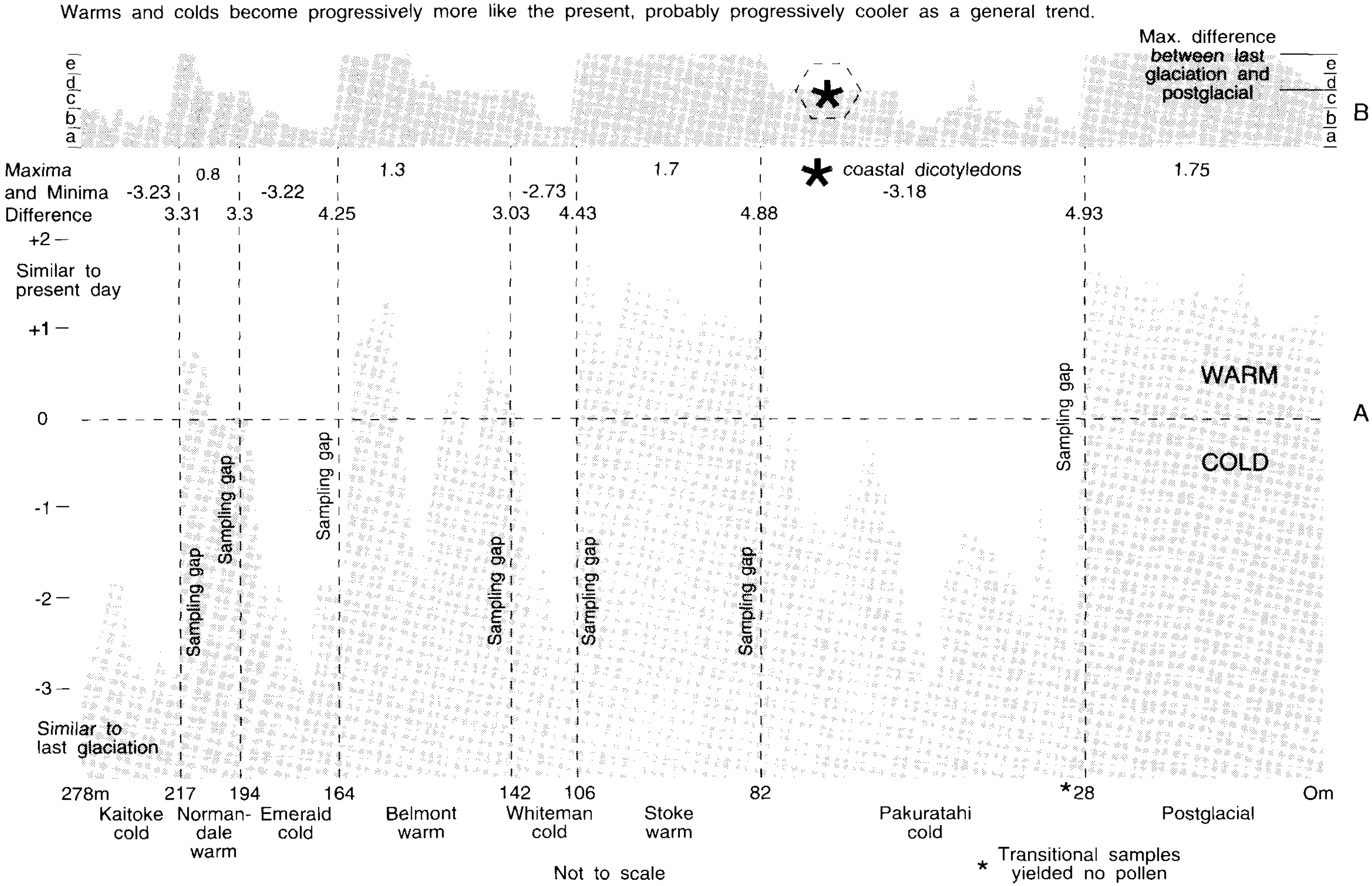
Most of the sequence is marine, or at least estuarine, and includes dinoflagellates in most samples. The coastal nature of the vegetation is borne out by the association together of number of pollen types from marginal and lowland coastal forest, including, in addition to taxa mentioned above, *Myoporum laetum* (ngaio), *Fuchsia* (almost certainly tree fuchsia), *Pseudowintera*, *Muehlenbeckia*, and *Coriaria* (tutu; Allan 1961).

The scarcity of spores from lycopods characteristic of open spaces indicates an interglacial climate during which forest cover was extensive and nearly continuous. The spores that are present are typically of the *Lycopodium varium* type, and are probably derived from the epiphytic form growing in the lowland forests. The most abundant tree fern spores are from *Cyathea*, comprising *C. dealbata*, *C. medullaris*, and *C. smithii* (with sporangia), *Dicksonia squarrosa*, and unidentifiable, smooth monolete spores. The spores range in number from 177 (average c. 400) to 1,446 per 100 *Dacrydium cupressinum* pollen grains. Spores of liverworts, hornworts, and other bryophytes, also typical of open spaces, are rare as well.

Radiocarbon dating: The sequence contains four radiocarbon dates (Grant-Taylor & Rafter 1971; Harris, Darwin & Newman 1976). These dates are recorded in Grant-Taylor and Rafter as coming from samples N164/594/25, /53, /84, and /96 (N164/594 = metric R27/f8696). The last figures, 25, 53, 84 and 96, represent depths in feet and are not sample or fossil record numbers. There are no corresponding fossil record numbers. Table 3 outlines the current position of these dates. In this table the first column gives the fossil record numbers as assigned by Grant-Taylor and Rafter (1971), with the associated radiocarbon number in column 4. Column 2 allocates the current metric sheet fossil number with the sample number appended. This number was obtained from data on the original fossil record form. However, it is not a registered fossil record number; these forms were used as substitutes for radiocarbon forms. Column 3 gives, where possible, the nearest fossil record number to the radiocarbon sample, based on data obtained from the original logs on which all samples are plotted. The radiocarbon dates are plotted on the pollen diagrams according to depths given on the old "fossil" record forms.

The lowest date of 8,840 ± 84 yrs BP (NZ701) in this biozone is from wood at the 29.3 m level. According to Grant-Taylor & Rafter (1971) the climate was cool but not cold, based on pollen results by W. F. Harris. However, the sample, collected from estuarine sediments, is the lowest *Dacrydium cupressinum* dominated sample containing abundant *Ascarina lucida*, and as such is regarded as representing the beginning of the peak Postglacial warm phase. The date is probably at least 1,000 years too young, since the radiocarbon sample above, derived from aragonite, is regarded as completely reliable.

Fig. 11 – Pollen zones from the Petone Drillhole based on discriminant function and dominant and/or co-dominant analyses. Part A = variations in spore and pollen assemblages relative to a temperature gradient between the Last Glaciation and present-day, expressed in terms of discriminant functions calculated for 48 species. Part B = types of assemblages as characterised by dominants or co-dominants and interrelated as in the pollen assemblages of Harris (1963). Letters *a* to *e* represent the five pollen assemblages described in Harris (1963) and Harris, Darwin, & Newman (1976), arranged in an ascending warming sequence. The scale in metres at the base is not to scale since the diagram is organised on the basis of the number of samples from each biozone, because it is impossible to scale the diagram accurately in one figure, as well as indicating the size of sample gaps. ➤


Warms and colds become progressively more like the present, probably progressively cooler as a general trend.
Max. difference between last glaciation and postglacial
e
d
c
b
a
B
Maxima and Minima Difference
-3.23
0.8
-3.22
1.3
-2.73
1.7
coastal dicotyledons
-3.18
1.75
3.31
3.3
4.25
3.03
4.43
4.88
4.93
+2
Similar to present day
+1
0
-1
-2
-3
Similar to last glaciation
WARM
COLD
A
Sampling gap
278m
217
194
164
142
106
82
*28
Om
Kaitoke cold
Norman-dale warm
Emerald cold
Belmont warm
Whiteman cold
Stoke warm
Pakuratahi cold
Postglacial
Not to scale
* Transitional samples yielded no pollen

The next date, of 9,650 ± 140 yrs BP (NZ528), is from shells from the lowest beach deposit at 25.6 m, immediately above a thin estuarine bed and terrestrial peats, and dates the time when the Postglacial sea level rise reached a level to inundate the Petone area. This date is also consistent with the lower part of the sequence representing the Postglacial climatic optimum as discussed by, for example, Pittock & Salinger (1983), and Mildenhall & Brown (1987), who gave a maximum age of c. 9,800 yrs BP for the climatic optimum in Poverty Bay, 350 km northeast of Petone. This date was omitted from the zonation scheme for the Petone Drillhole produced by Harris, Darwin & Newman (1976). The Postglacial marine transgression culminated about 6,500 years ago (Gibb 1986).

The third date, 3,750 ± 60 yrs BP (NZ563), is also from shells from marine sands at 16.1–17.1 m, and deposited close to low tide level. The youngest date of 1,410 ± 65 yrs BP (NZ562) is from shells from marine sands deposited close to low tide level and is from 7.6–7.9 m.

Although it is possible to use the radiocarbon dates to obtain subsidence and uplift rates, the reversal of the two lower samples suggests that some caution is advisable before attempting this exercise. Ideally, another drillhole, preferably on the upthrown side of the Wellington Fault, would assist in providing better data on rates of tectonic movement.

Climatic assessment: Warm, but cooling and becoming gradually more frosty and prone to summer drought from c. 7,000–5,000 years BP.

SEAVIEW DRILLHOLE

Stratigraphic and paleontological zonation

Sediments in the Seaview Drillhole are predominantly sand and gravel with relatively thick horizons of silt, clay, and occasional thinner carbonaceous beds. The gravel beds are composed of a mixture of well-rounded and angular greywacke pebbles, up to 100 mm in size, which are weathered and break very readily between the fingers. Only one large peat horizon was located between 73.2–75.0 m towards the top of Biozone P4, at approximately the same stratigraphic position as the peat bed between 152.4–153.6 m in the Petone Drillhole. Marine sediments containing shells lie at the top of the section, corresponding with the shelly beds of Biozone P9 at the top of the Petone Drillhole (Petone Marine Bed). There are other shelly horizons at about 48 m to 52 m (top of Biozone P6; Moera Basal Gravel), and from 62.2 m to 65.2 m (probably Biozone P5; either the basal part of the Moera Basal Gravel or the top of the underlying saline and marine gravel beds of Stevens (1956) and Grant-Taylor (1974)).

I have attempted to correlate the biozones of the Petone and Seaview drillholes. However, because of the lack of independent dating and the difficulties of correlation, these links are to be regarded as indicative only. Recent revision of the stratigraphic correlations between the Petone and Seaview drillholes by J. G. Begg (*pers. comm.*, November 1993), based solely on a reinterpretation of publicly available drillhole information, has materially assisted this correlation. From his work it appears that the sediments thin out sharply from the Petone Drillhole eastward to the Seaview Drillhole, but that essentially the same sediments are preserved in both. The palynology does not contradict this view. Diagrams in Stevens (1956, 1973, 1974, 1991) show the older sediments in the lower part of the Hutt Valley to be flat-lying and to young rapidly to the east, but Stevens' illustrations are diagrammatic, intended to illustrate the position of aquifers, and are not intended accurately to portray the dip of the beds or the east-west chronostratigraphic succession.

Palynology

In the Seaview Drillhole, 38 out of a total of 44 submitted samples yielded useable pollen data. Large, potentially fossiliferous, intervals of the drillhole have not yet been sampled (Figs 12, 13). These unsampled intervals are regarded as encompassing much of the glacial sedimentation at Seaview; hence it is unlikely that any glacial sediments were sampled. Comments on the palynology of the Petone Drillhole also apply here.

Generally speaking, the palynology of the Seaview Drillhole is similar to that found in correspondingly aged sections of the Petone Drillhole. However, there are enough differences to make comparisons based solely on palynology rather subjective. These comparisons will be made below (p. 240).

Zonation

Biozone P1 – 179–130 m (Fig. 12)

Lithology: Weathered greywacke basement; fine, blue, sand and silt with rare organic horizons (all pollen samples); abundant weathered gravel (not sampled).

