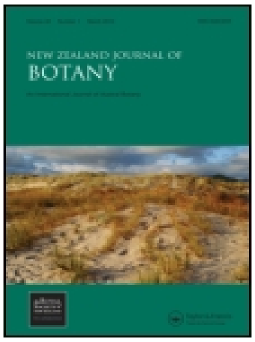

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Contributions to the Quaternary history of the New Zealand flora

8. Interglacial and glacial vegetation in the Westport District, South Island

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Abstract Pollen analysis of organic layers exposed in quarries and road cuttings provides the framework for an understanding of vegetation and climate history during and since the last (Oturi) interglacial in the Westport district.

The early and late Oturi are separated by a stadial of unknown duration when forest was replaced by grassland–shrubland. During the early Oturi *Nothofagus* forest was dominant, but during the late Oturi *Dacrydium cupressinum* was dominant until it was replaced by *Nothofagus*.

The Otiran record, like the Oturian, is incomplete, but an interstadial characterised by shrubland and by minor spread of *Nothofagus* began earlier than 31 000 yr B.P. and ended *c.* 26 000 yr B.P. Subsequently vegetation of grassland or grassland–shrubland remained dominant until the post-glacial spread of forest. The transition from grassland to forest was abrupt and not preceded by the shrubland phase common to the early post-glacial in most areas investigated in New Zealand; there is no evidence of a break in deposition at the sites concerned.

The pollen diagrams are compared with pollen data from other sites on the west coast of the South Island and an attempt to correlate them in terms of glacial/interglacial chronology is presented.

INTRODUCTION

The post-glacial (Aranuian) history of vegetation and climate in New Zealand is fairly well known and there is a recent regional study for central South Island (Moar 1971). Much less is known about Oturian (last interglacial) and Otiran (last glacial) vegetation and climate. However, there is an incomplete Oturian sequence from south Westland (Moar 1975) and the transition from interglacial to glacial is represented by pollen diagrams from Sunday Creek, north Westland (Dickson 1972) and Joyce's Creek, central Canterbury (Moar & Gage 1973). On the basis of Suggate's (1965) review of glacial geology in the northern part of the South Island, the Westland sites noted above are late Oturian and early Otiran, but because of continuing discussion over trans-alpine correlations the stratigraphic position of the Joyce's Creek sequence remains uncertain. Middle or late Otiran sites are known from north Westland (Moar & Suggate 1973), from south Canterbury (Moar 1973a), and from central North Island (McGlone & Topping 1973). There are other pollen data from Otiran sites in Westland and Canterbury, and these, from single samples, generally represent the more severe periods of the late Otiran (Harris in Suggate 1965, Suggate & Moar 1970, Nathan & Moar 1973), when open grassland was dominant.

Post-glacial patterns of vegetation in the South Island are influenced by the events of the Otira Glac-

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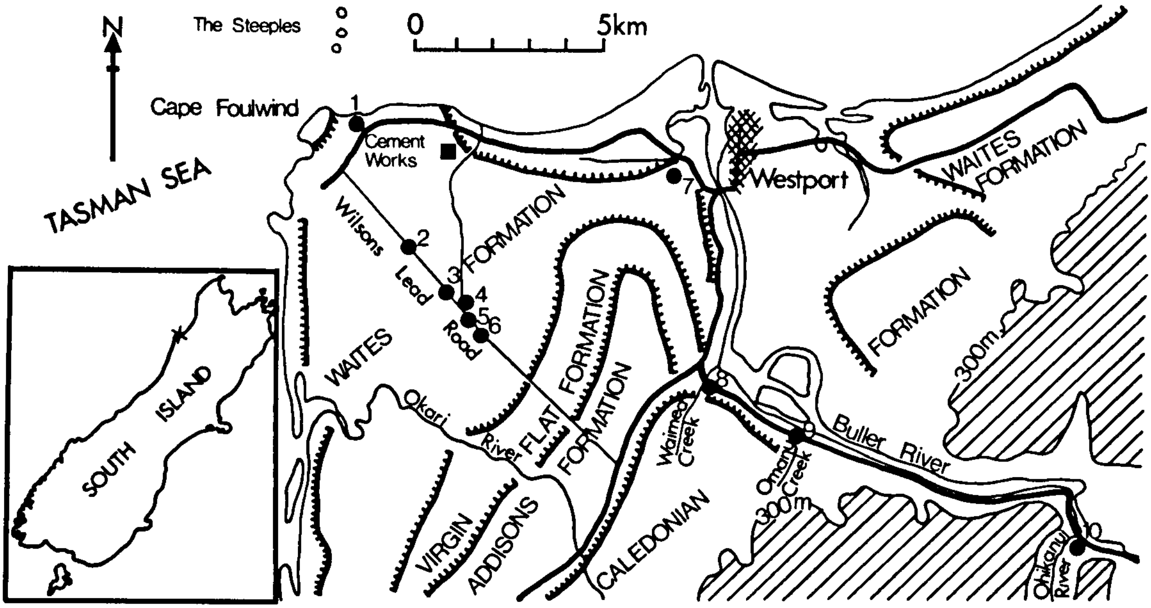

Fig. 1 Oturian and Otiran sites in the Westport area. 1, Cape Foulwind; 2, The Yards; 3, The Hill; 4, Sand Quarry and Cement Works Track; 5, Junction Cutting; 6, Reids Rise; 7, Martins Quarry; 8, Waimea Creek; 9, Omanu Creek; 10, Ohikanui River.

ial. To understand these patterns better it is appropriate to study Otiran and Oturian sites in central South Island where the post-glacial vegetation history is relatively well known. It was relatively easy to find thin layers of organic sediment for single sample analysis, but it was much more difficult to locate sites with layers thick enough for details of vegetation history spanning long periods to be recorded. One such area was found near Westport (Fig. 1), where Oturian and Otiran sediments include long, but incomplete, sequences suitable for pollen analysis. This paper describes the sites and discusses the pollen diagrams derived from them in terms of vegetation and climate. Plant names are those used in Allan (1961) and Moore & Edgar (1970).

Geologic setting

The coastal terrace sequence west and south-west of Westport is the imprint of a succession of relatively high sea levels on a moderately rapidly rising land (Suggate 1965, McPherson 1967, Nathan 1976). Ancient cliffs, wave-cut platforms covered by marine and aeolian deposits, and gravels of rivers graded to the former sea levels characterise the area. Four major cycles of cliff formation and sea recession were recognised by Suggate (1965). The fourth is the post-glacial partial cycle and the third is characterised by having two sub-cycles.

The deposits of the third cycle were mapped on the Geological Map of New Zealand, 1:250 000, sheet 15, as Awatuna Formation (Bowen 1964, Suggate 1965) and were attributed to the Oturi Interglacial. McPherson (1967) studied the area in more detail, and retained the separation of the third cycle into two sub-cycles, naming the deposits of the older, Virgin Flat Formation, and those of the younger, Waites Formation. He recognised several "recessional levels" following the initial high sea level of the Waites Formation. The sediments studied lie either within, or on, the deposits of the third cycle and were formed in various environments including estuaries, lagoons, and swamps. The sites (Fig. 1) are discussed later.

The deposits of the second cycle were mapped as Karoro Formation (Bowen 1964, Suggate 1965) and were attributed to the Terangi (penultimate) Interglacial. McPherson (1967) named them the Addisons Formation (Fig. 1) and his mapping and terminology were generally adopted by Nathan (1976).

The deposits of the first cycle were mapped as Albion Formation (Bowen 1964, Suggate 1965) and were attributed to the Waiwhero Interglacial. McPherson (1967) named them the Caledonian Formation, which is adopted here (Fig. 1).

Soils in the area are acidic, and on the coastal terraces they are peaty, often very wet, and overlie an impervious iron pan which usually rests on cemented marine gravels.

Vegetation

In most lowland forests podocarps, especially *Dacrydium cupressinum*, often in association with *Nothofagus truncata*, are dominant. *Weinmannia racemosa* is widespread and other common trees include *Podocarpus dacrydioides, Dacrydium colensoi, Nothofagus menziesii, N. solandri* var. *cliffortioides, Metrosideros robusta, M. umbellata*, and *Quintinia acutifolia*. Ferns, including tree ferns, are everywhere abundant. *Nothofagus* is generally dominant at higher altitude. The main timber line species is *N. menziesii*, but in places *N. solandri* var. *cliffortioides* and the large shrubs *Dacrydium biforme, Archeria traversii, Olearia colensoi*, and *Senecio bennettii* are important. Alpine grassland extends above timber line.

Rigg (1962) described semi-pakihi and pakihi vegetation on the coastal terraces south of Westport. Semi-pakihi occurred on deeply dissected lagoonal or estuarine sands (Waites Formation) which until European times were covered by podocarp forest usually dominated by *Dacrydium cupressinum*. The forest was logged late last century and since then the area has been fired many times. The following species were noted in a badly damaged forest remnant near Junction Cutting (Fig. 1): *D. cupressinum, D. intermedium, D. colensoi, Podocarpus dacrydioides, P. ferrugineus, Quintinia acutifolia, Griselinia littoralis, Pseudopanax crassifolium, Elaeocarpus hookerianus, Coprosma australis, Phyllocladus alpinus, Aristotelia serrata, Weinmannia racemosa, Hedycarya arborea, Cyathodes fasciculata*, and *Astelia nervosa*. Most of this once forested area, now semi-pakihi, is dominated by stands of *Leptospermum scoparium* and open herbaceous communities of *Gleichenia circinata, Tetraria capillaris, Baumea teretifolia*, and *Lepidosperma australe* which are being rapidly replaced by pasture.

The so-called true pakihi occurs on the strongly acid, thin peaty soils on the cemented marine gravels of Virgin Flat Formation and Addisons Formation. In the study area a mosaic of *Leptospermum scoparium*, sedges, and fern is rapidly disappearing as land is being converted for grassland farming. Common herbaceous plants within this mosaic included *Astelia linearis, Carpha alpina, Hemiphues suffocata, Herpolirion novae-zelandiae, Liparophyllum gunnii, Oreobolus pectinatus*, and *Oreostylidium subulatum*. Of these, *A. linearis, C. alpina*, and *Oreobolus* are usually restricted to the subalpine or alpine regions and the others generally occur at lower altitudes. In broad peat-filled drainage channels, *Baumea teretifolia*, stunted *Phormium tenax, Gleichenia circinata*, and *Sphagnum* are variously represented.

Holloway (1954) described the colonisation of pakihi by forest species, a process arrested at Wilsons Lead Road for many years by repeated fires which may have been a factor long before European settlement began. However, parts of the "true" pakihi were formerly forested, for stumps of *Dacrydium colensoi, D. intermedium, Podocarpus* spp., and *Leptospermum scoparium* occur on, and beneath, the surface of peat-filled drainage channels within the pakihi area. There were also numerous stumps of *Dacrydium colensoi* on the surface of an old scour channel attributed to the Oturi Interglacial (van der Lingen & Andrews 1968) just west of the marine cliff cut at the maximum of the second Oturi sub-cycle (Suggate 1965).

Stabilised sand dunes of Oturi age run across the pakihi more or less parallel to the coast and on these there remain patches of forest, despite the ravages of fire. In one such patch *Nothofagus truncata* is dominant, *Dacrydium cupressinum, Myrsine salicina*, and *Weinmannia racemosa* common, and there is often a tangle of *Ripogonum scandens* and *Freycinetia banksii*.

Climate

The climate is equable. Precipitation is high near Westport (2000 mm annually) and evenly distributed throughout the year; rainfall is higher further inland. The mean daily temperature range is *c*. 7°c and the yearly mean at Westport aerodrome is 11.9°c (New Zealand Meteorological Service 1973). Westerly winds predominate, but easterly winds blowing from the mountains and through river gorges locally produce temporary cold conditions.

SURFACE SAMPLES

A general idea of the current pollen rain was obtained by analysis of four surface samples of moss and forest litter. Three samples were taken from sites along Wilsons Lead Road and a fourth was taken from the forest edge near Totara River *c*. 6 km to the south (Table 1).

Samples 1 and 2 were from pakihi dominated by *Baumea teretifolia* and *Gleichenia circinata*. Other species included *Tetraria capillaris, Centrolepis ciliata, Centella uniflora, Liparophyllum gunnii*, and dwarf *Leptospermum scoparium*.

Samples 3 and 4 were collected from the margins of forest remnants dominated by *Nothofagus truncata*. *Weinmannia racemosa* was frequent and other species included *Dacrydium cupressinum, Podocarpus acutifolius, Metrosideros umbellata, Myrsine salicina, Pseudopanax crassifolium*, and *Freycinetia banksii*.