Palynology: Seven pollen samples were collected from the lowest 49 m (179–130 m) of the Seaview Drillhole, but with gaps from 172.2–156.6 m and 150.0–132.6 m. The assemblages obtained are primarily dominated by pollen of Myrtaceae, mainly *Metrosideros*, but also containing abundant *Leptospermum* and/or *Kunzea*. However, the basal sample (41), at 172.2 m, is dominated by *Plagianthus* pollen (78%, in a count of less than 200 pollen grains) and the sample above (40), at 156.6 m, is dominated by Restionaceae pollen plus *Podocarpus/ Prumnopitys*.

The sequence represents a warming phase, with *Ascarina lucida* and *Dacrydium cupressinum* becoming more frequent towards the top of the profile. The local vegetation probably consisted of *Ascarina lucida*, Myrtaceae, Malvaceae, herbaceous and swamp taxa, and other broadleaved species, while the vegetation on the nearby hills probably consisted primarily of podocarps. The relative scarcity of *Nothofagus* pollen indicates that there were no beech trees near the deposition site, and probably only in scattered pockets regionally.

Abundant *Cyathea* and other tree fern spores, *Fuchsia*, and other water-demanding taxa indicate abundant available moisture. Ground ferns (e.g., *Gleichenia*, Hymenophyllaceae), ground and epiphytic lycopods (mainly *Lycopodium varium* and *L. volubile*), bryophytes (*Sphagnum*), liverworts (Ricciaceae), and hornworts (Anthocerotales) are frequent and abundant. Occasionally thousands of *Cyathea* spores were counted before the count for the dominant angiosperm or conifer pollen type reached 100. In one sample (35), noted with an asterisk on Fig. 12, <100 pollen grains were counted.

Spores of *Lygodium articulatum* were found in this biozone and indicate a climate warmer than the present-day, even though they are found only at the base of the sequence before the probable warmest period (represented by the *Dacrydium cupressinum* and *Ascarina lucida* peaks and the presence of *Dodonaea viscosa*) in the overlying Biozone P2. *Knightia excelsa* was found in one sample; the significance of this taxon is discussed above (p. 226, 231).

Although the sediments in this biozone are marine, no dinoflagellate cysts were recorded, and only one marine diatom (identified by W. F. Harris as *Cosinodiscus*), from sample 38 (153.9 m).

In spite of two large breaks in the sequence, during which no pollen samples were collected because the lithology appeared unsuitable (weathered gravels in a sand and clay matrix), the sequence seems to represent continuous vegetation trends. However, there appears to be no comparable vegetation represented in the Petone Drillhole, except over a very small interval at the top of Biozone P1, where Myrtaceae pollen is also common, so that comparisons on palynological grounds are difficult. If Biozone P1 at Seaview (49 m) is the equivalent of only the top of Biozone P1 at Petone (a maximum of 30 m between two Poaceae-dominant samples), then this part of the sequence appears to be thicker at Seaview than at Petone. Alternatively, since all available samples from Seaview appear to represent relatively warm and moist conditions, the whole interval may be better correlated with the basal part of Biozone 2 at Petone: but then the biozone would still be thicker at Seaview than the equivalent interval at Petone. I understand that the condition of the Seaview Drillhole after storage and sampling for various purposes over the last 30 years precludes further accurately located sampling for spores and pollen.

Seaview Biozone P1 can also be divided into finer zones, as is the case in Biozone P1 in

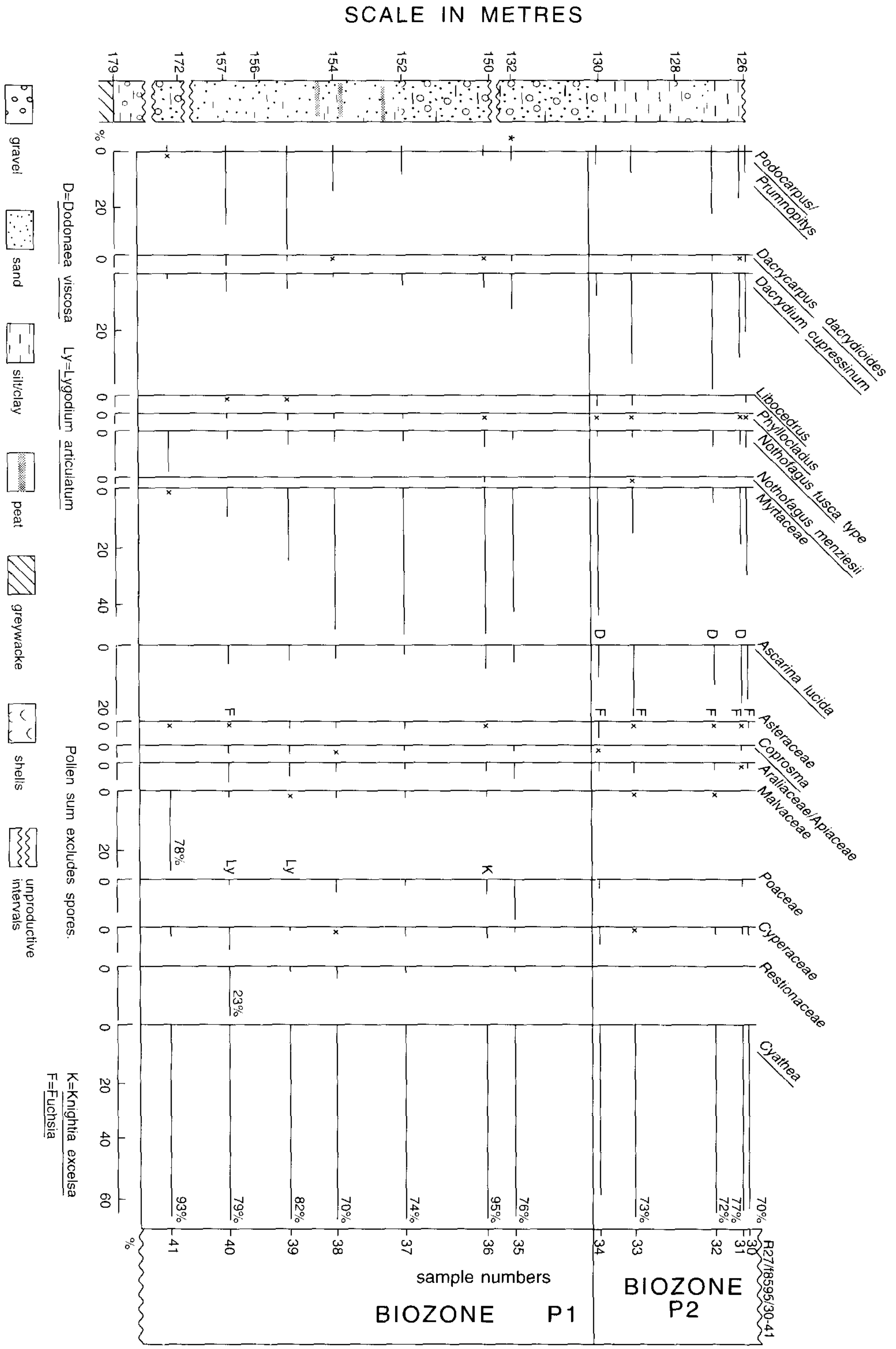


Fig. 12 – Pollen diagram, Seaview Drillhole, 179–126 m; biozones P1 and P2. Omitted from the diagram are samples 42 and 43 collected from below the top of the basement. * = count of pollen <100; X = < 1%.

the Petone Drillhole. This is not done here because the sampling was so broad that some of the zones would be represented by single samples, that could have recorded local events rather than correlatable valley-wide events.

Climatic assessment: Moist and warm.

Biozone P2 – 130–120 m (Fig. 12)

Lithology: Fine, blue-grey silty, sandy clay (all pollen samples), with gravel horizons and occasional organic matter.

Palynology: Five samples were collected from this interval. The samples are dominated by Myrtaceae (mainly *Metrosideros*), *Ascarina lucida*, *Dacrydium cupressinum*, and various other podocarps. The pollen rain was formed from a podocarp/broadleaved forest, probably growing on both the valley sides and floor. *Ascarina lucida* forms up to 20% of the total pollen count and *Cyathea* spores form up to 77% of the total count. The presence of abundant *A. lucida*, *Dodonaea viscosa*, *Fuchsia*, *Typha*, and other plants of warm and moist situations suggests a climate probably at least 1°C warmer than the present-day. *Nothofagus fusca* type pollen forms less than 10% of total pollen and is probably locally absent. This assemblage is similar to that found in the basal part of Biozone P2 at Petone.

The same abundant and varied fern, lycopod, and bryophyte spores located in Petone Biozone P1 are also found in this biozone, and represent continuing optimal growing conditions.

No dinoflagellates were recorded in any of these samples, although the sediments could be marginally marine.

There is a large unsampled gap (containing sediments of mostly grey-brown, and often very weathered gravel, with occasional silty beds) of 37.2 m between the top of Biozone P2 and the base of the overlying Biozone P4. Biozone P3 is missing, or unsampled; from the logs of the Seaview Drillhole this interval might have contained some potentially fossiliferous sediment.

Climatic assessment: Possibly an average of 1°C warmer than the present-day, and moist.

Biozone P3

Missing or unsampled from the Seaview Drillhole.

Biozone P4 – 89–72 m (Fig. 13)

Lithology: Blue-grey silty, sandy clay with gravel and occasional organic matter; peat (all horizons sparsely sampled).

Palynology: Since Biozone P2 represents an interglacial, then the unsampled 37 m gap between biozones P2 and P4 probably represents part or all of the Waimaunga (Emerald) Glacial (Fig. 14). Between 89.0–72.5 m, all twelve samples examined were dominated by *Nothofagus fusca* type. This is probably the equivalent of the upper part of Biozone P4 in the Petone Drillhole, and is correlated as such. The base of Biozone P4 at Petone is dominated by *Dacrydium cupressinum* with frequent *Dodonaea viscosa* and *Ascarina lucida*, and this warmer and moister phase of Biozone P4 is not recorded by any samples collected at Seaview.

Nothofagus fusca type forest was at this time growing close to the deposition site. Myrtaceae (both *Metrosideros* and *Leptospermum*/*Kunzea*) was still very common and also appears to have been growing on-site. Podocarp pollen is sparse relative to that in biozones P1 and P2. *Dacrydium cupressinum* pollen is constantly present in small numbers throughout the biozone. This phase is the coolest recorded by pollen samples in the Seaview Drillhole but, even so, abundant moisture was still available and temperatures warm enough allow the continued survival of *Ascarina lucida*, throughout the biozone, and *Knightia excelsa* (one sample, 22). Frosts were not intense enough to eliminate *A. lucida*. Spores of tree ferns remain at a high level, but are now considerably less frequent than in biozones P1 and P2.

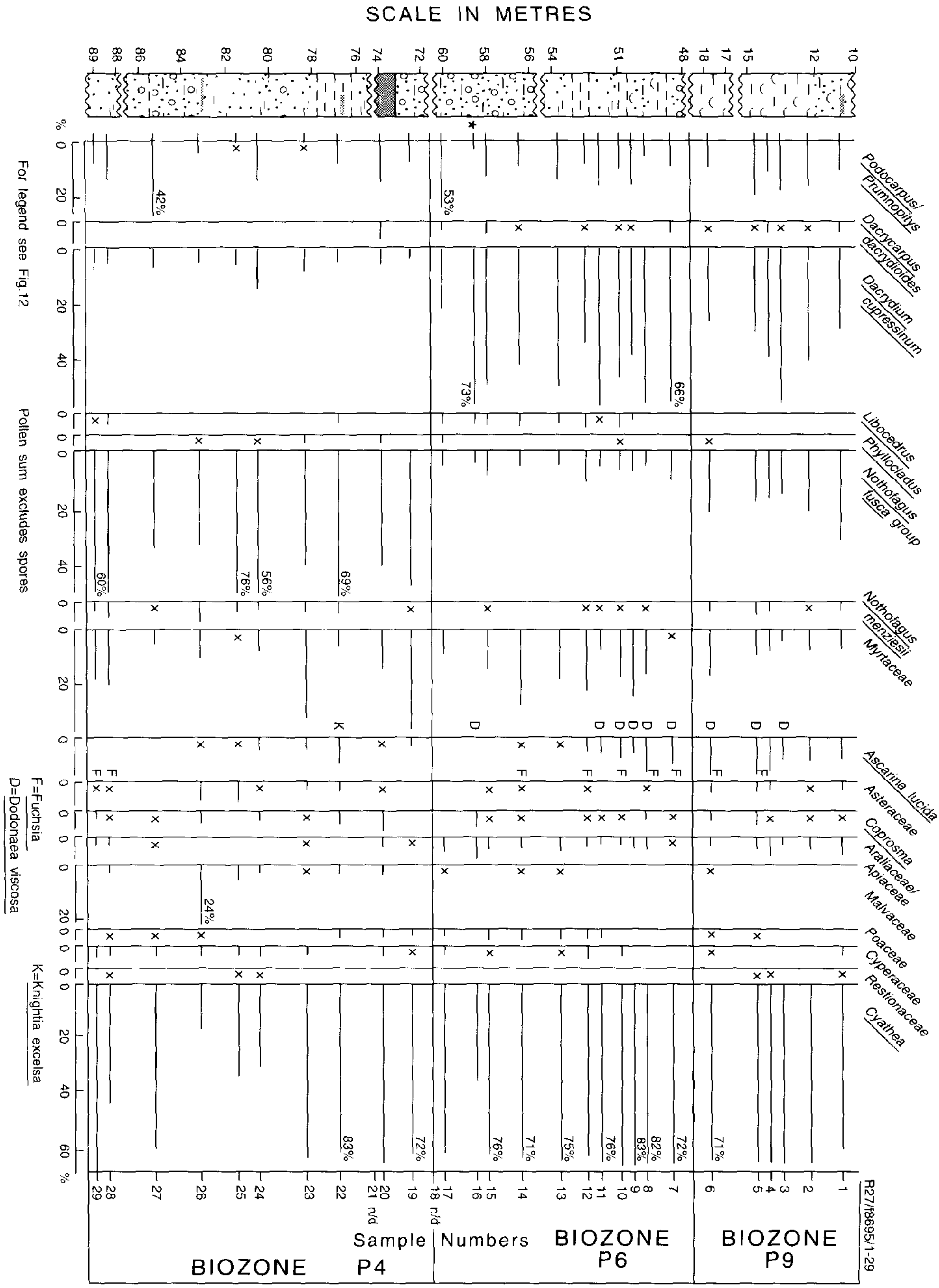


Fig. 13 – Pollen diagram, Seaview Drillhole, 89–10 m; biozones P4, P6, and P9. n/d = too few spores and pollen to count; * = poor assemblage; X = < 1%.

Spores of lycopods and bryophytes are sparse or missing, indicating full vegetation cover. Full counts were possible, and 150 pollen grains or more were counted in most samples.

There is an unsampled and unfossiliferous gap of 12.5 m between the top of Biozone P4 and the base of the overlying Biozone P6. These sediments are composed of often deeply weathered, grey-brown gravel, with occasional marine shells at the top of the unsampled gap.

Climatic assessment: Cool and moist.

Biozone P5

Missing from the Seaview Drillhole.

Biozone P6 – 65–48 m (Fig. 13)

Lithology: Blue-grey, sandy silt and gravel; brown silt; blue clay; gravel. All fine-grained beds were sampled for pollen, but there was a large unsampled gap between 48.5 to 17.7 m at the base of the overlying biozone. Marine shells were scattered throughout this biozone.

Palynology: Eleven pollen samples were taken from 17 m of sediment representing the Last Interglacial. All the pollen assemblages are dominated by pollen of *Dacrydium cupressinum*, except for the basal sample (17) which contains abundant pollen of *Podocarpus* and *Prumnopitys*. The pollen is derived from a podocarp/broadleaved forest, which probably covered both the alluvial flats and sides of the valley. Myrtaceae pollen is common, represented by *Leptospermum* and *Kunzea*. *Dodonaea viscosa* is present and *Ascarina lucida* is common, particularly in the upper part of the biozone. Conditions were probably warmer than the present-day, considering the relative abundance of *Ascarina* and *D. cupressinum* pollen, and relatively frost-free and moist. The frequency of *Fuchsia* (probably *F. excorticata*, commonly found in shaded situations beside running water), Cyperaceae, and other pollen from mesophytic plants indicates abundant available moisture.

Spores of *Cyathea* are abundant, forming between 35%–83% of the total count before counts of the dominant taxon reached 100. Pollen counts were usually over 200 grains per count; one sample (16) contains a sparse palynoflora in which only 94 grains were counted (labelled with an asterisk in Fig. 13). The area was probably well vegetated, because bryophyte spores were not recorded.

An unsampled interval, between about 18–48 m and consisting of very weathered, blue-grey, silty clay, sand, and gravel containing occasional marine shells, probably represents the whole of the Last Glaciation, and so biozones P7 and P8 appear to be missing.

In spite of the obvious marine nature of the sediments (shells are present) in this biozone, no dinoflagellate cysts were recorded.

Climatic assessment: Moister than the present-day, and with temperatures up to 1°C warmer than present.

Biozones P7 and P8

Missing or unsampled from the Seaview Drillhole.

Biozone P9 – 18–10 m (Fig. 13)

Lithology: Brown, marine, sandy silts; gravel. Contains occasional organic material and shells. All fine-grained horizons sampled to 10.7 m.

Palynology: Six samples were collected from sediments within this biozone. The interval is dominated by pollen of *Dacrydium cupressinum*, with *Nothofagus fusca* type pollen increasing in the top two samples. As in the Petone Drillhole, the sequence demonstrates the gradual rise of *Nothofagus fusca* type pollen in the profile towards the present-day at the expense of the podocarps. However, the quantities of *Nothofagus* pollen indicate that the parent plants were probably never closer than at least 25 km from the deposition site. Modern pollen samples from the Wellington area contain abundant *Nothofagus* pollen up to this level at c. 25 km from the nearest source (author's personal observations). *Cyathea* spores are abundant, averaging about 60% of the total spore and pollen count combined. This, the presence and abundance of *Ascarina lucida*, and the presence of *Dodonaea viscosa*, together indicate warmer and moister conditions than in Wellington today, probably relatively frost-free.

The Postglacial *Nothofagus* peak, apparent in the Petone Drillhole, is not reached in this core, neither is the decline of *Ascarina lucida* all that obvious, although there are slightly lower percentages of *Ascarina* pollen in the top three samples. This suggests that the samples represent the early to middle part of the Holocene. The *Ascarina* decline is regarded (e.g., McGlone, Salinger & Moar 1994) as commencing after about 7,000 years BP, and is absent in the top sample in the Petone Drillhole. The top 10.7 m of the sequence was not sampled. By comparison with the Petone Drillhole it appears that the Seaview samples represent between about 9,000 and 4,000 years BP.

Although there are marine shells in this part of the sequence, no dinoflagellate cysts were recorded.

Climate assessment: Warm, moist, probably representing the warmer phases of the early to middle Holocene.

DISCUSSION

Correlation between Petone and Seaview Drillholes

Of the nine biozones recognised in the pollen sequences obtained from the Petone Drillhole only five are matched by pollen samples at Seaview. Although there are considerable differences between the palynology of both drillholes, some points of comparison are possible, and they allow correlations to be made.

Biozone P1

At Seaview this biozone is characterised by abundant Myrtaceae pollen. The only parts of the Petone Drillhole with assemblages dominated by Myrtaceae are in the middle of the Last Glaciation (Biozone P7) at approximately 66–62 m, and in a very short interval, represented by 2 pollen samples, towards the top of Biozone P1 (Fig. 5).

Also, the only horizons in the Petone Drillhole where Malvaceae (*Plagianthus*, but possibly also including *Hoheria*) gets close to the quantities found in the basal sample in the Seaview Drillhole is at approximately 53 m (Biozone P7; Fig. 9, sample 69), 76 m (Biozone P7; Fig. 9, sample 89), 183.5 m (Biozone P3; Fig. 6, sample 180), and at approximately 215.8 m (Biozone P1; Fig. 5, sample 192). However, in each case the palynoflora is dominated by pollen of *Nothofagus fusca* type (first three horizons) or by Poaceae (at 215.8 m). A correlation with *Plagianthus* in any of the biozones would be a co-incidence rather than a point of correlation, because *Plagianthus* forms a very transitory phase in many pollen diagrams and so is often missed in coarsely sampled sequences (M. S. McGlone, *pers. comm.*, September 1992). However, at about 239.5 m in the Petone Drillhole, Myrtaceae pollen and *Cyathea* spores are also abundant, Poaceae is rare, and *Ascarina lucida* is common: all these features are similar to those of Biozone 1 at Seaview. Pollen of *Knightia excelsa* is found infrequently throughout both drillholes, but especially in both Biozone P1 at Seaview and at the top of Biozone P1 at Petone. Thus Biozone P1 at Seaview seems to correlate most closely with the top of Biozone P1 at Petone. However, as mentioned above, it is possible that Biozone P1 at Seaview may be better correlated with the base of Biozone P2 at Petone, since there is no palynological evidence of any cold temperate or glacial environments at Seaview.

However, at Petone at this time, *Nothofagus fusca* type pollen formed between 27% and 33%, while it never reached more than about 10% at Seaview. The percentages do not indicate a local presence at either site, but it could be that the parent trees were closer to Petone than Seaview, possibly on skeletal soils of the western hills of Wellington.

Spores of *Lygodium articulatum* are found in Biozone P1 at Seaview, but not at Petone. These spores are very infrequent, but this slight discrepancy is not unexpected. The paleoenvironmental significance of the presence of this species is discussed above (p. 235).

Biozone P1 at Seaview is approximately 49 m thick; at Petone the equivalent part of the sequence is possibly only 30 m, but insufficient fossiliferous material was recovered at the base of the Petone Drillhole to confirm whether this eastward thickening of the sequence was real. Even with the possible correlation of Seaview Biozone P1 with basal Biozone P2 at Petone, there would still be an apparent eastward thickening of the sediments.

Biozone P2

At Seaview this biozone is dominated by *Dacrydium cupressinum*, *Podocarpus/Prumnopitys*, Myrtaceae, and *Ascarina lucida* pollen. The only place in the Petone Drillhole where *A. lucida* pollen is so abundant is in the basal part of Biozone P2. At Petone this basal part of Biozone P2 is also dominated by *D. cupressinum*, *Podocarpus/Prumnopitys*, Myrtaceae, and abundant *Cyathea* spores (the latter not included in Fig. 6). *Dodonaea viscosa* is also common to both sites. The match between the two sites appears close (Figs 6, 12), even to the relative lack of *Nothofagus fusca* type beech pollen at both.

At Seaview the zone is approximately 10 m thick; at Petone the equivalent part of Biozone P2 is about the same, or slightly thicker, taking into account an unsampled interval of about 10 m above the equivalent samples (f191-f187; Fig. 6).

Biozone P4

At Seaview and at Petone (except in the lowest part) this biozone is dominated by *Nothofagus fusca* type pollen. A further point of similarity between the two drillholes is the presence of peat in both sections. At Seaview the peat lies towards the top of the sampled part of the biozone at about 71.2–75.0 m, while at Petone the peat is at about 153 m, immediately preceeding the rise in dominance of *Nothofagus fusca* type pollen. The palynology of these peats is similar, but that may reflect a similar depositional environment, rather than an equivalent age. In both drillholes, *Ascarina lucida* pollen was frequently encountered and so in both cases there is evidence of a climate warmer than today. However, at both sites *Dodonaea viscosa*, which often co-exists with *Ascarina*, is very infrequent, or absent.

Other points of similarity between Biozones P4 at both sites are the relative unimportance of the podocarps, although *Dacrydium cupressinum* is more abundant at Petone; and the scarcity of *Nothofagus menziesii*, although in one sample at Petone it reaches 28%.

Libocedrus pollen is present only at the base of the biozone at Seaview, and is very infrequent at Petone.

Biozone P4 is approximately 17 m thick at Seaview, while the equivalent part of Biozone P4 at Petone is a minimum of 25 m thick. This is the first of the zones that appear to become appreciably thinner east from Petone to Seaview.