The pollen analyses (Table 1) reflect the general character of the regional and local vegetation. The relatively high frequencies for *Nothofagus fusca*

Table 1 Surface samples from Westport area. Figures represent percent frequency of total pollen counted, excluding aquatics and spores. 1, rock surface *c*. 75 cm above ground level, Wilsons Lead Road; 2, ground level beside rock, Wilsons Lead Road; 3, forest margin on sand dune at younger Oturi; 4, forest margin just south of Totara River.

	1	2	3	4
Cupressaceae		2		
Dacrydium colensoi type		tr		1
D. cupressinum	1	8	2	2
Phyllocladus	1	2		tr
Pinus	1	+	1	
Podocarpus dacrydioides	1		tr	+
P. ferrugineus		3		
P. spicatus			tr	
Podocarpus	1	1	tr	
Ascarina	1			tr
Compositae	1	tr	tr	
Coprosma	7	3	5	4
Elaeocarpus				tr
cf. *Epacris*		2		
Leptospermum		1	2	1
Metrosideros		2	5	tr
Myrsine		6	tr	2
Nothofagus fusca type	19	27	51	84
N. menziesii	1	tr	2	
Pseudopanax		tr	4	
Quintinia	1			1
Weinmannia	1		4	1
Centrolepidaceae		1		
Chenopodiaceae			tr	
Compositae–*Cirsium* type			tr	
–*Taraxacum* type	1		2	
Cyperaceae	26	20	3	tr
Gramineae	31	14	15	tr
Gunnera		tr		
Haloragis	4	7		
Plantago (indigenous)	1			
Plantago lanceolata	1	+		
Umbelliferae		+		
Cyathea colensoi type	8		3	6
Dicksonia squarrosa			1	2
Dicksonia		tr		
Gleichenia	2	5	tr	
Histiopteris	1		tr	1
Hypolepis			tr	
Lycopodium		2	tr	
Monolete fern spores	6	2	77	5
Ophioglossum	2	17		
Phymatodes				1
Pteridium	6	6		
Sphagnum		1		
Trilete fern spores	5		2	4

tr = <1%
\+ = noted after formal count stopped.

type pollen in the pakihi samples represent drift from nearby sites and are representative of its importance in the region. *Dacrydium cupressinum* is found only locally in the sampling area, and the low relative frequencies of its pollen probably reflects its present role in the area fairly well.

SITES AND POLLEN DIAGRAMS

The sites are discussed according to age, Oturian sites being discussed first.

Oturian sites

(a) HIGHWAY BETWEEN WAIMEA AND OMANU CREEKS (Fig. 2).

The last 10 km of the Buller River is across the coastal plain that lies west of the Paparoa Range. Terraces border the lower course of the river, the most prominent ones being graded to the various coastal marine terraces. On the south side of the river, the road runs principally on the terrace graded to the surface of the Virgin Flat Formation (McPherson 1967, Nathan 1976) and the sections of the deposits underlying the terrace are exposed in road cuttings where the road descends to cross the main creeks. Cuttings on the approaches to Omanu Creek and Waimea Creek, 2.5 km apart (Fig. 2), show rapidly varying sequences of river gravel, sand, and some bands of clay and peat. Aggradation of at least 25 m is represented, but the full thickness is not exposed.

From the nature of the deposits and their setting within the river valley close to the coast, it is probable that they are the deposits of a river with a low gradient subject to floods bringing gravel close to, if not within, tidal influence. The cause of aggradation is presumed to be rising sea level in the early part of the Oturi Interglacial.

(i) *Road cutting west of Omanu Creek* (NZMS 1 S31: 102645, Figs 2, 3).

The top of the cutting is eroded, but it is *c*. 5 m below the aggradation surface of the Virgin Flat Formation terrace. It is further below the aggradation surface than sections near Waimea Creek but their relative ages are not necessarily indicated by this because deep channel scour and fill will have been locally significant. Two profiles were examined. The first, now overgrown, was sampled by D. J. Young and analysed by W. F. Harris and C. Lennie of the New Zealand Geological Survey and the second, 50 m west, was examined by N.T.M. in 1976. The section descriptions are:

(D. J. Young profile)

cm	
0 – 200	river gravel;
200 – 320	well sorted sand;
320 – 350	brown sand with twigs;
350 – 680	sand, pebbles in lower part;
680 – 780	brown silt with organic matter;
780 – 1180	gravel.

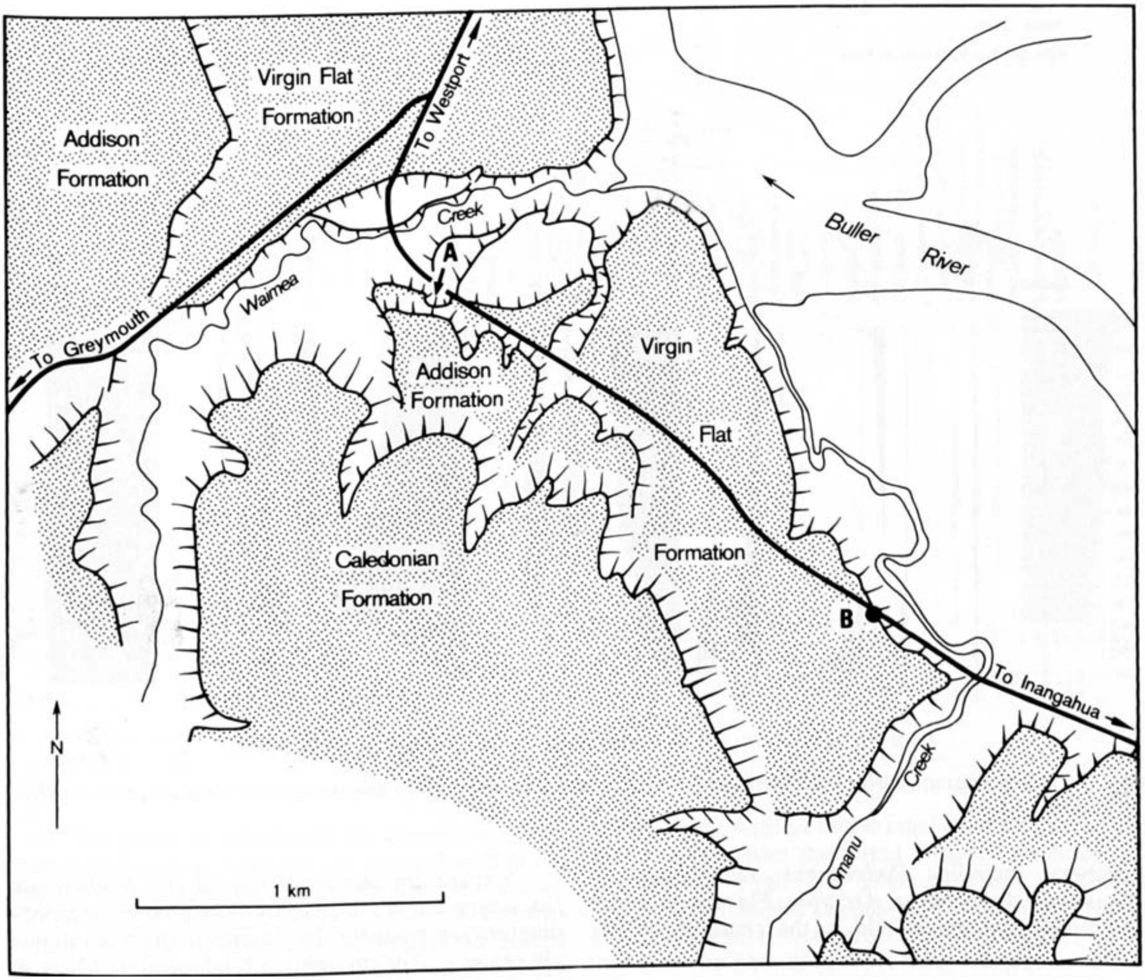

Fig. 2 Waimea Creek (A) and Omanu Creek (B) sites and their relationship to the Virgin Flat Formation.

(N.T.M. profile)

cm	
0 – 100	well sorted sand with pebbles in layers;
100 – 110	brown sand with twigs;
110 – 120	peaty silt with clay lens;
120 – 140	brown sand;
140 – 240	organic silt with clay, wood fragments scattered throughout;
240 – 260	silty clay with scattered wood to road level at 260 cm.

The pollen spectra from both profiles are similar and so are related to the same period, and the sediments are consistent with accumulation in an area subject to river flooding. The absence of pollen derived from aquatic or mire plants (Fig. 3) suggests that any pools were temporary and supports the assumption of relatively rapid accumulation influenced by river aggradation.

According to the trends of the pollen curves, two pollen zones are recognised.

01. *Cyathea – Myrsine – Metrosideros*, 260-220 cm:

The zone is characterised by rising curves for *Nothofagus*, *Weinmannia*, *Metrosideros*, and *Cyathea* and by falling curves for *Griselinia* and *Myrsine*. At 220 cm the *Cyathea* and *Weinmannia* curves peak, *Metrosideros* is falling, and *Griselinia* and *Myrsine* are scarcely represented.

02. *Cyathea – Weinmannia – Nothofagus fusca* type, 220–110 cm:

The slow rise of the *Nothofagus fusca* type curve continues, the *Weinmannia* curve remains relatively high, and the *Cyathea* curve falls gradually from high to low levels. The sudden appearance of pollen of other forest genera at or about 220 cm, albeit in low

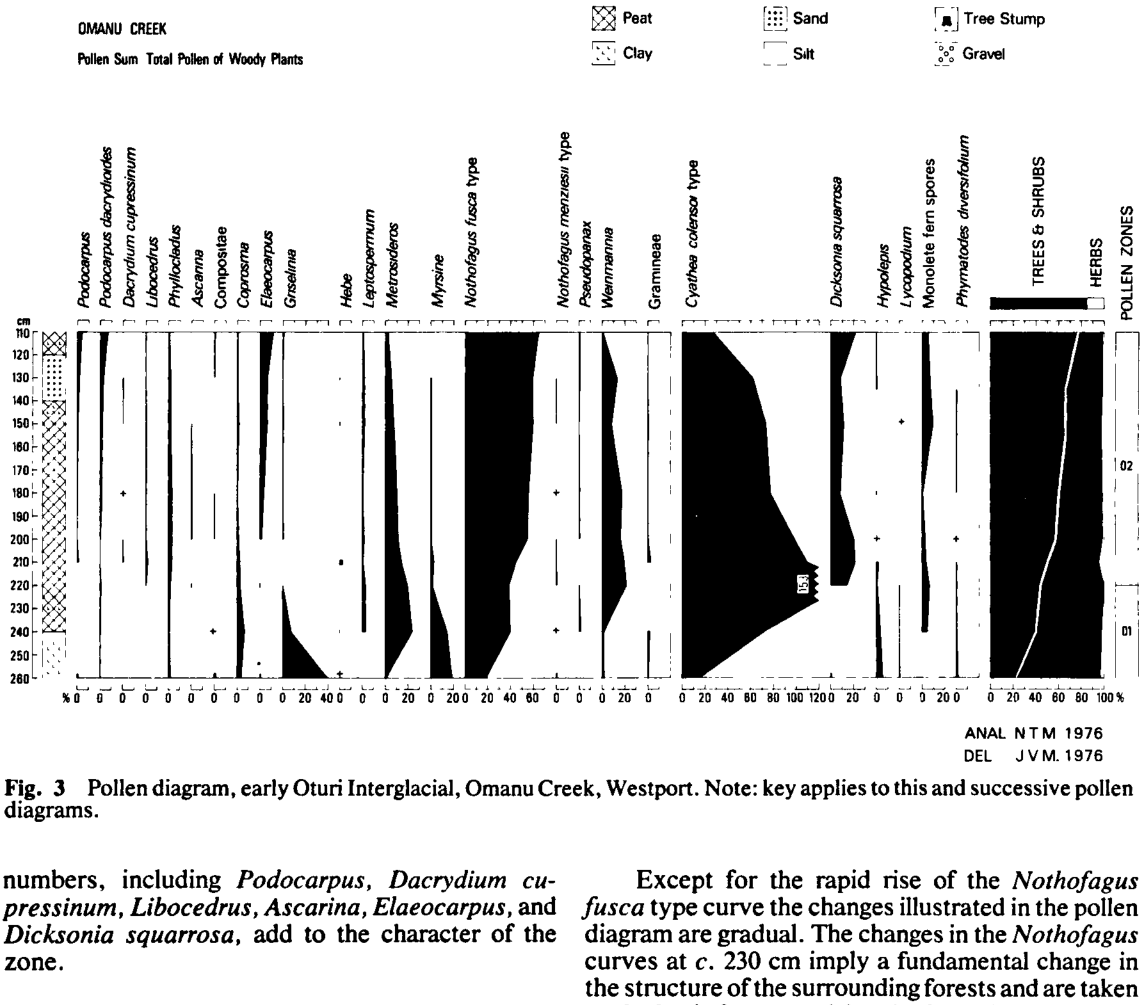

Fig. 3 Pollen diagram, early Oturi Interglacial, Omanu Creek, Westport. Note: key applies to this and successive pollen diagrams.

numbers, including *Podocarpus, Dacrydium cupressinum, Libocedrus, Ascarina, Elaeocarpus*, and *Dicksonia squarrosa*, add to the character of the zone.