Biozone P6

There is little difference between biozones P6 at Seaview and Petone. At both sites the palynoflora is dominated by *Dacrydium cupressinum*, with abundant *Cyathea* spores. *Podocarpus/Prumnopitys*, Myrtaceae, and *Nothofagus fusca* type are common. *Libocedrus* pollen is relatively common, and has the highest frequency at this time at both sites. *Ascarina lucida* and *Dodonaea viscosa* are also common and frequent.

The only point of difference appears to be the frequency of *Fuchsia* pollen at Seaview, and an apparent absence of this pollen type at Petone.

Biozone P6 is approximately 17 m thick at Seaview, while the equivalent interval at Petone is a minimum of 24 m, and is probably substantially thicker than this.

Biozone P9

Both Petone and Seaview sequences are identical except that the last 4,000 years or so of Postglacial sediments is missing or unsampled at Seaview. At Petone the biozone consists of c. 30 m of mainly marine Postglacial sediment, while at Seaview only about 9 m of sediment is of Postglacial age. Both sequences demonstrate the gradual replacement of *Dacrydium* *cupressinum* pollen with *Nothofagus fusca* type pollen. However, the peak *Nothofagus fusca* type period (representing the arrival onto the nearby eastern hills of Wellington of *Nothofagus solandri* var. *solandri* and *N. truncata*, extending almost to the southern coast, and *N. fusca* to just north of Waiorongomai River, near the headwaters of the Orongorongo River), and the decline of *Ascarina lucida*, are unrecorded at Seaview, although may be present in the unsampled 10.7 m top part of the section.

Biozone P9 is approximately 9 m thick at Seaview, while the same interval at Petone is at least 22 m thick. The differences in thickness between sediments of similar age at Seaview and Petone are probably more a reflection of the sampling and preservation of the fossiliferous sediments, periodic erosion, and non-deposition, rather than just an indication of tectonic movement.

Correlation and age of the biozones

Biozone P1

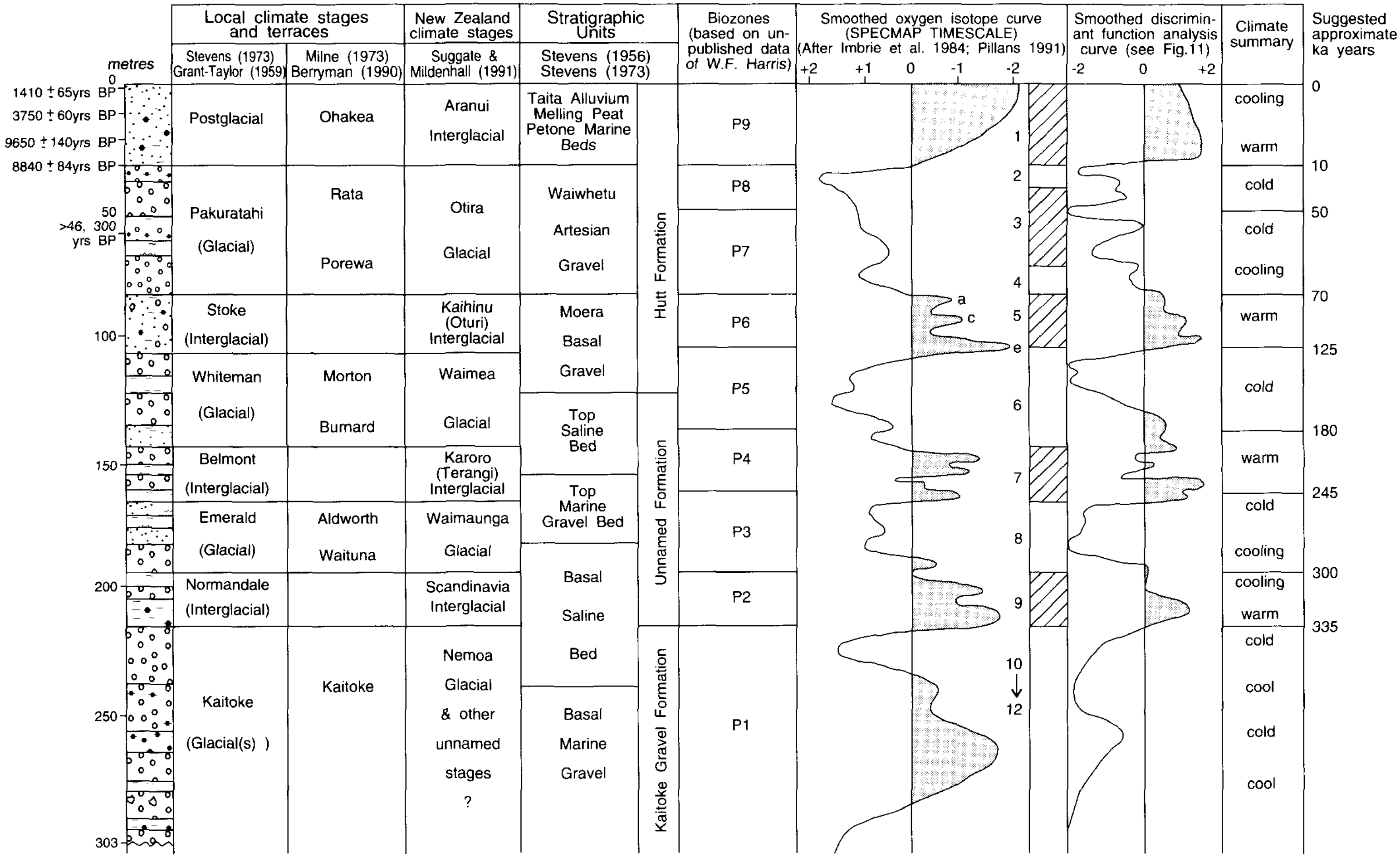
Deposition in the Petone area commenced during a glacial period, regarded by Stevens (1973) as being the local Kaitoke Glacial (including the Nemona Glacial plus probably older unnamed national stages; Figs 3, 14) climatic stage. The gravels are the southwards extension of the Kaitoke Gravel Group (Formation), originally described by Grant-Taylor (1959) from the Kaitoke area to the north of Upper Hutt (north of Fig. 1). The group was subsequently referred to as a formation by Grant-Taylor (1974), Grant-Taylor in Healy (1980) and Te Punga (1984c). Thus the sediments could be as old as Castlecliffian and Marahauan (Grant-Taylor 1978; Te Punga 1984c), or c. 1,800,000 to 300,000 years old (Grant-Taylor in Healy 1980). Since there is no evidence of red- or drab-weathering in these gravels, episodically recorded by Te Punga (1964, 1984a) between c. 520,000 and 27,000 years ago, they could be slightly younger, although with such active deposition and erosion, there has probably been little time for such weathering to become apparent or be preserved. These sediments form only the top part of the Kaitoke Gravel Formation. The base of the Seaview Drillhole contains deeply weathered sediments of this age, but even here there is no evidence of red-weathering.

Based on a count back of oxygen isotopes stages (Fig. 14), the sequence is probably much older than 300,000 years and probably correlates with a span of these stages, possibly 9 to 13 (cf. Imbrie et al. 1984; Pillans 1991).

Biozone P2

Correlation of this interglacial from the Petone Drillhole is uncertain, but it is certainly less than the 335,000 years, or so, assigned to the top of the Kaitoke Gravel Formation. It is likely to correlate with the locally named early to late Pleistocene "Normandale" Interglacial (Grant-Taylor 1959; Stevens 1973; Figs 3, 14). Both the *Dacrydium cupressinum* (warm) and *Nothofagus* (cooling) phases of Biozone P2 fall into this interglacial. If the correlations of the overlying Kaihinu (Oturi) and Karoro (Terangi) interglacials with oxygen isotope stages 5

Fig. 14 – Diagram of the Petone Drillhole summarising the data presented in this paper. The stratigraphic column is from Stevens (1973). Because of the scale of the diagram it is not possible to place the position of each of the >200 samples, but this and additional information on the lithology and discriminant function curve is given in previous diagrams (Figs 5–11). Because of the different scales used the boundaries are a best fit and might need readjusting if more detailed analysis is ever undertaken. The oxygen isotope and discriminant function curves are drawn freehand and independent of each other. Since no oxygen isotope work was done on the sediments from the drillhole the curve is based on relationship of the curve to the boundaries of the New Zealand climate stages after Pillans (1991) and correlations as discussed in the text. The discriminant function curve is not to scale on Fig. 10 and has been smoothed and fitted to the boundaries of the local stages (Grant-Taylor 1959). Note, if there are unconformities in the sequence (Harris, Darwin, & Newman 1976) whose significance is not recognised, further adjustments of the boundaries may be necessary. The numbers 1–12 refer to oxygen isotope stages. ➤


metres
Local climate stages and terraces
Stevens (1973) Grant-Taylor (1959)
Milne (1973) Berryman (1990)
New Zealand climate stages
Suggate & Mildenhall (1991)
Stratigraphic Units
Stevens (1956) Stevens (1973)
Biozones (based on unpublished data of W.F. Harris)
Smoothed oxygen isotope curve (SPECMAP TIMESCALE) (After Imbrie et al. 1984; Pillans 1991)
+2 +1 0 -1 -2
Smoothed discriminant function analysis curve (see Fig.11)
-2 0 +2
Climate summary
Suggested approximate ka years
1410 ± 65yrs BP
3750 ± 60yrs BP
9650 ± 140yrs BP
8840 ± 84yrs BP
0
50
>46, 300 yrs BP
100
150
200
250
303
Postglacial
Pakuratahi
(Glacial)
Stoke
(Interglacial)
Whiteman
(Glacial)
Belmont
(Interglacial)
Emerald
(Glacial)
Normandale
(Interglacial)
Kaitoke
(Glacial(s))
Ohakea
Rata
Porewa
Morton
Burnard
Aldworth
Waituna
Kaitoke
Aranui
Interglacial
Otira
Glacial
Kaihinu
(Oturi)
Interglacial
Waimea
Glacial
Karoro
(Terangi)
Interglacial
Waimaunga
Glacial
Scandinavia
Interglacial
Nemoa
Glacial
& other
unnamed
stages
?
Taita Alluvium
Melling Peat
Petone Marine
Beds
Waiwhetu
Artesian
Gravel
Moera
Basal
Gravel
Top
Saline
Bed
Top
Marine
Gravel Bed
Basal
Saline
Bed
Basal
Marine
Gravel
Hutt Formation
Unnamed Formation
Kaitoke Gravel Formation
P9
P8
P7
P6
P5
P4
P3
P2
P1
1
2
3
4
a
c
5
e
6
7
8
9
10
12
cooling
warm
cold
cold
cooling
warm
cold
warm
cold
cooling
cooling
warm
cold
cool
cold
cool
0
10
50
70
125
180
245
300
335

and 7 are correct, on the basis of the two peak pre-Last Glaciation warm periods found in the Petone Drillhole, then this interglacial should correlate with oxygen isotope stage 9 (cf. Imbrie et al. 1984; Pillans 1991) and thus date to between 300,000 and 335,000 years ago (Fig. 14). There are weathered sediments of this age in the Seaview Drillhole.

Biozone P3

According to Harris (unpublished MS notes) Biozone P3, from the Petone Drillhole, indicates a return to a periglacial climate. This early late Pleistocene Waimaunga Glacial (Emerald Glacial of Grant-Taylor, 1959; Stevens, 1973; Figs 3, 14) is younger than 300,000 years ago and should, on a count back, correlate with oxygen isotope stage 8 at between 245,000 and 300,000 years ago (Fig. 14). Harris, Darwin, & Newman (1976) noted an unconformity in this zone at 165 m. Its duration is unknown. Sediments of this age were probably included in the Seaview Drillhole core but were unfossiliferous or unsampled for the current study.

Biozone P4

According to Stevens (1973) the sediments placed in Biozone P4 from the Petone Drillhole fall into the top of Grant-Taylor's (1959) local Belmont Interglacial (Karoro or Terangi Interstadial) and the base of his succeeding Whiteman Glacial (Waimea Glacial; Figs 3, 14). From a palynological point of view it would be better to place the whole phase into the late Pleistocene Karoro Interglacial, since all the samples indicate warm and moist climatic conditions.