(ii) *Gravel pit east of Waimea Creek* (NZMS 1 S31: 082656, Figs 2, 4).

An organic layer over 1 m thick lies between river gravels *c.* 5 m above the floor of the pit. Erosion and construction works have destroyed the surface of the much overgrown section which has the following sequence of sediments:

cm	
0 – 200	poorly sorted gravel with silt lens;
200 – 330	compressed silty organic layer;
330 – 430+	well rounded gravel, base concealed by slumping and vegetation.

The sequence suggests that, as at Omanu Creek, peat accumulation was dependent on changes in the course of the Buller River. However, the high organic content implies a slower rate of accumulation and the *Myriophyllum* pollen, together with a few records of *Potamogeton, Isoetes*, and *Typha*, imply areas of open water with enough permanence to maintain a sparse aquatic flora.

Except for the rapid rise of the *Nothofagus fusca* type curve the changes illustrated in the pollen diagram are gradual. The changes in the *Nothofagus* curves at *c.* 230 cm imply a fundamental change in the structure of the surrounding forests and are taken as the basis for recognising the following two pollen zones.

W1. *Nothofagus menziesii – Coprosma*, 330–230 cm:
The curve for *N. menziesii* pollen is consistently high and several pollen types including *Coprosma*, Compositae, *Pseudopanax*, Gramineae, and Cyperaceae are better represented during this period than later. Pollen of *Rubus, Nestegis, Muehlenbeckia*, and *Elaeocarpus* appear late and generally continue into the succeeding zone.

W2. *Nothofagus fusca* type, 230–200 cm:
At 230 cm the *N. menziesii* curve begins to fall to low levels and *N. fusca* type follows a reciprocal course. The curves for *Nestegis* and *Quintinia* rise from very low levels in the upper part of W1 to *c.* 5% of the pollen sum at 230 cm when *Metrosideros* appears consistently for the first time. Several shrubs, or trees, including *Nestegis, Quintinia*, and *Metrosideros* disappear from the record before peat accumulation ceased.

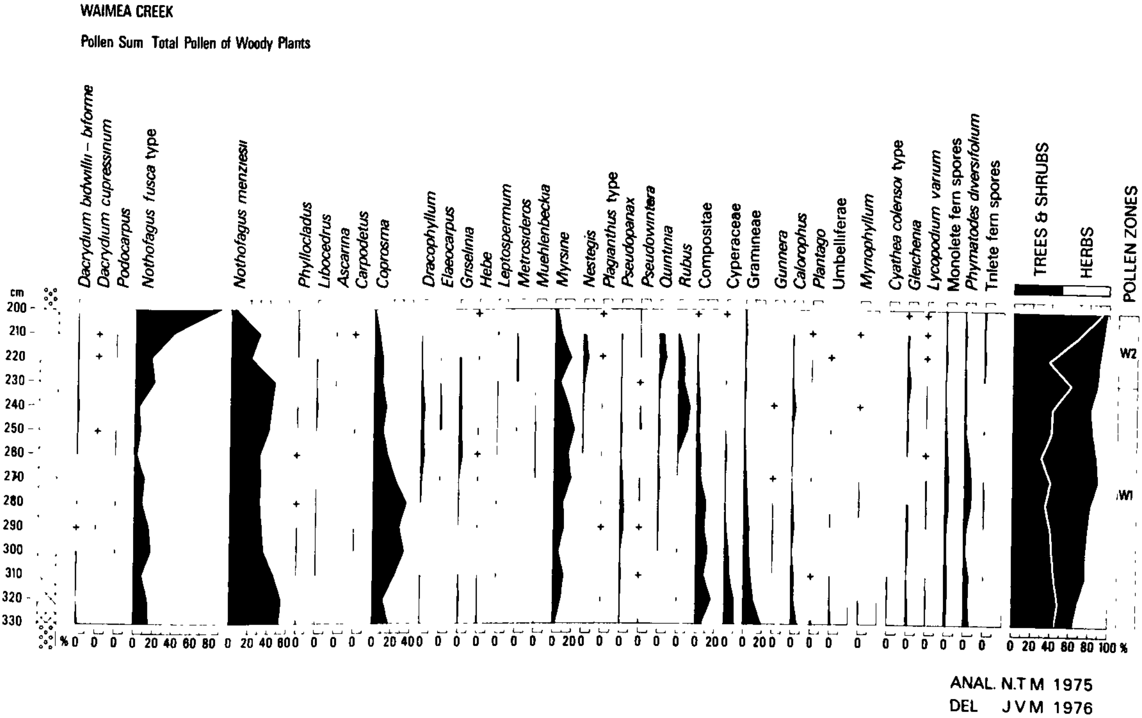

Fig. 4 Pollen diagram, early Oturi Interglacial, Waimea Creek, Westport.

The differences between the Omanu and Waimea Creek pollen diagrams are so obvious that the source vegetation about each site must have been different. It is difficult to reconcile these differences when sites are so close together unless we accept that one is older than the other, and since the top of the Waimea Creek section is the aggradation surface this section may be the younger.

(b) CAPE FOULWIND (NZMS 1 S23 : 981733, Figs 1, 5).

The following section is exposed on the track that leads to the beach north of Cape Foulwind Hotel.

cm	
0 – 900	sand, rusty-brown, manganese stained, thin-bedded;
900 – 930	grey clay and sand;
930 – 950	well-compacted dark brown peat, wood fragments;
950 – 980	granite boulders: single layer in sand matrix;
	Unconformity;
	Tertiary siltstone.

The top of the section is at *c.* 30 m a.s.l. and a surface at this altitude is extensively preserved east of the Cape Foulwind promontory, which rises above it. It is mapped (Nathan 1976 after McPherson 1967) as the highest recessional level formed as the sea receded from the initial Waites Formation aggradational level. The absence of any significant thickness of marine deposit below the peat indicates that the boulders were probably left during retreat of the sea; the peat then represents subsequent emergence, but this was apparently temporary since the overlying sand, which may be lagoonal, indicates a rising base level.

McPherson (1967) considered that there was a single wave-cut bench beneath the Waites Formation and that the recessional levels mark "pauses during the gradual withdrawal of the sea". If one accepts the single bench and only erosion during recession, the fluctuation of sea level inferred to be recorded in the Cape Foulwind section probably took place in the later stages of the transgression leading to the second (Waites) sub-cycle of the Oturi (last) Interglacial.

The peat layer was rich in pollen and the details are shown in Fig. 5. The sediments accumulated under a high water-table but there is little evidence of standing pools of water. The few recorded grains of *Myriophyllum* could have been derived from isolated plants growing in wet hollows, an assumption supported by the curves for *Gaimardia*, other Centrolepidaceae, *Calorophus*, *Gleichenia*, *Sphagnum*, and the records of *Astelia*, *Bulbinella*, and *Gunnera* pollen.

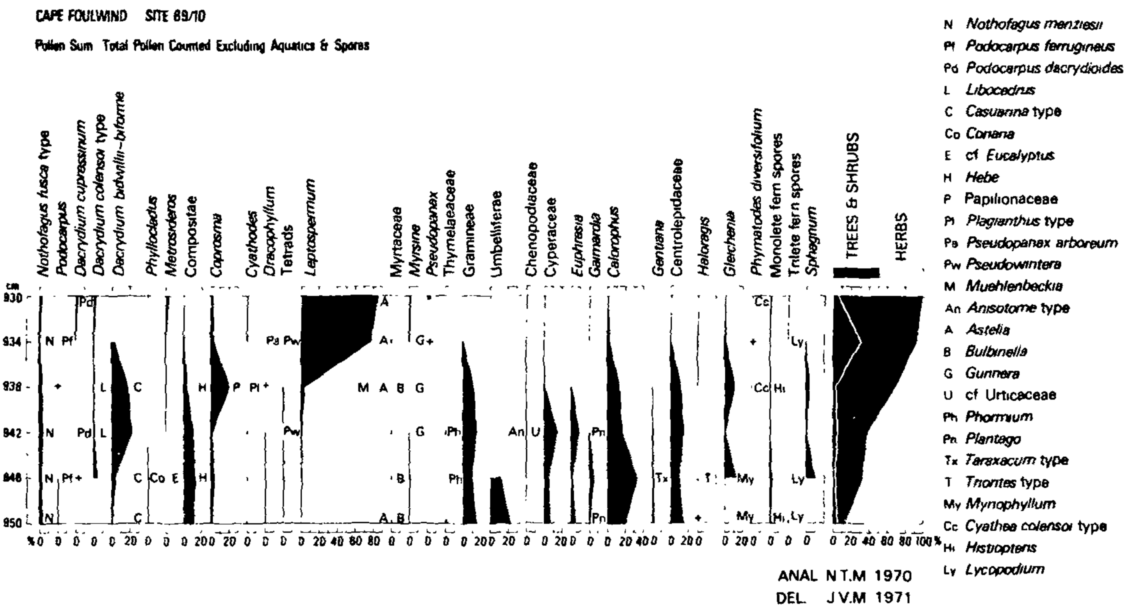

Fig. 5 Pollen diagram, mid-Oturi stadial, Cape Foulwind, Westport.

Table 2 Pollen frequencies (percent) for principal pollen types from three upper samples from Cape Foulwind site. Pollen sum, total pollen excluding *Leptospermum*, aquatics, and spores.

	Depth (cm)		
	930	934	938
Dacrydium bidwillii/biforme		19	20
D. colensoi type	12	5	tr
D. cupressinum	11	1	
Phyllocladus	1	1	tr
Podocarpus dacrydioides	2		
Compositae	3	7	4
Coprosma	12	19	22
Leptospermum	583	349	4
Metrosideros	20	1	1
Myrsine	6	5	
Nothofagus fusca type	11	7	3
Astelia	4	7	1
Calorophus	1	14	15
Gramineae	2	4	12

tr = <1%.

The pollen diagram, constructed on the basis of total pollen, may conceal the true role of trees in the area, especially when the upper layers, dominated by locally produced *Leptospermum* pollen, were accumulating. Calculations based on a pollen sum excluding *Leptospermum* (cf. Dickson 1972, for the Sunday Creek sequence, north Westland) change tree and shrub pollen frequencies in the uppermost sample (Table 2). At that level *Dacrydium colensoi* type, *D. cupressinum*, *Metrosideros*, and *Nothofagus fusca* type show a marked increase and so demonstrate the increasing role of trees in the regional vegetation only hinted at in the total pollen diagram. The intermittent occurrence of *Casuarina* and *Eucalyptus* type pollen is considered to represent drift from Australia.

There are nine radiocarbon dates (Table 6) based on samples of wood and peat from the Cape Foulwind site (Grant-Taylor & Rafter 1971). Samples from the same level gave contrasting finite and infinite ages and similar conflicts occurred with duplicate samples, e.g., duplicate peat samples NZ 1086 34 100 ± 1200 yr B.P., NZ 1087 >49 400 yr B.P. There was no systematic relationship between dates and stratigraphy and it is accepted that samples were contaminated by younger carbon.

(c) SAND QUARRY (NZMS 1 S31: 007686, Fig. 1, Table 3).

Well-bedded yellow-brown sand is exposed in a disused sand pit north of the junction of Wilsons Lead Road and the track to the cement works. Erosion has produced a ground surface with smooth steep slopes, and the sand has a clay-rich layer at the top of the quarry. The top of the quarry is at an altitude of *c.* 24 m, but the original depositional level must have been substantially higher, presumably being that of the initial Waites surface. The sand contains thin clay layers, some of them darkened by carbonaceous matter. These, and the thin bedding, suggest lagoonal conditions.

Table 3 Pollen spectra (percent) from Cement Works Track site (1) and from Sand Quarry site (2, 3). Pollen sum, total pollen of trees and shrubs excluding *Myrsine*.

	1	2	3
Dacrydium bidwillii/biforme	2	tr	tr
D. colensoi type	2	tr	tr
D. cupressinum	1	36	43
Libocedrus	4		
Phyllocladus	2	tr	
Podocarpus dacrydioides			tr
P. ferrugineus	tr		
P. totara type		6	9
Podocarpus	3	7	7
Coprosma	13	4	3
Dracophyllum	2		tr
Griselinia	2	tr	
Myrsine	127	36	16
Nestegis	12	5	6
Nothofagus fusca type	37	27	20
N. menziesii	9	12	8
Plagianthus type	3		1
Quintinia	3	tr	tr
Papilionaceae		tr	
Metrosideros	tr		
Muehlenbeckia			1
Weinmannia	2		
Compositae	1		
Cotula	1		
Cyperaceae	tr		
Gramineae	8	4	1
Galium		tr	
Ranunculus		2	
Cruciferae	tr		
Gunnera	1		
Myriophyllum			tr
Potamogeton	2		
Histiopteris	tr		
Gleichenia	5		
Phymatodes	tr		
Monolete fern spores	4	tr	
Trilete fern spores	tr		

tr = <1%.