Correlation of this biozone with the national stages is uncertain, but it is likely to be younger than the 240,000 years or so assigned to the previous biozone, and probably older than 180,000 years ago (Fig. 14). This interval between 153.6 and 128.3 is the second of two major peak warm periods, and on count back probably correlates with oxygen isotope stage 7 (cf. Imbrie et al. 1984; Pillans 1991). Sediments of this age are registered by the Seaview Drillhole.

Biozone P5

These periglacial sediments in the Petone Drillhole were assigned by Stevens (1973) to the late Pleistocene Whiteman (Waimea) Glacial (Figs 3, 14). Correlation of this biozone with New Zealand stages is uncertain, but it must be younger than the 180,000 years, or so, assigned to the previous biozone, and older than 125,000 years ago, if the correlation of the Karoro Interglacial with oxygen isotope stage 7 is correct. Therefore, this stage correlates with oxygen isotope stage 6 (cf. Imbrie et al. 1984; Pillans 1991). The basal part of the Moera Basal Gravel Member of the Hutt Formation (Stevens 1956, 1973) lies at the top of this biozone. Weathered sediments of this age were probably included in the Seaview drillhole core, but were unfossiliferous or unsampled during this study.

Biozone P6

This biozone falls into the late Pleistocene Oturi Interglacial (Stoke Interglacial of Grant-Taylor 1959; Figs 3, 14). From the age of these sediments in the Petone Drillhole, determined on stratigraphic grounds by Stevens (1973), and their relationship with the underlying Terangi Interglacial, this biozone must correlate with oxygen isotope stage 5 (*cf.* Pillans 1991) and thus be between 70,000 and 125,000 years ago. The upper part of the Moera Basal Gravel Member of the Hutt Formation (Stevens 1956, 1973) falls within this biozone. Sediments of this age are registered in the Seaview Drillhole.

The boundary at the top of Biozone P6 is placed in gradually cooling conditions in the transition from the Last (Kaihinu or Oturi) Interglacial to the Last (Otira) Glacial. The boundary between oxygen isotope stages 5 and 4 falls in this interval. The upper boundary of Biozone P6 and the boundary of oxygen isotope stages 5 and 4 has been placed to coincide with the top of the Moera Basal Gravel Member (Fig. 14).

Biozone P7

The Otira Glacial (Pakuratahi Glacial of Grant-Taylor 1959; Figs 3, 14) commences at 76 m and continues up to at least 35.4 m in the Petone Drillhole. During this time the climate fluctuated greatly, culminating in a peak cold period (Biozone P8) at the top of the sequence. This sequence correlates with the Otira Glacial of the West Coast, South Island (Fig. 14) and, depending on the precise placement of the P6/P7 boundary, may also include Last Interglacial sediments as correlated by Stevens (1973). Because of the large unfossiliferous gaps towards the top of this biozone, the upper boundary is also uncertain but is here placed at 46 m. The zone in Fig. 14 is correlated with oxygen isotope stages 3 and 4. It is no older than 70,000 years ago, and could be as young as c. 50,000 years old. Biozone P7 is probably represented by unsampled or unfossiliferous sediment in the Seaview Drillhole.

The biozone includes most of the Waiwhetu Artesian Gravel Member of the Hutt Formation (Stevens 1959, 1973).

Biozone P8

The peak cold period of the Otira Glacial falls into Biozone P8 (Stevens 1973; Figs 3, 14), which is found only in the Petone Drillhole. It correlates with the latest part of the Otira Glacial and oxygen isotope stage 2 (and possibly part of oxygen isotope stage 3) and thus is older than 10,000 years and younger than c. 50,000 years ago (Fig. 14). There is probably an unconformity between biozones P8 and P9, so up to 20,000 years may be missing or represented by unfossiliferous sediment.

The biozone includes the upper part of the Waiwhetu Artesian Gravel Member of the Hutt Formation (Stevens 1956, 1973).

Biozone P9

All the Holocene (Postglacial of Stevens 1973) sediment in the Petone and Seaview drillholes fall into Biozone P9, which is probably <10,000 years old (Figs 3, 14). It correlates with oxygen isotope stage 1. The earliest part of the Postglacial is probably missing or unrepresented by fossiliferous material, if this sequence is like other Last Glaciation/Postglacial sequences around the Wellington area (Mildenhall 1980, 1993a; Harris & Mildenhall 1984; Lewis & Mildenhall 1985). The base of the Postglacial at Seaview could be older (the basal sample is dominated by *Podocarpus* and/or *Prumnopitys* as opposed to *Dacrydium cupressinum* at Petone) and the top of the sequence younger, since *Nothofagus* does not reach the levels achieved at Petone and the *Ascarina lucida* decline is not complete.

The biozone includes the Petone Marine Bed, Melling Peat, and Taita Alluvium Members of the upper part of the Hutt Formation (Stevens 1959, 1973).

Discriminant function and assemblage analyses from the Petone Drillhole

Harris, Darwin & Newman (1976) published a paper on species clustering and the New Zealand Pleistocene climate, in which the Petone (Gear Meat Company) Drillhole was one of the prime sites discussed. A set of assemblages was determined and characterised by the letters *a* to *e* in what was regarded as a warming sequence. It was acknowledged that not all of these assemblages would be recognised in any one long pollen sequence. The assemblages were designated thus:-

a Grass, herbs, shrubs with little or no tree pollen – lack of forest (deforestation); cold.
b Rare tree pollen, especially *Nothofagus menziesii* and/or *Halocarpus* – transition between grassland and forest; cold.
c Dominant *Nothofagus fusca* type – forest; warming.
d Dominant *Podocarpus* (including *Prumnopitys*) – forest; warm.
e Dominant *Dacrydium cupressinum* – forest; warmest.

This upwards warming sequence was discussed by Harris (1963). In particular environments some other assemblage types could replace one or more of the *a* to *e* set. For example, a *k* assemblage was designated by coastal dicotyledons, an *l* assemblage by *Phyllocladus*, a *q* assemblage by *Agathis* (kauri), and an *r* assemblage by *Metrosideros*.

For each of these *a* to *e* assemblages Harris, Darwin & Newman (1976, Table II, p. 237) determined the average discriminant function, and then applied these results to all 133 samples from the Petone Drillhole (ibid. Table II, Run 4) that produced normal counts (i.e., full counts of 100 grains of the dominant taxon). The analysis clearly distinguished glacials from interglacials. They then compared each of the 133 samples with every other sample and used correlation coefficients, where the standard error was not too great, to produce a computerised chart at three levels of significance (high, medium, and low; ibid. Fig. 3, p. 244). The two methods of analysis provided sets of data with well-defined boundaries that coincided closely with the lithological boundaries established by Grant-Taylor (1959) and with boundaries estimated from visual comparison of the pollen and spore lists (ibid. Fig. 2, p. 241). For a full discussion of this work the reader is referred to Harris, Darwin & Newman (1976). A summary of the results of the discriminant function analysis and analysis of the dominants and co-dominants is presented in Fig. 11.

Identification and correlation of interglacial and glacial periods

There have been numerous fluctuations in the climate over the time period covered by the sediments of the Petone and Seaview drillholes, not all of which produced full interglacial or glacial conditions. The correlations between the vegetation changes and (1) the major climatic fluctuations and (2) the oxygen isotope curves assume that only the largest changes in climate are recorded in these drillholes, sited at about present-day sea level, but that all of the important vegetational changes are recorded. If any major glacial and interglacial episode is missing then the correlations made here break down. Similarly, if a stadial or interstadial has been labelled as a full glacial or interglacial, then the correlations will also be incorrect. The criteria used in this paper for the identification of glacials and interglacials are as follows.

Criteria for an interglacial

The palynological criteria for interglacial conditions are relatively simple. During interglacials, full forest vegetation flourished, predominantly podocarps but with southern beech in less hospitable situations. As climate fluctuates, so does the ratio of southern beech to podocarps as determined by pollen production and recovery. Within these forests broadleaved (hardwood) taxa are frequent and pollen of these species are usually also recovered, and sometimes form the dominant pollen type – for example, *Metrosideros*, *Hoheria*, and *Laurelia novae-zelandiae* (pukatea). We cannot, as yet, recognise the existence of *Beilschmiedia* (tawa) forest, which should also flourish under interglacial conditions, because pollen production is very low in this genus and it does not preserve well (Macphail 1980).

During interglacial time, frost-sensitive plants were able to spread. These include *Agathis australis*, *Lygodium articulatum*, *Ascarina lucida*, *Dodonaea viscosa*, *Ixerba brexioides*, *Knightia excelsa*, *Tetrapathaea tetrandra*, *Tupeia*, and others. Pollen analysis of swamps that developed under temperate conditions often show a dominance of grasses, sedges, or rushes. The interglacial nature of these deposits is usually gauged by the types of regional pollen forming the background, and the presence of taxa like *Azolla rubra*, *Tupeia antarctica*, *Dodonaea*, and *Tetrapathaea* (Moar & Mildenhall 1988). However, full interglacial conditions have been relatively rare during the last 2 million years, and it appears that for most of the Pleistocene New Zealand has only been partly forested and has had a cool and dry climate (McGlone 1983).

The Postglacial vegetation has been taken as a model for interglacials. The vegetation types would fall into assemblages *d* and *e* of Harris (1963) and Harris, Darwin & Newman (1976).

Criteria for a glacial

At the peak of glacial periods, the vegetation over most of New Zealand was reduced to shrub/grassland in which many of the known alpine and subalpine plants grew to at least 1,000 m below their present-day ranges. Since the most frequently preserved glacial carbonaceous sediments consist of swamp deposits, many of the taxa identified are those that prefer damp conditions. During glacial periods the woody vegetation consisted of bog or pink pine (*Halocarpus*) and celery pine (*Phyllocladus*), with abundant Asteraceae, *Coprosma*, Epacridaceae, *Hebe*, and *Myrsine*; the herbaceous vegetation included taxa like *Arthropodium*, *Bulbinella*, *Drosera*, *Epilobium*, *Gentiana*, *Geranium*, *Libertia*, *Montia*, and *Wahlenbergia*.

The vegetation of the Last Glaciation has been taken as a model for glacials. The vegetation types would fall into assemblages *a* and *b* of Harris (1963) and Harris, Darwin & Newman (1976).

Periods of intermediate temperature

In the intermediate phases between the peak warm and cold periods a variety of vegetational associations developed. Most of these associations contain as the dominant emergent tree *Nothofagus fusca* type, *N. menziesii*, and *Phyllocladus*, usually *P. alpinus*. These tend to be recorded mainly in sediments of glacial or late and early interglacial origin, although the *Nothofagus fusca* type pollen assemblages are more widespread. In this paper the assignment of these types of assemblages to glacial periods depends on the high percentages of dryland Poaceae pollen also present in the same samples.

The transitional vegetation types would fall into assemblage c of Harris (1963) and Harris, Darwin & Newman (1976).

As a general rule the alternating cycles from interglacial to glacial conditions follow the same pattern. Thus temperate podocarp/hardwood (=podocarp/broadleaf) forest gives way to *Nothofagus* and subalpine forest associations and finally to full glacial shrub/grassland with small patches of forest in sheltered areas (McGlone 1985), and then back again.

Correlation with local and New Zealand interglacials and glacials

Stevens (1973) ascribed the various lithologies in the Petone Drillhole to the local climate stages of Grant-Taylor (1959). This scheme is followed in Fig. 3, and further extended (Fig. 14) in comparison with the terrace and loess sequence of Milne (1973) from the Rangitikei Basin of the Manawatu, and again extended by Berryman (1990) to correlations in the Upper Hutt area, and to the New Zealand climatic stages as revised in Suggate & Mildenhall (1991). In spite of the high probability of large unconformities in the sequence (see Harris, Darwin & Newman 1976, p. 241) the overall pattern of the succession seems to be valid.

Correlation with oxygen isotope stages

Fig. 14 attempts to correlate the late Pleistocene oxygen isotope curve with the biozones of the Petone Drillhole section. This curve has been adjusted to fit the biozones and should not be taken to indicate a complete sedimentary sequence. Nonetheless, there are two tie points which suggest that the sequence is essentially complete. The first is the radiocarbon dated Postglacial (Biozone P1), which is clearly related to oxygen isotope stage 1, and the second is Biozone P6, with its abundant pollen from frost-intolerant plants, which is correlated with the peak pre-Postglacial warm period within oxygen isotope stage 5. The discriminant function curve mirrors the oxygen isotope curve very closely.

Summary of vegetation characteristics of each interglacial and glacial period in the Petone Drillhole

Table 4 summarises the vegetational differences and similarities between each interglacial (including the Postglacial) and glacial period based on the dominant and co-dominant spores and pollen identified from the Petone Drillhole. Particularly interesting is the apparent absence of *Phyllocladus*-dominant phases which are common in other sequences of Last Glaciation and older glacial ages around Wellington. Presumably these *Phyllocladus* (?*P. alpinus*) phases are represented in the Petone Drillhole by other vegetation associations, suggesting that there was a mosaic of different vegetational types in the Wellington area at any one time. An unlikely alternative is that the *Phyllocladus* associations are generally older than anything represented in the Petone Drillhole. However, some *Phyllocladus* associations have been assigned to the Last Glaciation (see for example Harris & Mildenhall 1980, 1984; Mildenhall 1978, 1983, 1993a, 1993b). Also the other basins, e.g., Wainuiomata, Mangaroa, which are smaller in size and surrounded by hills, may have been frost basins during the peak cold of the glacials; Petone, being more exposed, may not have suffered such severe frosts, thus permitting the survival of more woody vegetation.

The Holocene and Last Glaciation vegetation can be compared with that recorded historically in the Wellington area in the 1840's, remnants of which still survive. The vegetation of the

Table 4 – Comparisons of interglacial and glacial periods as determined from the Petone Drillhole

Comparison of vegetation of interglacial periods

	Dacrydium cupressinum	*Nothofagus fusca* type	Sub-dominants	*Ascarina lucida*	Other comments
Holocene (Postglacial)	Very common	more common towards present-day up to 30%	*Podocarpus*	less common towards present	Other taxa not common
Oturi Interglacial	Very common throughout	Always less than 15%	*Podocarpus* Myrtaceae	common towards present	Other taxa frequent, high diversity
Karoro Interglacial	Very common at base only	Very common above base of zone	*Podocarpus* *Dacrycarpus*	common top and bottom of zone	Rapid changes in abundances of of pollen from shrubby plants
"Normandale" Interglacial	Very common except at top of zone	Very common at top of zone, rare elsewhere	*Podocarpus* pollen of broad-leaves	Very common, except at top	High percentages of tricolporate pollen types

(*Podocarpus* includes *Prumnopitys*)

Comparison of vegetation of glacial periods

	Nothofagus menziesii	*Nothofagus fusca* type	Poaceae	Wetland plants	Other comments
Otira Glacial	Common throughout	Very common throughout	Not common except at top of zone	Relat-ively rare	Pollen from woody taxa abundant, conditions appear relatively mild Peak cold grassland at top.
Waimea Glacial	Very rare	More common at base of zone	Abundant at top of zone	Common at top of zone	Two phases – beech and grass. Mainly a shrubland.
Waimaunga Glacial	Common	Common	Abundant	Rare	Abundant pollen from shrubs, *Phyllocladus* common but not dominant.
Nemona (=Kaitoke) Glacial(s)	Very rare or absent	Rare	Abundant	Common	*Phyllocladus* common or abundant Asteraceae common. Tree pollen rare.

hills surrounding the Hutt Valley and Port Nicholson was described by Druce (1957), while Druce & Atkinson (1959) listed the characteristics of the vegetation found on various substrates in the valleys. On the Western Hills of Wellington all four beech species are missing, replaced with podocarps (mainly *Dacrydium cupressinum*), *Metrosideros robusta* (northern rata), *Beilschmiedia tawa* (tawa), and *Elaeocarpus dentatus* (hinau). On the Eastern Hills only *Nothofagus fusca* (not found south of Waiorongomai River) and *N. solandri* var. *cliffortioides* (not found south of the Manawatu Gorge) is missing. The valley floors contained *Dacrycarpus dacrydioides*, *Laurelia novaezelandiae*, and *Syzygium maire* (swamp maire) swamp forest with *D. cupressinum*, *Nothofagus* species, and *Weinmannia racemosa* (kamahi) on the better-drained soils. Coarser sediments supported a *Melicytus ramiflorus* (mahoe), *Podocarpus totara* (totara), *D. dacrydioides*, and *Beilschmiedia tawa* broadleaf/podocarp forest. The wettest areas in the lower reaches of the Hutt Valley contained shrub and herbaceous vegetation in which *Phormium tenax* (flax) was prominent (Heaphy 1879). Some of the coastal and river terraces contained dense stands of *Leptospermum scoparium* (manuka).

Although this table may be used to relate spot samples from around the Hutt Valley, it is better to compare floral successions within sequences. The differences between individual interglacials and glacials are not very great, and it is known that vegetation assemblages of the same age differ markedly with changes in topography and geography. It is also possible, and likely, that vegetational associations are missing from the Petone Drillhole that are frequently represented by deposits in the hills around Hutt Valley and Wellington.

The climatic implications of the differences recorded in this table are discussed under the individual biozones in sections above.

Comparison of the Petone Drillhole with other published pollen sequences

Our understanding of the altitudinal and latitudinal climatic and vegetational variations through time increases directly with the number of pollen sequences analysed. A number of pollen diagrams from the lower half of North Island have been published, dated with varying degrees of accuracy, which generally show podocarp and beech forest during interglacials and shrub/grassland, *Phyllocladus* (?*alpinus*), and beech forest during glacials. Local vegetation during glacial periods is very variable.

Published pollen diagrams from the Wellington area (Harris 1951; Mildenhall 1980; Mildenhall & Moore 1983; Harris & Mildenhall 1984; Lewis & Mildenhall 1985) show a slow rise of *Nothofagus fusca* type pollen, at the expense of *Dacrydium cupressinum* and other lowland podocarps, throughout the Postglacial. The same pattern is also found in pollen diagrams from the Ruahine Ranges to the north of Wellington (Moar 1961, 1967; Lees 1986) and probably reflects a combination of a slow migration of *Nothofagus truncata* and *N. solandri* var. *solandri* into the Wellington area, a decrease in rainfall and temperature, and an increase in windiness. The decrease in the *Ascarina lucida* and *Dodonaea viscosa* curves since about 7,000 years BP, also reflect increasing drought and frostiness (McGlone & Moar 1977; McGlone, Salinger & Moar 1994). The vegetation consisted of a podocarp/hardwood forest around Wellington, with beech forest more common inland (Harris 1951; Harris & Mildenhall 1984; Mildenhall 1993c). The early Postglacial dominance of *Prumnopitys taxifolia* and subsequent dominance of *Dacrydium cupressinum* found in the southern Ruahine pollen profiles (Lees 1986) is not reflected in the record for Wellington, except at Porirua (Mildenhall 1993a) where sediments that are immediately Postglacial in age appear to have been preserved, and at Turakirae Head (Mildenhall & Moore 1983) where a pollen profile, dated between c. 7,200 to 4,800 years old, suggests windy conditions with high evapotranspiration.

A number of pollen diagrams and species lists covering the Last Glaciation in the Wellington area have been published (Mildenhall, Williams, & Seward 1977; Harris & Mildenhall 1984; Lewis & Mildenhall 1985; McLea 1990; Mildenhall 1992; Pillans et al. 1993; Mildenhall 1993a, 1993b, 1993c, 1994). These diagrams and lists, which encompass oxygen isotope stages 2 and 3, represent a period of great paleoenvironmental change

(Pillans et al. 1993). The vegetation in southern North Island was essentially a subalpine shrub/grassland with beech and tall podocarp forest remnants scattered in favourable and sheltered areas. Only *Nothofagus fusca* type and *N. menziesii* are at times locally abundant and appear with reasonable consistency. At Petone there is evidence of the presence of both forest and shrub/grassland, perhaps alternating as climate fluctuated during this period.

A number of pollen diagrams from undated sediments in the Wellington area have been published (Mildenhall 1983, 1986a, 1986b, 1986c). It is difficult to relate these to the Petone Drillhole but some characteristics can be used to suggest possible correlations.

An interglacial sequence from Kaiwharawhara, near Wellington (Mildenhall 1986c), probably relates to the Last (Oturi or Kaihinu) Interglacial (Biozone P6; oxygen isotope stage 5) in the Petone Drillhole. Both sequences contain abundant pollen from *Libocedrus* and *Metrosideros* at higher percentages than is recorded elsewhere, either at Petone or from the wider Wellington area. Both localities also contain pollen of *Ascarina lucida, Dodonaea viscosa, Fuchsia, Ixerba brexioides*, and *Quintinia*, which are infrequent in other parts of the Petone Drillhole sequence, and indicate a warm, moist climate (Mildenhall 1986c).

A short, probably condensed, sequence recorded at Boxhill, Khandallah (Mildenhall 1986b) contains a vegetation assemblage, suggestive of climatic instability, that could relate to any cold, wet glacial period. It is probably too far from Petone, and represents too short a time, to allow for accurate comparisons.

A pollen diagram from Judgeford, near Lower Hutt (Mildenhall 1986a), may come from sediments of Putikian age (Te Punga 1984c; uppermost Castlecliffian) and is probably slightly older than the Kaitoke Gravel Formation at the base of the Petone Drillhole. Similarly, a pollen profile from Whitby, which may be as old as Castlecliffian (Mildenhall 1983), is also older than the base of the Petone Drillhole. However, both these sequences contain assemblages that closely resemble those obtained from the Kaitoke Gravel Formation (see also Harris 1959): all contain relatively high percentages of pollen of *Phyllocladus*, Poaceae, *Halocarpus biformis* type, *Nothofagus fusca* type, and other herbs.

A number of pollen diagrams have been published from the Wanganui area illustrating the climate and vegetation of isotope stages 5, 6 (Bussell 1990, 1992), and 9 (Bussell & Pillans 1992). At Ohawe East a pollen profile, related to oxygen isotope stage 5e, indicates warm, moist climate (Bussell 1990) indicating full interglacial conditions similar to the Kaihinu Interglacial in the Petone Drillhole. *Ascarina lucida* and *Dodonaea viscosa* are common but *Lygodium articulatum, Quintinia*, and *Ixerba brexioides*, found in oxygen isotope stage 5 (Biozone P6) of the Petone core, were not recorded. The coastal *Acacia* palynoflora of the Rapanui Lignite (Bussell 1992), related to oxygen istope stage 5d, does not resemble any palynoflora from the Petone Drillhole, but one of the layers within Biozone P6 could well be its equivalent.

At Ohawe Waterfall a pollen profile, related to oxygen isotope stage 6, contains fully glacial pollen assemblages (Bussell 1990), which are difficult to compare with the Petone Drillhole because at the presumed equivalent stratigraphic position only a few pollen samples were examined. These few samples show little difference from those at Ohawe Waterfall, and all indicate a cold, windy, drought- and frost-prone climate with subalpine vegetation.

The interglacial peak of isotope stage 9a at Fordell, Wanganui (Bussell & Pillans 1992) coincides with a high in the pollen profiles of both *Ascarina lucida* and *Dodonaea viscosa*. The maximum peak of these two taxa is also located at the same stratigraphic position in the Petone Drillhole in sediments correlated with the locally named "Normandale" Interglacial and oxygen isotope stage 9. This provides some additional confirmation that the correlations made here (Fig. 14) may be correct.

Overall, it appears that the Petone Drillhole, with its long pollen profile, will provide a good basis for the comparison of dated and undated pollen profiles from elsewhere in southern North Island, and possibly northern South Island, and assist our understanding of the climatic and vegetational changes that have happened in the Wellington area during much of the late Pleistocene.

Recycled spores, pollen, and dinoflagellates

A number of recycled spores and pollen have been recorded from the Petone and Seaview drillholes. They are recognised by their darker colour and affinities to pollen of extinct plants; they are often better preserved than the *in situ* palynomorphs, possibly because of "case-hardening" during the fossilisation process. Thus recycled palynomorphs with affinities to modern pollen types probably go unrecognised. These recycled spores and pollen include the pollen *Haloragacidites harrisii (Casuarina)*, *Nothofagidites cranwelliae (brassii* or large-leaved beech), *Proteacidites minimus* (protea), and the polypodiaceous spore *Polypodiisporites inangahuensis* (Couper) Potonié.