A similar section is found *c*. 1 km along the track to the cement works. There, an organic clay layer *c*. 10 cm thick lies below 4 m of weathered yellow-brown sand and above blue-grey sand of unknown thickness.

On stratigraphic grounds these Oturi deposits are thought to be younger than the early Waites Formation sediments at Cape Foulwind.

Two samples from the Sand Quarry and one from the Cement Works Track site were prepared for pollen analysis. The pollen spectra (Table 3) are characterised by high values for trees and shrubs. The two Sand Quarry samples contain relatively high frequencies of *Dacrydium cupressinum* pollen in contrast to the Cement Works Track sample which is dominated by dicotyledonous tree and shrub pollen including *Myrsine*, *Nothofagus*, and *Nestegis*. *Myrsine* is excluded from the pollen sum (Table 3) because in sample 1 it appears to be over-represented.

(d) MARTINS QUARRY (NZMS 1 S24 : 075724, Figs 1, 6).

Developed on river gravel beneath a terrace surface, this site exposes a section *c*. 10 m high with the following detail at the site sampled.

cm	
0 – 100	silty clay with thin organic bands and fine silt layers;
100 – 145	peaty clay, small pieces of wood;
145 – 190	peat, layer of small wood 10 cm above base; peat sampled at 167–177 cm for radiocarbon assay;
190 – 220	peaty clay; transition from underlying sand;
220 – 300	blue-grey sand, rimu (*Dacrydium cupressinum*) stump, in place, 60 cm high; top of stump (at 220 cm) removed for radiocarbon assay;
300 – 800+	boulder gravel; iron pan at top.

The top of the terrace is at *c*. 24 m above sea level and slopes gently west into a shallow former channel of the Buller River and then rises to 28 m. It was mapped by Nathan (1976) as graded to the second recessional surface below the initial Waites surface. The north face of the terrace is the post-glacial sea cliff and a short distance to the east the terrace faces the flood plain of the Buller River. Because of sea and river erosion it is not possible to judge former stream patterns, or when there was a stream capable of depositing the sand in the channel if it was not left by the Buller River immediately after deposition of the gravel. Accordingly, the age relation of the gravel to the overlying deposits is not known, but it seems improbable that the river could have remained at (or regained) that level after any significant time. On the basis of stratigraphy the maximum – indeed the probable – age of the deposit is very late Oturi Interglacial although radiocarbon dates (Table 6) suggest a middle Otiran age which is considered to be too young because of the prevalence of contamination in many old samples (see p. 382).

The stump, rooted well below the base of the organic sediment indicates that *D. cupressinum* was established locally before peat accumulation, and the pollen record, began.

The changes in hydrology leading to peat formation are reflected by the marked increase in *Calorophus* pollen at 180 cm and by the regular occurrence of *Potamogeton* pollen between 140 and 180 cm. The reverse trend is evident at 140 cm when *Calorophus* pollen frequencies decline, *Potamogeton* pollen disappears from the record, and there is a change in sediment from peat to peaty clay.

The trend of the pollen curves allows subdivision of the pollen diagram into the following four zones.

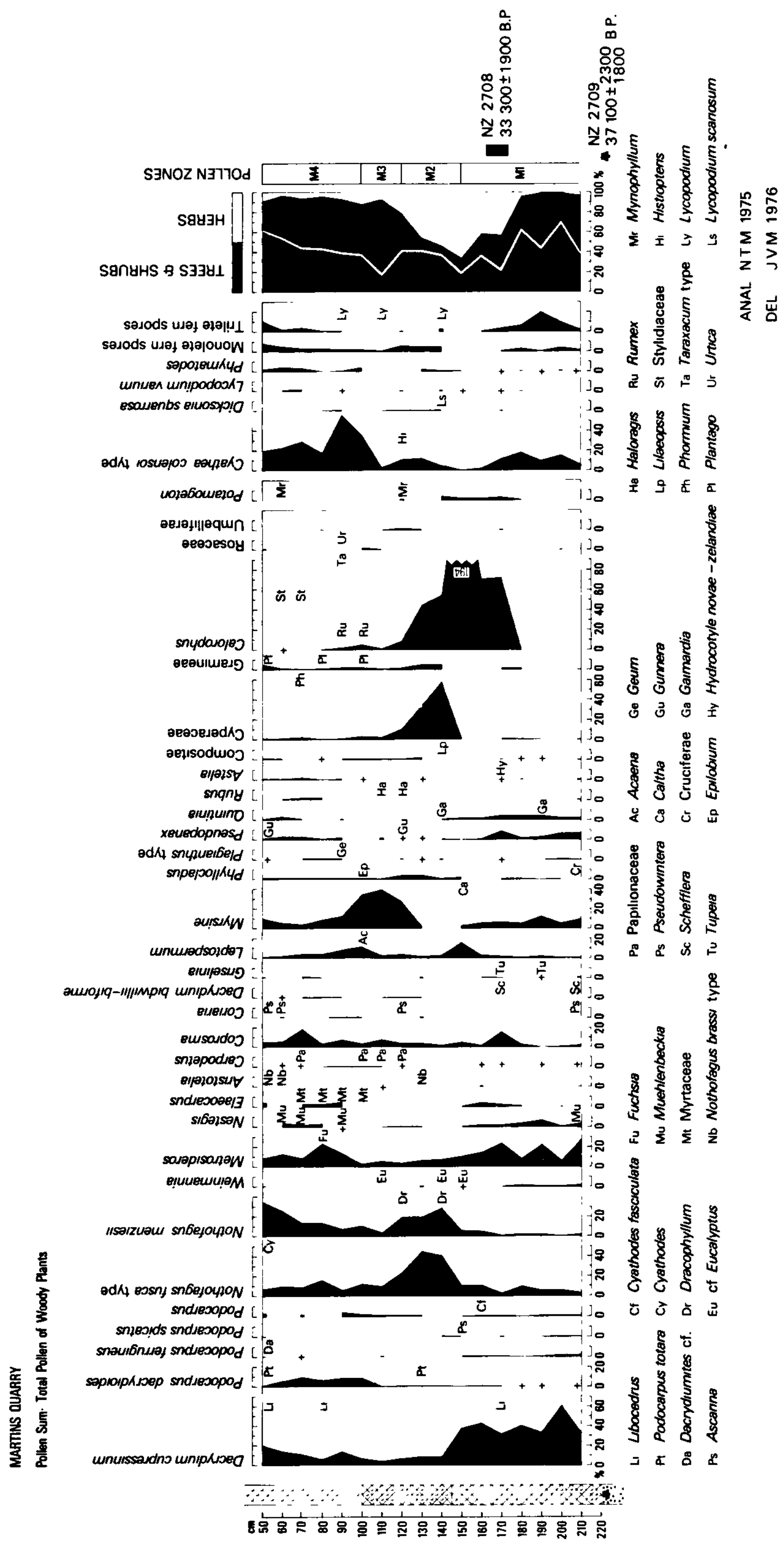

Fig. 6 Pollen diagram, late Oturi Interglacial, Martins Quarry, Westport.

M1 *Dacrydium cupressinum – Calorophus,* 210–150 cm:
D. cupressinum pollen is dominant until the rapid rise of *Calorophus* at 180 cm which reaches its maximum frequency at 150 cm. *Metrosideros, Myrsine,* and *Nothofagus fusca* type are relatively important, as are other forest species such as *Nestegis* and *Elaeocarpus*.

M2 *Nothofagus fusca* type – *N. menziesii* – Cyperaceae, 150–120 cm:
The pollen of *N. fusca* type and *N. menziesii* are dominant forest types and Cyperaceae is the dominant herbaceous pollen type. *N. fusca* type begins to decrease in frequency at 130 cm, *N. menziesii* at 120 cm, the *Calorophus* curve falls steadily throughout the zone, and after a rapid rise at 150 cm Cyperaceae pollen declines as rapidly as does *Calorophus*. The *Myrsine* pollen curve rises at 120 cm and continues to rise into the next zone.

M3 *Myrsine,* 120–100 cm:
Myrsine pollen is dominant; *Dacrydium cupressinum, Metrosideros, Nothofagus fusca* type, and *N. menziesii* pollen are all at low levels.

M4 *Nothofagus – Metrosideros,* 100–50 cm:
The zone is characterised by higher values for *D. cupressinum, N. menziesii,* and *Metrosideros* pollen, and by a rapid fall in *Myrsine* pollen frequencies. Pollen of *N. fusca* type remains at low levels, but *Coprosma* increases briefly in the middle of the zone. A few pollen grains of the *Nothofagus brassi* type were observed in four samples. Pollen grains of this type are usually found in much older sediments and are unlikely to be contemporary with the Oturian pollen rain.

Otiran–Aranuian sites
With one exception Otiran sites are located in cuttings along Wilsons Lead Road (Fig. 1) where they occur in hollows in deeply eroded sands of the Waites Formation. Erosion began with the lowering of sea level after the maximum of the second Oturi cycle and in conjunction with land uplift. The organic sediments accumulated in erosion hollows and were preserved despite continuing erosion which has resulted in the present deeply dissected landscape.

(a) THE YARDS (NZMS 1 S23 : 993703, Table 4).
This site, some 30 m above sea level, has been destroyed by road works and the stratigraphy is not clear. Outcrops of organic clay are, however, still visible in road cuttings.

cm	
0 – 30	soil;
30 – 180	grey-brown sand;
180 – 198	black organic clay with wood remains;
198+	blue-grey sand.

Table 4 Pollen spectra (percent) for three samples from The Yards site. Samples 1, 2, and 3 are from the top, middle, and bottom respectively. Pollen sum, total pollen excluding aquatics and spores.

sample:	1	2	3
Dacrydium bidwillii/biforme	36	69	8
D. colensoi	1	tr	2
D. cupressinum	tr		
Phyllocladus	tr	tr	
Podocarpus spicatus		1	1
P. totara type		tr	tr
Compositae	5	6	15
Coprosma	13	10	23
Cyathodes	3		
Dracophyllum	1		
Tetrads	3		
Hebe		tr	tr
Leptospermum	1	1	5
Metrosideros	1		
Myrtaceae	tr		tr
Muehlenbeckia	tr		tr
Myrsine	1	1	4
Nothofagus fusca type	3	1	1
N. menziesii	1		
Papilionaceae			1
Phyllachne		tr	
Plagianthus type	tr	tr	
Astelia			1
Bulbinella	12	3	2
Calorophus	12	4	1
Cheesemania		tr	tr
Cruciferae			8
Cyperaceae	1		13
Gramineae	5	1	5
Gentiana	1		
Haloragis	tr	tr	tr
Oreomyrrhis			tr
Umbelliferae			8
Phormium			1
Myriophyllum			212
Gleichenia	5	10	
Histiopteris	tr		4
Phymatodes diversifolium	1	tr	tr
Lycopodium		1	tr
Monolete fern spores	2		9
Sphagnum	tr	tr	4

tr = <1%.

Three samples, one each from the top, middle, and bottom of the organic layer, were taken for pollen analysis (Table 4). The site, as judged by Cyperaceae, *Myriophyllum,* and *Sphagnum* records, was wettest in the first stages of development, but as peat accumulated the surface became drier and supported shrubland dominated by *Dacrydium bidwillii,* wood of which (taken from near the base) was identified by R. Patel, Botany Division, DSIR.

(b) THE HILL (NZMS 1 S31 : 001693, Figs 1, 7, 8, 9).
The Hill site on Wilsons Lead Road rises to *c.* 33 m a.s.l., *c.* 5 m below the level of the initial Waites surface; much of the surrounding area is lower still.