Haloragacidites harrisii is recorded in both drillholes, becoming more frequent towards the base of the Petone Drillhole and particularly in Biozone P4. Its presence may be due to long-distance transport of individual grains from Australia (Moar 1969), as well as recycling from totally eroded Cenozoic sediments once deposited on the now uplifted peneplain (Kaukau Surface). *Nothofagidites cranwelliae* (not distinguished from *N. matauraensis* (Couper) Hekel by Harris in his notes) is recycled from Miocene to lower Pleistocene sediments. It is not as frequent as *H. harrisii*, found in only 5 samples from the Petone Drillhole. *Proteacidites minimus*, which is difficult to distinguish from the present-day pollen of *Knightia excelsa*, was recognised from one sample towards the base of the Petone Drillhole.

The spores identified by Harris as *Polypodiisporites inangahuensis* were randomly checked: they are almost certainly *Polypodiisporites radiatus*, described by Pocknall & Mildenhall (1984), a form of polypodiaceous spore that was not recognised when Harris was studying the Petone Drillhole. This species has an age range of late Oligocene to early Pleistocene. This robust spore is readily recycled and was found in c. 20 samples from the Petone Drillhole, most frequently in Biozone 7, but also commonly towards the base of the hole.

I could not ascertain whether any of the dinoflagellate cysts are recycled. All the cysts that have been identified are from present-day species.

Recycled taxa have been reported from Pleistocene sediments in the Wellington area before now (Lewis & Mildenhall 1985; Mildenhall 1986b, 1992, 1993a). The late Cretaceous dinoflagellate *Manumiella cretacea*, identified by J. G. Wilson, was recorded by Mildenhall (1992) from a drillhole at Miramar, Wellington, in the same sample as a pollen grain very similar to the Eocene to early Miocene *Proteacidites rectomarginis* Cookson. The same sequence contains the Cenozoic pollen type *Beaupreaidites elegansiformis* Cookson. Drillholes in Evans Bay, Wellington (Lewis & Mildenhall 1985) contain *Polypodiisporites radiatus, Microcachryidites antarcticus* Cookson, *Podocarpidites ellipticus* Cookson, *P. otagoensis* Couper, *Podosporites parvus* Couper, *Acaciapollenites myriosporites* (Cookson) Mildenhall (possibly *in situ*), ?*Cranwellia striata* (Couper) Srivastava, *Haloragacidites harrisii, Nothofagidites cranwelliae, N. matauraensis, Proteacidites*, and "*Tricolpites*" *sphericus* Cookson of lower Pleistocene and/or late Cenozoic age. Pollen from the Australian family Gyrostemonaceae was also recorded by Lewis & Mildenhall (1985). This pollen type was not then recognised in the New Zealand Cenozoic and was explained by possible trans-Tasman dispersal. Now that it has been documented from the New Zealand Miocene (Mildenhall & Pocknall 1989) recycling from Miocene sediments must also be considered a possibility. *Nothofagidites cranwelliae* was recorded by Mildenhall (1986b) from a glacial mid to late Pleistocene locality at Boxhill, Khandallah, near Wellington. Two additional long-ranging Cenozoic taxa, *Proteacidites obscurus* Cookson and *Phyllocladidites mawsonii* Cookson ex Couper (also late Cretaceous), were recorded by Mildenhall (1993a) from a drillhole in Lambton Harbour, Wellington.

All these records support the idea that the peneplain around Wellington had Cenozoic, and possibly late Cretaceous, sediments deposited on it and that erosion slowly re-exposed them during the deposition of all the pre-Postglacial sediments in the Hutt Valley and Lower Hutt/ Port Nicholson Basin. Sedimentation would have commenced in the mid to late Pleistocene (Te Punga 1982; Stevens 1991) when the east side of the Wellington Fault began to buckle leading to the disruption of the Kaukau Peneplain. None of these pre-Pleistocene sediments have been preserved, except for two marine deposits, one at Makara (Grant-Taylor & Hornibrook 1964), on the south Wellington Peninsula, and another at Otaihanga, near Paraparaumu, north of Wellington (Macpherson 1949).

CONCLUSIONS

The Petone and Seaview drillholes have provided a rare opportunity to study long cores extending through deposits laid down throughout middle and late Pleistocene time. This paper provides only a summary of the data, but is presented so that other scientists can have an introduction to the information available that may be relevant to their own studies. A great deal of additional work is necessary to update the data and provide complete species lists. This could be done in association with any new drilling and high density pollen analysis in association with studies on the history of the Wellington Fault. Computerised listings of the present data are available on request.

This study has shown that the sediments beneath the lower part of the Hutt Valley, that is within 1 km of the deepest part (over 400 m depth) of the Hutt Valley-Port Nicholson Basin (Hochstein & Davey 1974) may represent at least 350,000 years of sedimentation and that the various biozones represented can be correlated, with caution, to local and regional climatic stages and to the deep-sea oxygen isotope scale. Although I have attempted to correlate the Petone Drillhole section with the national climate stages (Fig. 14), some revision may be necessary in light of current studies on late Pleistocene stratigraphy, underway in the Wellington area by John Begg and co-workers (Begg & Brown 1991; Begg, Brown, & Huber 1992; Begg et al. 1993; Begg 1992, 1993, 1994; see also Berryman 1990).

The four key features of the pollen diagrams are as follows. First, many of the important changes in the vegetation assemblages are separated by unfossiliferous zones, usually coarse-grained gravel, or erosion intervals. More time may be missing in the sequences than is represented by sediment. Certainly, the depth of weathering of many of the gravel deposits, and the coating of clay around many clasts, suggests that the gravels have been exposed to periodic episodes of prolonged oxidation and erosion, with each episode of unknown duration. Also, many of the pollen zones show no evidence of the intermediate vegetation assemblages that might have been expected to mark changes in climate from glacial to interglacial conditions. Thus, it is probably coincidental that each of the warm periods begins with a massive influx of pollen from podocarp forest taxa, usually *Dacrydium cupressinum*, which slowly decreases throughout the interglacial and then suddenly disappears or becomes sparse in the pollen profile. This pattern is well illustrated in the summary diagram (Fig. 11, part A), especially in the Oturi Interglacial and Postglacial where the peaks are predominantly *D. cupressinum*. Here each of the interglacials shows a slow cooling trend towards the succeeding glacial, or in the case of the Postglacial, towards the present-day.

Second, if the comparison between the Petone and Seaview drillholes is correct, then the Seaview Drillhole represents a much thinner sequence covering the last 300,000 years or so, but with the glacial episodes either missing or unsampled. The total pollen sequence at Seaview is c. 179 m, while in the Petone Drillhole the equivalent pollen sequence is c. 100 m. This may have some bearing on the tectonic interpretation of uplift differences on both sides of Hutt Valley, connected with movements of the Wairarapa, Wellington, and Owhariu faults (Fig. 1). On the other hand, it may reflect differences in depths of erosion, resulting from periodic lowering of sea level during the last 300,000 years.

Third, in spite of successive searches no tephras could be recognised in either of the drillholes. They may, however, be present, and could, perhaps, be found by further examination of the cores in the light of our knowledge of the distribution and frequency of tephras now being located in late Pleistocene sediments in the Wellington area. It may mean that tephras have been comprehensively reworked by fluviatile or marine processes and that microscopic glass shards will be found distributed through parts of the sequence. If the Mangaroa Ash (Te Punga 1963 1984b; Naeser, Nishimura, & Te Punga 1980), now known to be a correlative of the 350,000 year old Rangitawa Tephra (Pillans, Kohn, & McGlone 1992), is to be found in the Petone Drillhole, it will be at the base of the drillhole. If the Kawakawa Tephra is to be found, it will probably be within gravel sequences up to a few metres above the base of the Postglacial.

Fourth, the summary pollen diagrams together provide a profile which can be used as a basis for comparison of other shorter and less condensed pollen profiles from areas around Wellington that are less stable and/or more prone to erosive events than in the Hutt Valley, where net subsidence has provided a long sedimentary sequence.

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APPENDIX

List of samples

Sample and slide numbers, depth in metres, and lithological descriptions (where indicated on the fossil record forms) are presented for the Petone and Seaview drillholes. * = pollen samples from the same stratigraphic level; ang. = angular; c. = coarse; carb. = carbonaceous; dk = dark; f. = fine; gwke = greywacke basement; lt = light; med. = medium; uncon. = unconsolidated; v = very.

PETONE DRILLHOLE. R27/f8696

Sample no.	Slide no.	Depth in m	Bio-zone	Lithology
1	L2712	4.6–4.8	P9	uncon. silt & f. sand, shellbeds; lt blue grey
2	L2713	4.8–5.5	P9	
3	L2714	7.9–8.1	P9	uncon. f. sand & mud, carb., shelly; lt blue grey
4	L2715	11	P9	muddy sand with shells
5	L2716	11.8	P9	uncon. f. sand & mud, pyritic, carb.; v lt grey
6	L2717	13.1	P9	v soft f. sand & mud, pyritic; v lt grey
7	L2718	13.9–14.2	P9	v soft f. sand & mud, shelly; lt blue grey
8	L2719	14.5–14.8	P9	molluscs, wood
9	L2720	15.4–15.7	P9	v soft f. sand & mud, shelly; lt blue grey
10	L2722	16.2–16.3	P9	
11	L2721	16.5–16.6	P9	v soft f. sand & mud; lt blue grey

12	L2723	17.2–17.6	P9	v soft mud & f. sand, echinoderms, lt blue grey
13	L2724	18.1–18.4	P9	v soft f. sand & mud, echinoderms, lt blue grey
14	L2725	19.2	P9	uncon. mud & f. sand; med. blue grey
15	L2726	19.8	P9	uncon. mud & f. sand; lt blue grey
16	L2727	20.3–20.7	P9	v soft f. sand & silt; lt blue grey
17	L2728	21.0–21.4	P9	v soft silt & mud, echinoderms; lt blue grey
18	L2729	21.9	P9	soft mud & silt, shelly; lt blue grey
19	L2730	22.2–22.5	P9	v soft silt & mud, shelly; lt blue grey
20	L2731	23.0–23.1	P9	v soft f. sand & mud; lt blue grey
21	L2732	23.1	P9	v soft f. sand & mud; lt blue grey
22	L2739	24.4	P9	v soft med. sand & mud, carb., shelly
23	L2734	?	P9	
24	L2733	25.3	P9	uncon. f. sand & mud, shelly; lt blue grey
25	L2735	26.5	P9	uncon. med. beach sand; lt blue grey
26	L2736	26.5	P9	v soft carb. med. sand & mud; med. brown grey
27	L2737	27.1	P9	v soft carb. med. sand & mud; med. brown grey
28	L2738	27.1–28.0	P9	v soft f. sand & silt, shelly, woody; lt blue grey
29	L2740	27.6–28.3	P9	soft silt & mud, peaty; med. brown grey*
30	L2741	27.6–28.3	P9	soft silt & mud, peaty; med. brown grey*
31	L2742	27.6–28.3	P9	peaty silt*
32	L2743	27.6–28.3	P9	v soft silt & mud, peaty; med. brown grey*
33	L2745	29.3	P9	loess
34	L2746 L5282	29.9	?P9	
35	L2747 L5283	31.1	?P9	sandy gravel
36	L2748 L5284	31.4	?P8	well sorted carb. f. sand, & ang. muddy f. gravel
37	L2749 L5285	31.5	?P8	muddy f. ang. gravel
38	L2750 L5286	31.6	?P8	carb. silt
39	L2751 L5287	31.7	?P8	muddy silt; yellow brown
40	L2752 L5288	32	P8	clay; yellow mottled blue green
41	L2753 L5289	32.1	P8	clay, B horizon of a soil; yellow mottled blue green
42	L2765 L5290	35.5–35.6	P8	sandy mud, rounded sand grains, weathered, ferruginous; yellow brown
43	L2744	35.6–35.7	P8	gravel & loess
44	L2760A	35.8	P8	sand
45	L2760B L5685	35.9	P8	mud
46	L2760C L5686	35.7–35.9	P8	muddy grit
47	L2754	36.1–36.2	P8	silt, ?loess; dove grey
48	L2755	36.2–36.4	P8	carb. mud, oxides rapidly; blue green
49	L2766	36.4–36.6	P8	highly ang. silty mud fragments
50	L2767	36.6–37.4	P8	silty mud
51	L2768	45.1–45.2	P8	rounded gravel, sand, & mud, ferruginous; yellow brown
52	L2769	49.4	?P7	ang. gravel, sand, & mud; lt green blue grey
53	L2770	49.5–49.6	?P7	ang. grit, sand, & silt; lt blue grey
54	L2772	52.1	P7	carb. silty mud; lt grey
55	L2771	52.2	P7	silty mud; lt grey*
56	L2773	52.2	P7	silty, muddy peat, stems; dk brown*
57	L2774	52.3	P7	carb. f. ang. sand & silt; grey brown
58	L2761	52.6–52.7	P7	*