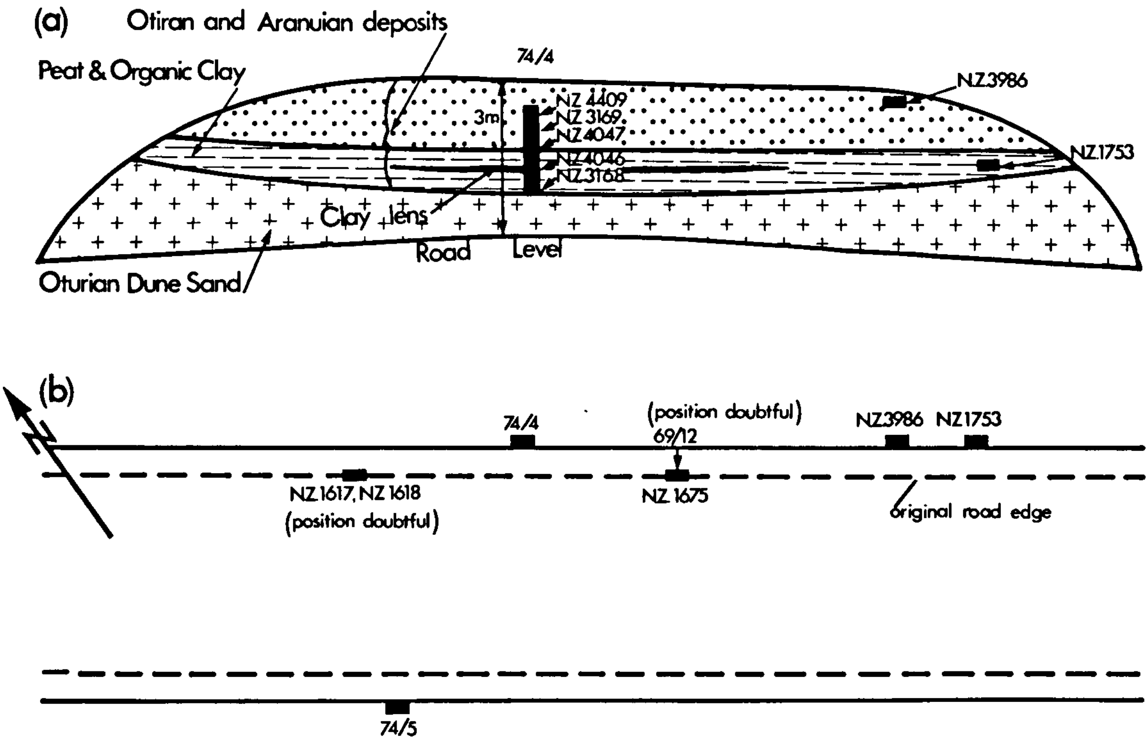

Fig. 7 (a) Sketch of the northern face of The Hill cutting, not to scale. (b) Ground plan of The Hill cutting, not to scale, indicating relative positions of all sites (e.g., 74/4) and radiocarbon samples (e.g., NZ 1753).

Resting in a hollow in dune sand by the road there are several metres of deposit, including peat, and its preservation at the site is because peat is more resistant to erosion than the dune sand. Other hills in the surrounding area of eroded Waites Formation have similar origins.

Three profiles were examined in the road cutting (Fig. 7). The first (69/12) has been destroyed by road works and its location in relation to the second (74/4) and third profiles (74/5) is uncertain, although it lay only a few metres to the east of 74/4 in the north-east bank of the cutting. In all three profiles the sediments were similar and overlay a bright yellow-brown paleosol developed in the eroded Oturian dune sand. Seven samples for radiocarbon assay were taken from the three profiles and a further four samples were taken at various levels by staff of the New Zealand Geological Survey either to check dates or as a check against contamination by modern carbon (Fig. 7, Table 6).

The most detailed stratigraphical notes were made of profile 74/4 on the north-east side of the cutting.

cm	
0 – 30	brown compacted sand;
30 – 82	sandy organic layer, radiocarbon sample at 42–35 cm and at 82–72 cm;
82 –137	blue sand;
137 –160	slightly organic sand, radiocarbon sample 147–137 cm;
160 –190	grey organic sand, radiocarbon sample 167–157 cm;
190 –197	sandy, slightly organic, clay;
197 –222	organic clay, slightly sandy, radiocarbon sample 222–212 cm;
222+	brown, cross-bedded dune sand, capped by bright yellow-brown paleosol.

The base of the dune sand is not exposed, but the altitude of the cutting indicates that it probably rests on one of the recessional surfaces and is of middle or late Oturi Interglacial age. The erosion and weathering of the sand implies a substantial interval before the accumulation of the peat which was eventually buried by sand as erosion continued in the surrounding area.

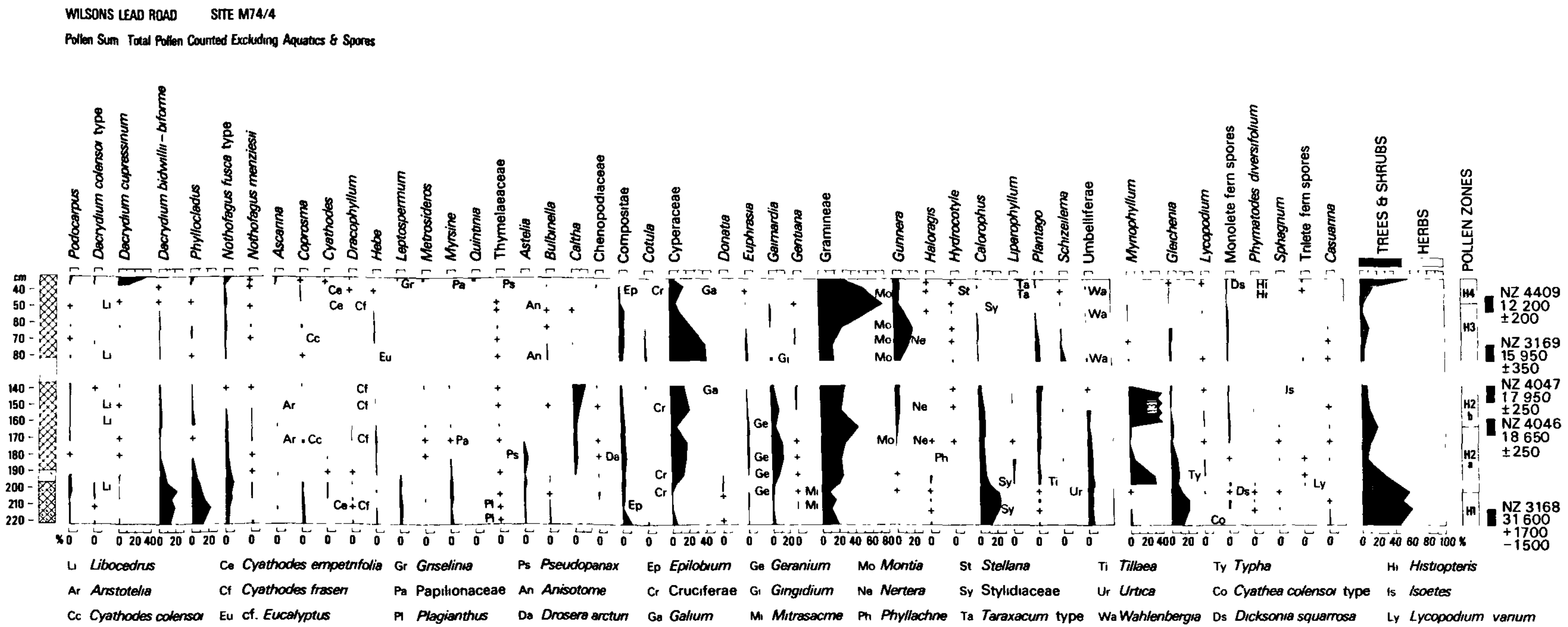

Fig. 8 Pollen diagram, late Otira Glacial, The Hill (74/4), Wilsons Lead Road, Westport.

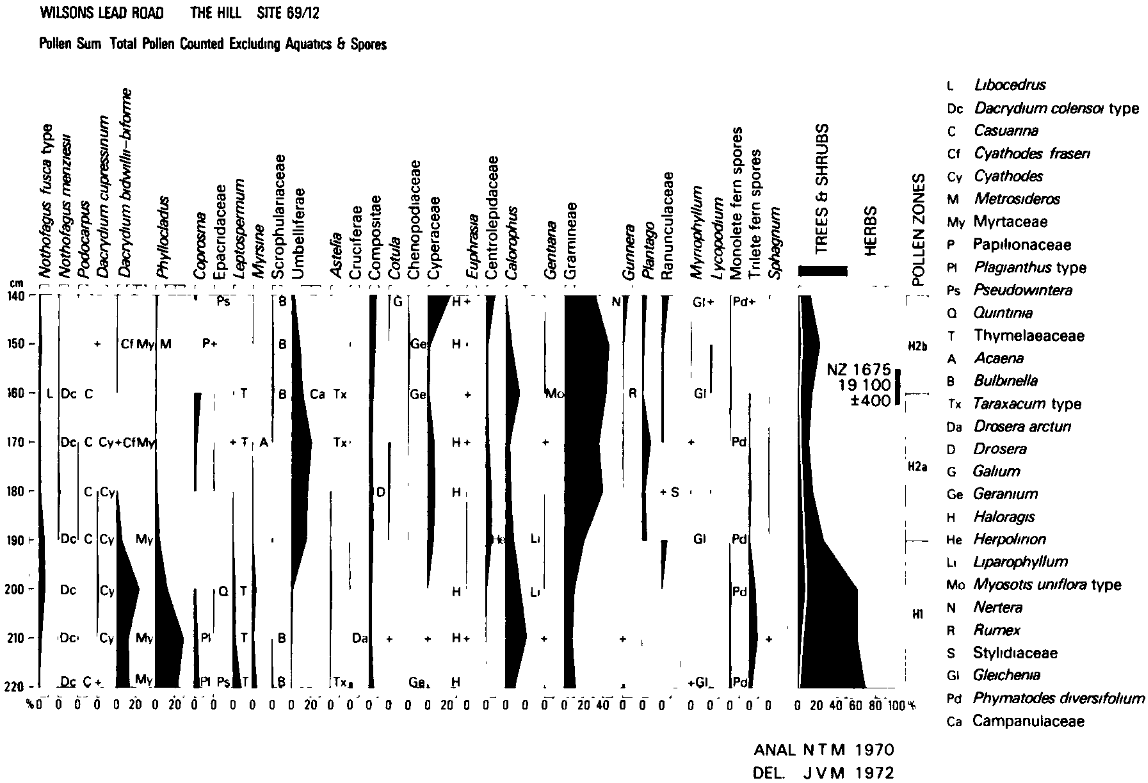

Fig. 9 Pollen diagram, late Otira Glacial and part Aranui Interglacial (post-glacial), The Hill (69/12), Wilsons Lead Road, Westport.

The sandy clay layer at 197–190 cm can be traced along much of the north side of the cutting until it finally thins out and disappears. It is taken to represent a layer formed during ponding and the relatively high values of *Myriophyllum* pollen in that layer (up to 30% total pollen), imply that there were standing pools of water. A dramatic rise of *Myriophyllum* from 2% to 131% of total pollen counted is recorded at 152 cm and indicates that pools continued to develop as sediment accumulated, although at this level the substrate was organic sand rather than clay. At both levels most of the grains were triporate and the pores were prominent as in *M. propinquum*. The high values for *Myriophyllum* pollen represent local phases of development in the peat area, for in profile 69/12 (Fig. 9) pollen grains of aquatic plants occur in low frequencies presumably because very wet areas or pools were absent. The site was obviously a damp one, however, and except for the ponding episode (197–190 cm in 74/4) wetland herbaceous communities were represented by *Astelia*, *Bulbinella*, *Calorophus*, Centrolepidaceae, and *Gentiana*.

The layer of blue sand at 82–137 cm (Fig. 8) separates the organic sediments and effectively divides the pollen diagram into two. The sand apparently overwhelmed the area rapidly, when judged by the abrupt change to sand, and probably represents a period of considerable erosion in the surrounding area. The accumulation of organic material, mixed with sand, began *c.* 2000 years later, according to radiocarbon assay, and continued into the Aranuian until sand again obilterated the site.

The pollen diagram (Fig. 8) is divided into several zones on the basis of marked changes in the pollen curves.

H1. *Phyllocladus, Dacrydium bidwillii, Nothofagus,* 222–200 cm:
The zone is characterised by relatively high values of *Phyllocladus, Dacrydium bidwillii, Nothofagus fusca* type, *Calorophus,* and Gramineae pollen. There is apparently a transition from *Phyllocladus, Dacrydium,* and *Nothofagus* and the upper boundary is drawn at the level where the *Nothofagus fusca* type curve begins to fall. Other pollen types contin-

uously represented include *Coprosma*, *Leptospermum*, *Myrsine*, Compositae, *Astelia*, *Bulbinella*, and *Plantago*.

The base of the zone is not recorded because only the beginning of peat accumulation is represented, but the peat at the base of the profile is dated at 31 600 $\pm^{1700}_{1500}$ yr B.P. (NZ 3168), and may be compared with samples NZ 1617 and NZ 1618 from basal layers at this site (Table 6).

H2 195–137 cm:
This zone, characterised by high frequencies of grasses, is divided into two sub-zones.

H2a Gramineae, Cyperaceae, Centrolepidaceae, 200–160 cm:
The curves for Gramineae, Cyperaceae, and *Gaimardia* rise and reach their peak at, or just below, the upper boundary drawn at 160 cm. The *Nothofagus fusca* type curve falls steadily and both *Phyllocladus* and *Dacrydium* pollen almost disappear from the record at *c*. 180 cm. *Coprosma*, *Myrsine*, and *Calorophus* values also fall and the first two pollen types are almost eliminated.