59	L2762	52.6	P7	*
60	L2763	52.7	P7	*
61	L2764	52.6	P7	*
62	L2756	52.6	P7	top; carb. mud*
63	L2757	52.6	P7	bottom; peat*
64	L2775	52.7	P7	f. compact peat, ang. grains; dk brown*
65	L2777	52.9	P7	carb. silt; grey brown
66	L2758	53.0–53.1	P7	top; carb. mud*
67	L2759	53.0–53.1	P7	bottom; carb. mud*
68	L2778	53.2	P7	carb. sandy silt; brown grey
69	L2776	53.4–53.6	P7	carb. ang. sandy mud & silt; lt grey
70	L2779	56.6	P7	ang. gravel & mud; lt grey
71	L2780	57.3–57.9	P7	ang. to subrounded sandy silt; lt brown grey
72	L2781	57.9–58.1	P7	ang. to subrounded sandy silt; lt brown grey
73	L2782	58.1–58.4	P7	carb. ang. to subrounded sandy silt; lt grey
74	L2783	58.4–58.5	P7	ang. to subrounded sandy silt; lt brown grey
75	L2784	61.7–62.0	P7	highly carb. f. silty mud
76	L2785	62	P7	f. silty mud, wood*
77	L2786	62	P7	f. carb. silty mud, slightly sandy*
78	L2787	62.0–62.1	P7	carb. silty mud; lt brown grey
79	L2788	62.8–63.0	P7	ang. to subrounded sand, silt & mud; lt yellow grey
80	L2789	63.4	P7	ang. to subrounded muddy sand & silt; sand slightly stained yellow grey
81	L2790	63.4–63.9	P7	muddy, silty, c. sand; lt yellow grey
82	L2791	63.9–64.3	P7	carb. muddy, silty sand; lt yellow grey
83	L2792	64.3	P7	carb. f. sandy mud; lt yellow grey
84	L2793	66	P7	carb. sand, silt & mud; lt yellow grey
85	L2794	66.9	P7	carb. sand, silt & mud; lt yellow grey
86	L2795	67.6	P7	slightly carb. silty mud; yellow grey
87	L2796	67.7	P7	slightly carb. sandy, silty mud; yellow grey
88	L2797	69.9–70.1	P7	carb. sandy mud; yellow, orange grey
89	L2798	75.8–76.0	P7	silty, sandy gravel; lt yellow grey
90	L3428	81.6–81.8	P6	soft marine, muddy sand; v dk grey
91	L3429	82.8–82.9	P6	soft f. marine, muddy sand; v dk grey
92	L3430	83.2	P6	f. sandy mud; v dk grey
93	L3431	83.4	P6	shelly, sandy mud; dk grey
94	L3432	83.5	P6	f. sand; dk grey
95	L3433	83.6	P6	muddy sand; dk grey*
96	L3457	83.6	P6	sandy mud, shelly; dk grey*
97	L3458	83.6	P6	f. sandy mud, shelly; dk grey*
98	L3455	83.7	P6	muddy sand; dk grey
99	L3456	83.9	P6	muddy sand; dk grey
100	L3459	84.7	P6	muddy sand, shells; grey to dk grey
101	L3460	86	P6	muddy f. sand, shells; lt to v dk grey
102	L3461	86.8	P6	muddy sand, shells; grey to v dk grey
103	L3462	87.9	P6	f. sandy mud; grey to v dk grey
104	L3463	91.3	P6	mud; lt brown to v dk grey
105	L3464	92.9	P6	mud, shells; grey to v dk grey
106	L3465	94.6	P6	mud, shells; grey to dk grey
107	L4506	98.8	P6	sandy mud; white
108	L4507	101.1	P6	med. sand, shelly; dk grey
109	L4508	101.2	P6	med. sand; grey brown
110	L4510	101.8	P6	muddy f. sand; lt grey
111	L4511	102.9–103.2	P6	muddy gravel, shells; grey
112	L4512	104.6–104.7	P6	gritty med. sand; white
113	L4513	105.4	P6	f. sand; white
114	L4514	114.1	P5	mud; white
115	L4515	114.3	P5	mud; dk grey

116	L4516	116.4	P5	mud; dk grey
117	L4517	117.8	P5	med. & c. sand, gravel; olive grey
118	L4518	120.1	P5	mud; olive grey
119	L4519	121	P5	mud; lt grey
120	L4520	124	?P5	mud, gravel; olive grey
121	L4521	127.3	?P4	mud, gravel; green grey
122	L4522	128	?P4	mud, gravel; olive
123	L4523	128.3	P4	mud, med. sand, & gravel; olive
124	L4524	135.2	P4	f. sand & gravel; dk grey
125	L4525	135.6	P4	med. sand, shells, wood; v dk grey*
126	–	135.6	P4	c. sand, shells; v. dk grey*
127	L4526	136.7	P4	mud, shells; dk grey brown
128	L4527	137.5	P4	f. sand; lt grey
129	L4528	138.1	P4	f. sand; dk grey
130	L4529	138.1–139.0	P4	f. sand; dk grey
131	L4530	139.3–139.9	P4	mud; dk grey
132	L4531	139.9–140.2	P4	mud; grey
133	L4532	148.6	P4	med. sand; olive grey
134	?	?		? ?
135	L4533	151.4	P4	med. sand, gravel; dk grey
136	L4534	152.1	P4	c. sand, shells; dk grey*
137	L4535	152.1	P4	peat*
138	–	152.1	P4	c. sand, shells; dk grey
139	L4536	152.3	P4	f. sand, gravel, wood; olive grey
140	L4537	152.4	P4	peat
141	L4538	152.7	P4	sandy peat
142	L4539	153	P4	mud; black
143	L4540	153.3	P4	peat
144	L4572	153.5	P4	peat
145	L4573	153.6	P4	mud; white
146	L4574	153.7	P4	mud; dk grey
147	L4575	154.2	P4	mud; grey to lt grey
148	L4576	154.6	P4	mud; grey to lt grey
149	L4577	154.8	P4	mud, gravel; dk grey
150	L4578	157.9	P4	med. sand; grey
151	L4579	161.5	P4	mud & f. gravel; grey
152	L4580	161.8	P4	f. sand; lt grey
153	L4581	162	P4	mud; grey
154	L4582	162.7	P4	mud; dk grey
155	L4583	162.9	P4	mud; dk grey
156	L4584	163.1	P4	mud; dk grey*
157	L4585	163.1	P4	mud; grey*
158	L4586	163.3	?P3	c. sand; olive grey
159	L4587	163.5	?P3	f. sand; green grey
160	L4588	164	P3	f. sand; green grey
161	L4589	164.0–164.4	P3	f. sand; olive grey
162	L4590	165.1	P3	f. sand; olive grey
163	L4591	166.7	P3	f. sand; olive grey
164	L4592	169.1	P3	f. sand; olive grey
165	L4593	170.4	P3	f. sand, peat; olive grey
166	L4594	171.3	P3	f. sand, gravel; olive grey
167	L4595	173.7	P3	f. peat
168	L4596	174.7	P3	peat
169	L4597	175.3	P3	f. sand & carb. mud; dk grey
170	L4598	175.6	P3	f. sand; green grey
171	L4599	176.8	P3	f. sand; olive grey
172	L4600	178	P3	f. sand; grey to lt grey
173	L4601	178.9	P3	f. sand; olive

174	?	?	?	?
175	L4602	179.8	P3	mud; dk grey
176	L4603	180.4	P3	peat
177	L4698	180.7	P3	carb. mud; lt grey
178	L4768	181	P3	sand; lt grey
179	L4769	182.3	P3	mud; dk grey
180	L4770	183.5	P3	mud; grey to lt grey
181	L4771	190.2	?P3	mud, gravel; grey to lt grey
182	L4772	193.9	?P2	med. sand & gravel; blue grey
183	L4778	194.8	P2	mud; grey*
184	L4779	194.8	P2	mud; white*
185	L4780	195.4	P2	mud; grey
186	L4781	196	P2	mud; grey
187	L4782	205.4	P2	mud; lt grey
188	L4783	209.1	P2	f. sand; grey
189	L4784	209.7	P2	mud; lt grey
190	L4785	210	P2	f. sand; grey
191	L4786	212.2	P2	mud; lt grey
192	L4787	215.8	P1	mud; white
193	L4788	235.9	P1	sandy mud; blue grey
194	L4789	239.6	P1	med. sand; grey*
195	L4790	239.6	P1	wood*
196	L4791	239.8	P1	c. sand; blue grey
197	L4792	242	P1	f. sand
198	L4793	242.3	P1	med. sand; green grey
199	L4794	244.7	P1	clay; green grey
	L5669			
200	L4795	245.3	P1	f. sand & gravel
	L5671			
201	L4796	245.8	P1	f. sand; grey
	L5670			
202	L4797	245.9	P1	mud; green grey
203	L4798	246.2	P1	sand, gravel, & carb. mud
	L5672			
204	L4799	247.9	P1	med. sand & gravel; lt grey
	L5673			
205	L4800	248.7	P1	mud; white
	L5675			
206	L4801	251.2	P1	mud; lt grey
	L5676			
207	L4802	251.7	P1	f. sand & peat
208	L4803	251.8	P1	f. sand; green grey
209	L4804	251.9	P1	f. sand; olive grey
210	L4805	255.1	P1	mud; olive grey
211	L4810	256.3	P1	mud; olive grey
	L5674			
212	L4811	256.9	P1	mud; lt grey
	L5677			
213	L4815	278.5	P1	peat with gravel
214	L4812	280.4	P1	mud; lt grey
215	L4813	295.6	P1	gritty mud; grey to lt grey
	L5678			
216	L4814	297.5	P1	mud; green grey
217	L3408	302.7	?	carb. mud with sand lenses, ?gwke
218	L3409	303	?	mud with sand grains, ?gwke; dk grey
219	L4816	309.9	?	c. sand, ?gwke
220	L4817	310.5	?	top; sand & gravel, ?gwke*
221	L4818	310.5	?	bottom; mud & gravel, ?gwke*

222	L4819	310.7	?	gravel, ?gwke; grey

SEAVIEW DRILLHOLE. R27/f8595

No lithological description was provided on the fossil record forms.

Sample number	Slide number	Depth in m	Bio-zone
1	L5013	10.7	P9
2	L5014	12.2	P9
3	L5015	13.4	P9
4	L5016	14	P9
5	L5017	14.6	P9
6	L5018	17.7	P9
7	L5019	48.5	P6
8	L5020	49.7	P6
9	L5021	50.3	P6
10	L5022	50.9	P6
11	L5032	51.8	P6
12	L5033	52.4	P6
13	L5034	53.6	P6
14	L5035	56.4	P6
15	L5036	57.9	P6
16	L5037	58.5	P6
17	L5038	60	P6
18	L5039	61.9	?P4
19	L5040	72.5	P4
20	L5041	73.8	P4
21	L5042	75	P4
22	L5043	76.8	P4
23	L5044	78.3	P4
24	L5045	80.4	P4
25	L5046	81.5	P4
26	L5047	83.2	P4
27	L5048	85.3	P4
28	L5049	88.4	P4
29	L5050	89	P4
30	L5051	126.1	P2
31	L5052	126.3	P2
32	L5062	127.1	P2
33	L5063	129.2	P2
34	L5064	130.1	P2
35	L5065	132.2	P1
36	L5066	149.9	P1
37	L5067	152.1	P1
38	L5068	153.9	P1
39	L5069	155.1	P1
40	L5071	156.6	P1
41	L5072	172.2	P1
42	L5073	176.8	?basement
43	L5074	177.4	?basement
44	L5075	180.3	?basement

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