The boundary between H2a and H2b is dated at 18 650 ±250 yr B.P. (NZ 4046).

H2b Gramineae, 160–137 cm:
The sub-zone is characterised by high values for Gramineae pollen, by the reappearance of *Phyllocladus* and *Dacrydium*, and by the disappearance of *Nothofagus fusca* type pollen. The upper levels are truncated by the overlying blue sand which began to accumulate *c*. 18 000 years ago (17 950 ±250 yr B.P. NZ 4047).

H3 Cyperaceae, Gramineae, 82–47 cm:
The Cyperaceae curve falls steadily in contrast to the regular rise of the Gramineae pollen curve which peaks at *c*. 47 cm and then begins to fall. The *Dacrydium bidwillii* and *Nothofagus* curves are continuous for the most part, *Phyllocladus* pollen occurs sporadically and Compositae pollen is better represented than before, albeit in low frequencies. The basal layers are dated at *c*. 16 000 yr B.P. (NZ 3169 15 950 ±350 yr B.P.) and the upper layers at *c*. 12 000 yr B.P. (NZ 4409, 12 200 ±200 yr B.P.).

H4 *Dacrydium cupressinum*, Gramineae, 47–30 cm:
The rapid rise of the *Dacrydium cupressinum* curve which is accompanied by the continuing fall of the grass curve is an outstanding feature of the zone. Although the organic layer is truncated by the overlying brown sand there are records of *Ascarina*, *Metrosideros*, and *Quintinia* pollen in the uppermost spectrum, all representative of post-glacial vegetation.

The pollen diagram for profile 69/12 (Fig. 9) is equivalent to the lower part of profile 74/4 and the same pollen zones are recognised, although there are some differences in the representation of pollen types. A radiocarbon date of 19 100 ±400 yr B.P. (NZ 1675) for a sample lying between 162 and 155 cm provides a check on the sequence of zones in the two diagrams.

In addition to the radiocarbon dates already mentioned, other samples collected either by R. P. S. or T. L. Grant-Taylor, New Zealand Geological Survey, have been dated. Their relative positions are indicated in Fig. 7 and it is clear that with some exception there is good internal consistency (Table 6). In this respect it is unfortunate that sample NZ 3986 (7790 ±110 yr B.P.) collected for humic acid extraction was not subject to pollen analysis to record mid-Aranuian forest vegetation. Samples from profile 74/5 have not been dated, but, since the stratigraphy of the three profiles from the same site is so similar, their chronology is assumed to be equivalent. A small log 32 cm from the base of profile 74/5 has been identified as *Dacrydium bidwillii* by R. Patel, Botany Division, DSIR.

(c) JUNCTION CUTTING (NZMS 1 S31 : 008683, Figs 1, 10, 11)

Junction Cutting runs through a hill 20 m above sea level, *c*. 50 m east of Wilsons Lead Road junction with the Cement Works track. At this site the deposits underlying the organic layer are marine and not dune sand as at The Hill, 1 km to the west. Two profiles were examined. The first, WL (Fig. 10), has since been destroyed by road works and the second, 74/12 (Fig. 11), is located as near the first as possible. WL was studied in most detail and its stratigraphy is:

cm	
0 – 25	top soil;
25 – 70	blue-grey sand with thin iron pans at 25 cm and at 58 cm;
78 – 86	black sand;
86 – 110	dark, slightly sandy organic clay;
110 – 187	blue-grey organic clay, clay more prominent between 148 and 154 cm and between 168 and 187 cm;
187+	blue sand with clay, thin iron pan at top.

The organic layers accumulated on the little-weathered erosion surface of Waites Formation marine sand and the absence of deep weathering suggests that erosion was rapid before deposition began. The second profile, 74/12 is shorter, but otherwise similar to the first. The eroded surface of marine sand on which it lies is gently sloping and the sand contains scattered small stones. Both sites were covered rapidly by sand, but, from the evidence of the pollen diagrams, 74/12 was overwhelmed earlier than its neighbour. Peat accumulation was slow and although the surface was wet, as judged by the pollen record, there is no evidence of flooding or of permanent pools of water.

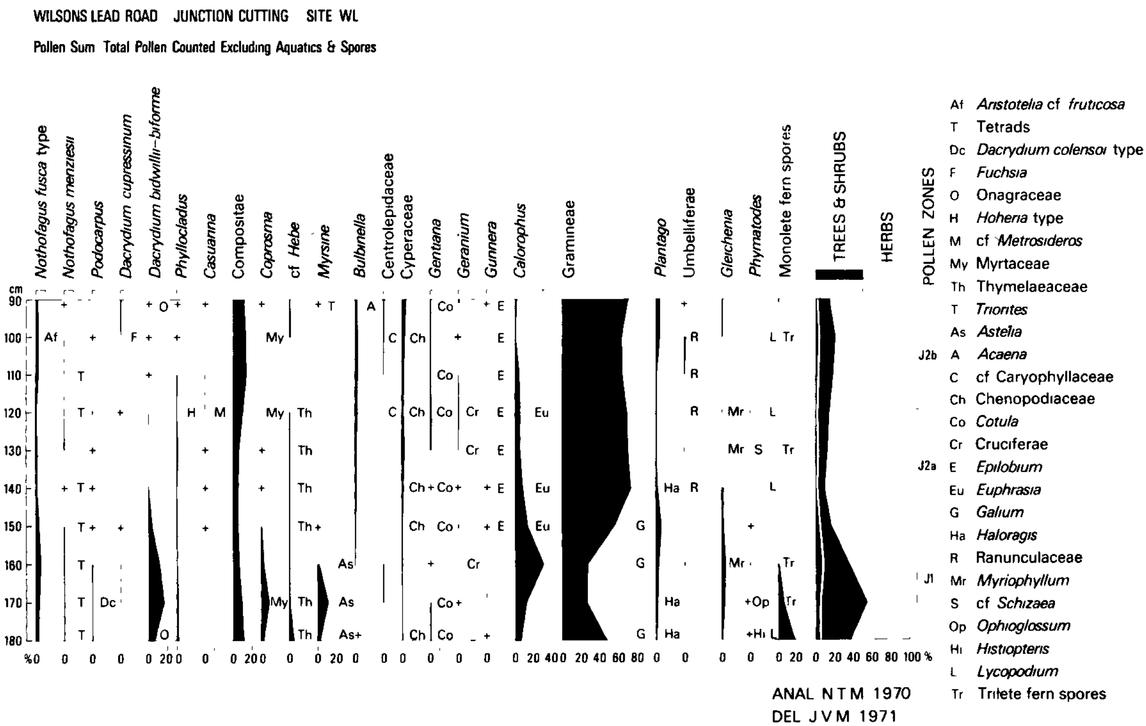

Fig. 10 Pollen diagram, late Otira Glacial, Junction Cutting (WL), Wilsons Lead Road, Westport.

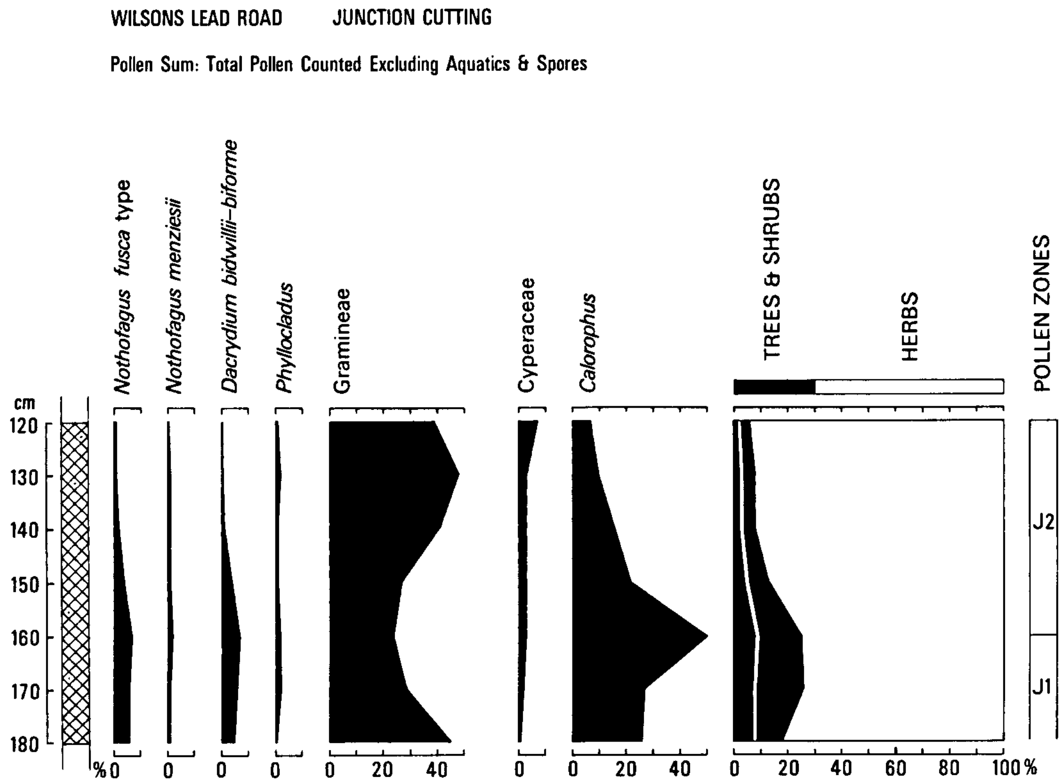

Fig. 11 Pollen diagram, late Otira Glacial, Junction Cutting (74/12), Wilsons Lead Road, Westport.

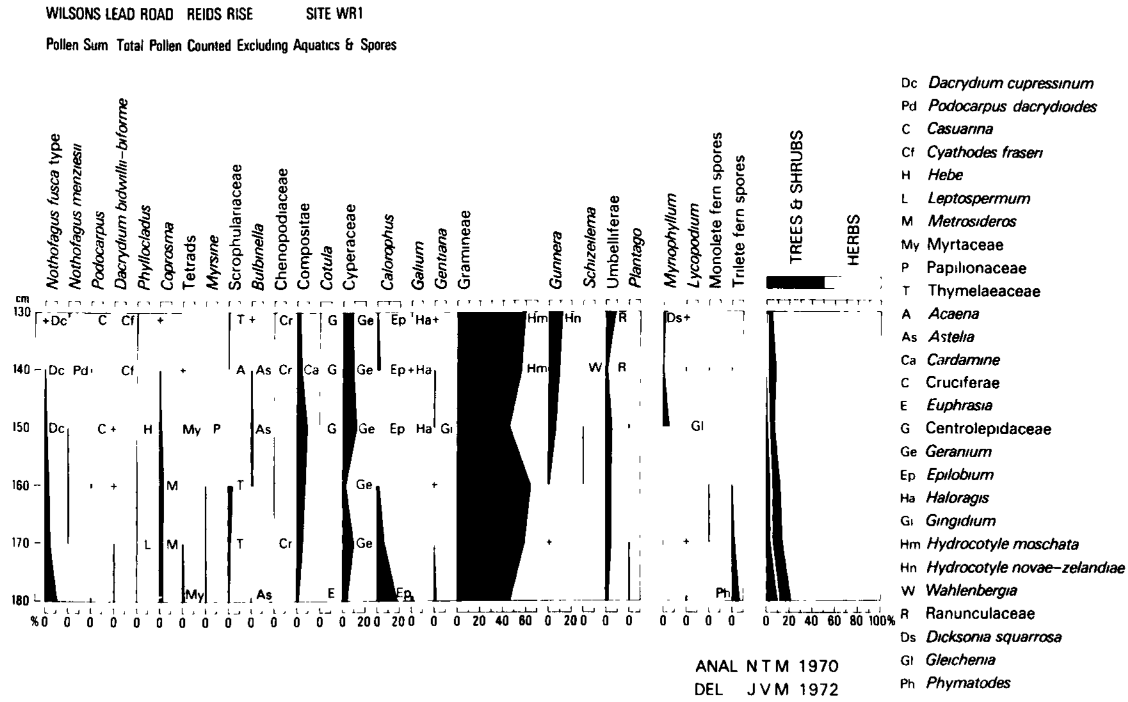

Fig. 12 Pollen diagram, late Otira Glacial, Reids Rise (WR1), Wilsons Lead Road, Westport.

The two pollen diagrams (Figs 10, 11) reflect the same trends recorded in the diagrams of the older parts of The Hill and the similarities between diagrams WL and 69/12 are especially clear. The longer diagram, WL, is sub-divided into two zones.

J1 *Dacrydium bidwillii, Coprosma, Myrsine,* 180–160 cm:
The zone is recognised by the relatively high values for shrub pollen and includes *Dacrydium bidwillii, Myrsine, Coprosma,* and pollen of the *Nothofagus fusca* type. The curve for *Calorophus* peaks at the upper boundary whereas the values for the shrub pollen fall. The *Phyllocladus* curve is continuous, but remains at very low levels.

J2 160–90 cm:
This zone, characterised by high frequencies of grass pollen, is separated into two sub-zones.

J2a Gramineae, 160–120 cm:
The Gramineae curve begins to rise at the base of the zone, reaches its highest value at 140 cm, and thereafter shows little variation. All other curves remain at low levels, but there is a general increase in the representation of herb pollen, including *Plantago, Bulbinella,* and *Gentiana.*

J2b Gramineae–Compositae, 120–90 cm:
Although the Gramineae curve remains at high levels there is a marked rise in the Compositae curve and a minor rise in the curve for *Nothofagus fusca* type pollen.

Although pollen diagram 74/12 apparently represents less time than WL similar zones are recognised (Fig. 11). In the first zone *Dacrydium bidwillii, Phyllocladus,* and *Nothofagus fusca* type pollen are important, and in the second zone, as in WL, these are poorly represented and Gramineae together with pollen of other herbaceous plants are dominant.

(d) REIDS RISE (NZMS 1 S31 : 017674, Figs 1, 12, 13)

The hill known as Reids Rise is at an altitude of 22 m (Fig. 1). The profiles examined in the road cutting have been destroyed by road works and their equivalents have not been exposed. According to van der Lingen & Andrews (1968) Reids Rise is a remnant sand body of Oturian age which was deposited along an open coast during a transgressive cycle. The organic sediments described below rested on an erosion surface and underlie sand, and in this respect they are similar to other Otiran sediments at The Hill and Junction Cutting. Two sections, WR1 and WR3, were examined in detail and their stratigraphy is described below.

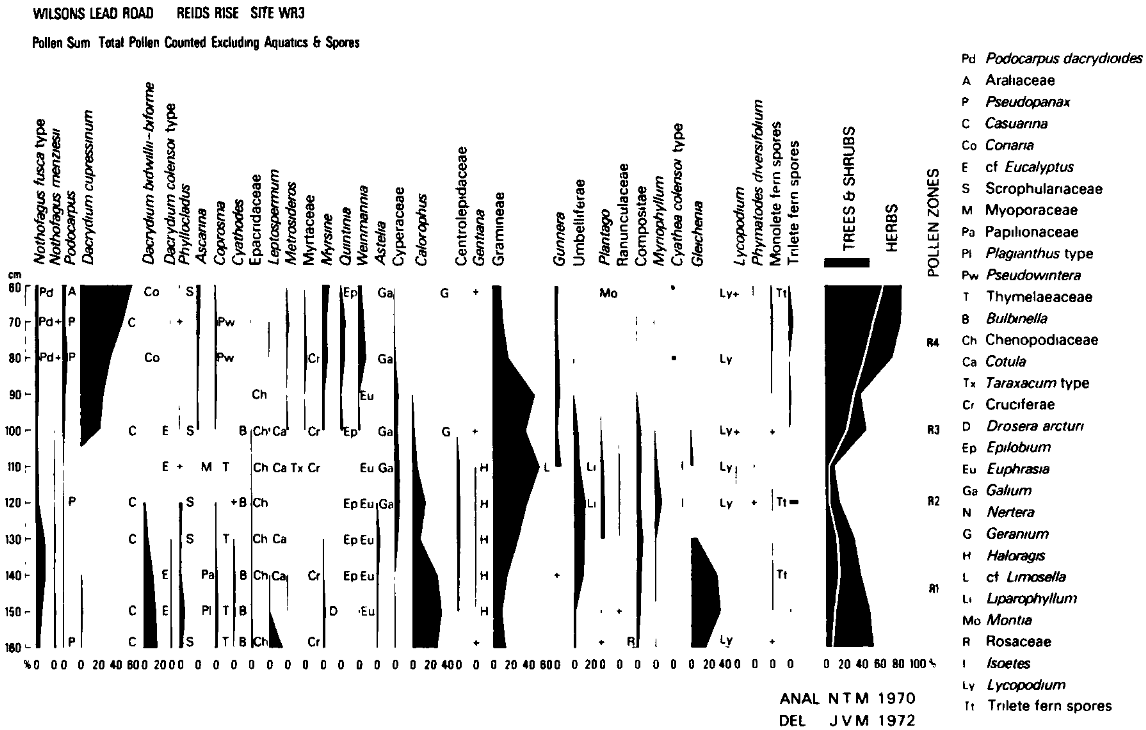

Fig. 13 Pollen diagram, late Otira Glacial and part Aranui Interglacial (post-glacial), Reids Rise (WR3), Wilsons Lead Road, Westport.

(i) *Section WR1* (Fig. 12)

cm	
0– 30	top soil;
30–128	coarse iron-stained sand;
128–159	grey organic sand;
159–175	grey clay mud;
175–198	blue-grey sandy clay;
198–203	iron pan;
203–250+	iron-stained marine sand.

Not much data are available to establish site conditions but it is clear that the accumulating organic sediments were wet and that the surface was probably flushed with water. There are no major changes in the pollen curves and no attempt has been made to zone the pollen diagram which reflects an open herbaceous vegetation equivalent to zone H2 of The Hill diagram and to zone R2 of site WR3.

(ii) *Section WR3* (Fig. 13) was located on the south-west side of the road cutting, close to an excavation made by Van der Lingen & Andrews (1968) and is described:

cm	
0– 58	top soil overlying coarse iron-stained sand;
58–123	black compressed peat;
123–165	peaty clay;
165–167	iron pan;
167–327+	blue-grey sand.

The organic layers which accumulated directly upon marine sand were dominated by a herb and shrub vegetation. The surface at first was apparently similar to modern pakihi in that *Calorophus* and *Gleichenia* were dominant and other herbs of pakihi vegetation, e.g., *Bulbinella, Drosera, Nertera, Haloragis, Liparophyllum,* and *Lycopodium,* were present. The records for *Myriophyllum* pollen suggest constantly wet surfaces with a rather wetter phase in the middle layers finally giving way to peat from which most of the plants of wetter habitats were absent. The upper boundary between peat and overlying sand is sharp, as in other sites, implying rapid deposition of sand during a marked cycle of erosion.

The pollen diagram (Fig. 13) may be divided into four zones:

R1. *Gleichenia, Calorophus, Dacrydium bidwillii*, 160–130 cm:
The upper boundary is drawn at the level, *c*. 130 cm, where the *Nothofagus fusca* type pollen curve begins to fall. At 130 cm several changes occur leading to the dominance of the herbaceous element.

R2. Gramineae, 130–110 cm:
The rising curve for Gramineae which peaks at the upper boundary and the general abundance of herbaceous elements characterise the zone.

R3. Gramineae, *Dacrydium cupressinum*, 110–90 cm:
The curve for *Dacrydium cupressinum* begins to rise and the Gramineae curve fluctuates only slightly. The pollen of several other trees enters the record at this time and includes *Ascarina, Metrosideros, Quintinia*, and *Weinmannia*.

R4. *Dacrydium cupressinum*, 90–60 cm:
The *Dacrydium cupressinum* curve rises slowly and there is a slight but significant rise of *Ascarina* and other forest tree pollen at the lower boundary. The Gramineae pollen curve falls to low levels and there is generally a marked increase in the shrub and tree element.

The rapid rise in the curves for the forest element occurs at the top of the diagram for profile 74/12 from The Hill site, and Moar & Suggate (1973) have reported a similar event from Blue Spur Road near Hokitika, 160 km to the south.

(e) OHIKANUI RIVER (NZMS 1 S31 : 193616, Table 5)

A terrace rises to *c*. 30 m on both sides of the Ohikanui River at its junction with the Buller River (Fig. 1). Most of the underlying deposits are gravels, the higher part being particularly coarse, with granite boulders up to a metre in diameter. On the roadside east of Ohikanui, finer gravel and sand *c*. 10 m from the top of the terrace includes a carbonaceous clay band *c*. 10 cm thick, from which one sample was taken for pollen analysis.

The terrace can probably be correlated with the late Otira Glacial (Speargrass Formation) terrace mapped by Nathan & Moar (1973) further up the Buller Valley and known to extend from the Black Hill moraine at Lake Rotoiti (Suggate 1965). Northeast of Inangahua, the aggradation surface of the Speargrass Formation is somewhat younger than 20 200 yr B.P. and within the time range of the $K2_2$ advance of the late Otiran Glacial (Suggate & Moar 1970).

The pollen spectrum (Table 5) is dominated by Gramineae and other herbaceous pollen.

Table 5 Pollen frequencies (percent) from the Ohikanui site. Pollen sum, total land pollen counted.

Dacrydium bidwillii/biforme	tr
Phyllocladus	tr
Podocarpus	+
Casuarina	+
Coprosma	tr
Cyathodes juniperina	tr
Metrosideros	tr
Nothofagus fusca type	6
N. brassi group	1
N. menziesii	2
Thymelaeaceae	tr
Astelia	+
Bulbinella	1
Claytonia	+
Compositae	1
Colobanthus	+
Cotula	tr
Cyperaceae	1
Cruciferae	tr
Epilobium	+
Galium	2
Geranium	tr
Gentiana	1
Gramineae	80
Haloragis	+
Kirkianella	+
Plantago	1
Ranunculus	+
R. lyallii type	+
Restionaceae	+
Umbelliferae	2
Wahlenbergia	+
Monolete fern spores	+
Ophioglossum	+

tr = <1%.
+ = noted after formal count stopped.

HISTORY OF VEGETATION

Forest sequences occur in Oturian and Aranuian sediments, shrubland occurs in Oturian and Otiran sediments, and grassland is recorded from Oturian, Otiran, and Aranuian sediments.

The forests were dominated by *Dacrydium cupressinum* or by *Nothofagus*. The *Nothofagus* forests, all recorded from Oturian sediments, reflect something of the variation in such forests today. Thus, the dominance of *Nothofagus fusca* type, together with *Metrosideros, Weinmannia, Cyathea colensoi* type, and *Dicksonia squarrosa* at Omanu Creek contrasts with the *N. menziesii* dominant forest at Waimea Creek in which *Coprosma*, Compositae, *Myrsine, Nestegis*, and *Quintinia* are variously represented (Figs 3, 4). The *Nothofagus* forests from Martins Quarry (Fig. 6) are different again and combine some of the features of those recorded at Omanu and Waimea Creeks. The high frequencies of *Myrsine* pollen, the relatively high frequencies of *N. menziesii* and *N. fusca* type pollen, and the near absence of *Dacrydium cupressinum* suggest that the Cement Works Track spectrum is equivalent to the *Myrsine–Nothofagus* phase of the Martins Quarry diagram.

The *N. fusca* type forest recorded in the uppermost part of the Waimea Creek diagram (Zone W2) is similar to that in the Omanu Creek diagram, although there are differences in detail. The differences are difficult to account for since the sites, less than 3 km apart, have a similar stratigraphy and as noted already (p. 364) need not differ much in age. On the other hand, the differences between the pollen diagrams could be reconciled if the Omanu Creek diagram was correlated with the *N. fusca* phase in the uppermost part of the Waimea Creek diagram. On palynological evidence, therefore, the Omanu Creek site may be younger but because its sediments accumulated rapidly the time involved need not be great. Because conflict between stratigraphic and palynologic interpretation is possible, the relative positioning of the Omanu Creek site is tentative (Fig. 14).

The podocarp forests were dominated by *Dacrydium cupressinum*. The younger Oturian forests, represented by the Martins Quarry site, were well established before peat accumulation began, and apparently were similar to forests in existence today. However, the presence of *Nestegis* and the absence of *Ascarina* provide a clear distinction between the Oturian and Aranuian forests, which is heightened by the relatively greater importance of *Metrosideros* in the Oturian forest. The two sand quarry spectra (Table 3) are considered a part of the younger Oturi podocarp-forest phase although certain genera, e.g., *Metrosideros* and *Weinmannia*, are absent.

The Oturian sequence represents the end, and the Aranuian sequence the beginning, of two separate podocarp forest phases, which explains some of the differences. However, the presence of *Nestegis* in Oturian sediments cannot be explained in terms of youth or senescence and, rather, is an expression of a difference between two similar forests separated in time by the Otira Glaciation. *Nestegis* was relatively abundant in the Westport area during the Oturian, in contrast to to its present distribution, the nearest known localities being 100 km north in Tasman Bay.

Few pollen diagrams from Oturian sites are available for comparison. The Sardine Terrace diagram from South Westland (Moar 1975) may reflect warming after the mid-Oturi stadial, whereas the Sunday Creek diagram (Dickson 1972) illustrates the Oturi/Otira transition. Dickson also commented on the pollen spectra of two samples collected near Schultz Creek (NZMS 1 S44 : 789031, Suggate 1965), 36 km to the north of Sunday Creek and 124 km south of Westport. The younger sample (S44/853) is similar to the *Nothofagus* dominated spectra in the Sunday Creek sequence, but the older sample (S44/852), dominated by *Metrosideros* pollen and containing *Ascarina* pollen, may have been closer to the Oturian maximum.

Although *Metrosideros* is dominant in sample S44/852, the pollen spectrum differs from the *Metrosideros* phase of Sardine Terrace, from which *Ascarina* and *Dacrydium cupressinum* are absent and *Nothofagus fusca* type pollen scarce. It is also possible that the Omanu Creek and Waimea Creek sequences together illustrate a succession from *N. menziesii* to *N. fusca* type forests, but, until more sites with good stratigraphic control are available for study, the relationship of these sites to each other remains obscure.

Post-glacial *D. cupressinum* forests are illustrated in pollen diagrams from The Hill and Reids Rise (Figs 9, 13). There is a rapid transition from grassland to forest as at Blue Spur Road 160 km to the south (Moar & Suggate 1973) although there, in addition to grassland, *Nothofagus* is an important element of the early Aranuian vegetation. These forests, with *Metrosideros, Ascarina, Weinmannia,* and *Quintinia*, are similar to early Aranuian forests from other sites in Westland (Moar 1971, 1973b).

Nothofagus played a minor role in the forest in the early Aranuian and later increased to its present importance. There is no pollen diagram from the Westport area recording this change, but surface samples, from nearby areas, dominated by *Nothofagus* pollen (Table 1) provide spectra representative of present vegetation which may not be characteristic of the virgin forest because of selective logging in the area. Although analogies between Aranuian and Oturian vegetation should not be drawn too closely, at Martins Quarry there is evidently a succession from *D. cupressinum*, through dominant *Nothofagus*, to mixed forest dominated by *N. fusca* type beeches.

Shrubland, in its various forms, is represented in all Otiran sites and in the lower part of the Cape Foulwind mid-Oturian site. During the Otiran shrubland phase *Phyllocladus* and *Dacrydium bidwillii* were prominent and together with *Coprosma, Leptospermum,* and *Myrsine*, amongst others, were part of the regional vegetation. Herbaceous plants are variously represented and local factors may have determined the particular character of vegetation at various sites. The overall impression is of a mosaic of shrubland and grassland, and variations of these, in which there were peaty areas with shallow pools of water and wet hollows, as judged by records of *Myriophyllum, Calorophus,* and *Liparophyllum* pollen. *Nothofagus fusca* type pollen was relatively abundant and may have been derived from stands of *Nothofagus* persisting in sheltered situations as is believed to have occurred in inland areas of mid-Canterbury during the late Otiran and early Aranuian (Moar 1971).

Shrubland of this type is not well documented in the historical record west of the Main Divide in the

South Island. It is not significant in any late Otiran (<20 000 yr B.P.) or early Aranuian site in the Westport area, but at Blue Spur Road, Hokitika, it was locally important during the mid-Otiran *c.* 30 000 years ago (Moar & Suggate 1973) and it is recorded at Crooked Mary Creek, Upper Grey River, *c.* 10 000 years ago (Moar 1971). Unlike the early Aranuian shrubland of inland Canterbury, where *Phyllocladus* succeeded *Dacrydium* (Moar 1971, Lintott & Burrows 1973), the two genera in the Westport area occurred together and grasses and other plants of wet and open sites were generally more common.

The shrubland vegetation during the middle Oturi, represented at the Cape Foulwind site, is generally similar to the Otiran communities discussed above. The most important difference lies in the overwhelming dominance of *Leptospermum* in the later phase of development. Although all the woody plants recorded were probably part of both the local and regional vegetation it is difficult to avoid the conclusion that *Leptospermum* was locally very abundant. If *Leptospermum* is excluded from the pollen sum, *Nothofagus* begins to increase upwards from about the 8 cm level (Table 2). There is no evidence that *Nothofagus* was important in the area at this time and it probably occurred in small, isolated communities then as it did during the Otiran.

Grassland, or grassland-shrubland, formed the regional vegetation during the late Otiran, the early Aranuian, and the mid-Oturian phase at Cape Foulwind. Many of the plants recorded generally prefer damp situations and many of them tend to be best represented in montane or sub-alpine grassland, herbfield, or bog, but some, e.g., *Liparophyllum, Bulbinella,* and *Astelia,* are commonest in the lowlands. It is possible, therefore, to compare these glacial and early post-glacial plant communities with existing pakihi, but the comparison must not be drawn too closely.

The "natural" pakihi, described by Rigg (1962), has a limited flora in contrast to the open herbaceous vegetation of 20 000–12 000 years ago. Thus, Chenopodiaceae, *Cotula, Drosera arcturi, Epilobium, Gunnera, Hydrocotyle, Schizeilema, Oreomyrrhis, Plantago, Stellaria,* and *Tillaea,* all represented in the early communities, are absent from the Westport pakihi of today. *Mitrasacme,* a plant of montane to sub-alpine herbfield, is represented and grasses, only poorly represented today, were more important than Cyperaceae. It is apparent that the herbaceous vegetation in the area studied was richer, and more diverse than it is now. Apparently grassland was dominant, and within the grassland there existed a mosaic of communities controlled by local factors of soil, drainage, and aspect. The woody element increased slightly, as in Zone H2b, but not enough to dispel the impression of a grassland which persisted for thousands of years.

CLIMATIC INFERENCE

Since the available sites do not offer an uninterrupted sequence, climatic inferences must refer only to parts of the Oturian, Otiran, and Aranuian. The pollen spectra from Omanu Creek suggest relatively stable vegetation and, by implication, a relatively stable environment. The presence of beeches of the *Nothofagus fusca* type, of *Metrosideros* and *Weinmannia,* together with *Pseudopanax, Pseudowintera, Elaeocarpus,* and some *Ascarina,* imply temperate rain forest conditions. The genera present generally range from sea level to *c.* 750–900 m, representing a range from lowland to lower sub-alpine conditions (Wardle 1964). The virtual absence of podocarp forest and the high frequencies of *Weinmannia, Cyathea* (probably *C. smithii*), and the infrequent occurrence of *Nothofagus menziesii* suggest that the forest was growing under similar conditions to those of the mid altitude, montane rain forests near Westport today. According to Wardle (1964) *Weinmannia racemosa* is at its extreme upper limit at the lower boundary of the sub-alpine zone.

The possibly slightly older sediments of Waimea Creek also suggest a period of relatively stable forests dominated by *Nothofagus menziesii* until its replacement by *N. fusca* type beech. The presence of dominant *N. menziesii,* together with other forest trees, implies heavy precipitation, probably heavier than at Omanu Creek.

Although *N. menziesii* is often characteristic of sub-alpine forests, the associates recorded in the pollen spectra, including *Quintinia* and *Nestegis,* imply similarities with montane beech forests in the Nelson area. *Nestegis* is not known to occur on the West Coast of the South Island and neither this genus, nor *Quintinia,* extends into the sub-alpine zone. The impression then is that cool and wet conditions prevailed. A marked increase in the ratio *N. menziesii–N. fusca* type pollen between 30 and 60 cm at Waimea Creek may imply a further temporary cooling in favour of *N. menziesii,* but subsequently, judged by the rapid increase in *N. fusca* type beeches, the decline of herbaceous elements and the increase in *Nestegis, Quintinia,* and the more consistent occurrence of other small trees and shrubs, conditions became slightly warmer, but not necessarily drier.

There is no record of the transition from forest to shrubland at the end of the first sub-cycle of the Oturi Interglacial or of the transition from shrubland to forest at the beginning of the second sub-cycle. The shrubland–grassland vegetation recorded from the Cape Foulwind site, inferred from the high values for shrub and herb pollen, indicates a cold climate although the gradual increase in beech pollen towards the top of the diagram may record a slow warming. There is little doubt, however, that this period was much colder than the preceding forest phase.

Warming to temperate conditions at some stage not yet recorded reached its optimum in the *Dacrydium cupressinum* phase seen in the lower part of the Martins Quarry pollen diagram. The presence of podocarps and other minor hardwoods suggests mild equable conditions with abundant precipitation. The change to *Nothofagus*-dominated forests, including *N. menziesii*, does not suggest any change in effective precipitation, but rather a cooling, also expressed by an increase in open areas involving wetlands, shrublands, and fernland. The continued presence of *D. cupressinum* in the region, and the expansion of *Podocarpus dacrydioides*, together with a return of small hardwood trees at *c.* 100 cm, may imply slight warming, with little or no change in precipitation. The Sand Quarry samples and the Cement Works Track sample are slightly older, but fit the warming sequence and need no further explanation.

The Otiran climate was generally much more rigorous than that of the preceding interglacial. There are no data yet for the earliest Otiran from Westport, but it is clear from Sunday Creek (Dickson 1972) near Hokitika, 160 km to the south, that the Oturian–Otiran transition was characterised by a marked, and apparently rapid, cooling severe enough to cause grassland to replace forest.

The subsequent record is not known until it begins again with the mid-Otiran shrubland recorded at Wilsons Lead Road. Mid-Otiran forests at Hokitika (Moar & Suggate 1973) would demand summer warmth of over 10°c (Zotov 1938, Wardle 1965) and the shrubland at Wilsons Lead Road may have been as demanding. However, hardy ecotypes of *Phyllocladus alpinus* are more frost resistant than *Nothofagus solandri* var. *cliffortioides*, but less resistant than *Dacrydium bidwillii* (Wardle & Campbell 1976). The temperature regime at Westport must have been more extreme than at Hokitika and much more subject to frost. Precipitation may never have been critical, and falling temperatures in a high-rainfall area may have been the necessary factor to initiate peat formation over a wide area in hollows and old stream or river channels.

The relatively mild interstadial was followed by climatic conditions severe enough to maintain grassland for thousands of years. This long period was relieved by a slight warming which resulted in some increase in density of the vegetation and a modest increase in woody plants (Zone H2b, Fig. 9). The break in peat accumulation in The Hill profile, 74/4, (Fig. 8) may well be a consequence of local erosion and unrelated to regional climatic factors, particularly as there is no similar break in profile WR3 at Reids Rise (Fig. 13).

According to present evidence the severe climatic conditions of the Late Otiran were followed by a rapid amelioration which led to the spread of podocarp forest *(Dacrydium cupressinum)* about 12 000 years ago. The character of the forest that developed, containing such trees as *D. cupressinum, Ascarina, Metrosideros, Weinmannia,* and *Quintinia,* implies abundant precipitation and mild, equable temperatures, not much different from the present.

CHRONOLOGY

The timing of events can be determined only partly by radiocarbon assay (Table 6). Thus, the sediments assigned to the Oturi Interglacial have been so placed on the basis of geological criteria and are considered to be beyond the range of radiocarbon dating. Finite and infinite dates ranging from 32 600 yr B.P. to over 46 800 yr B.P. have been reported from the Cape Foulwind site (Grant-Taylor & Rafter 1971) and a similar range of dates has been reported from Sunday Creek, Hokitika (Dickson 1972) and from Ship Creek, south Westland (Nathan 1975); the finite dates are judged to result from contamination by younger carbon.

Radiocarbon dates suggest that Martins Quarry is an Otiran site (peat at 167–177 cm, NZ 2708 33 000 ± 1900 yr B.P.; *Dacrydium cupressinum* wood at 220 cm, NZ 2709 37 100 $^{+2300}_{-1800}$ yr B.P.) but on stratigraphic grounds this is improbable. It is therefore considered that these samples too have been contaminated by younger carbon and a late Oturi Interglacial age is the most probable.

Ages of Virgin Flat and Waites Formation

No radiometric dating is available for the deposits assigned to the Oturi Interglacial; it is known only that they are beyond the range of radiocarbon dating — over 50 000 years old judged by the Sunday Creek peat determinations (Dickson 1972). The two-fold division into Virgin Flat and Waites Formation, comparable with the two-fold division in the Hokitika area (where the Sunday Creek peat sequence rests on the younger division (Suggate 1965)), is accepted as resulting from two main periods of rising and high sea level, although the possibility of only one period being represented, with tectonic uplift causing the separation into two, cannot be ruled out.

Between 50 000 and 140 000 years ago there was a series of relatively high sea levels, all of which are likely to be adequately recorded only in regions with very high uplift rates, such as New Guinea (Chappell 1974). Stearns (1976), in his discussion of the problems associated with estimation of absolute and relative sea levels in this period, accepted the New Guinea data, together with data from Barbados (Broecker *et al.* 1968) and from Hawaii (Ku *et al.* 1974), as indicating successive sea level maxima. However, he questioned previous values as to the relative heights of these maxima. He suggested values that he considered to be "closer":

Table 6 Radiocarbon dates from sites in the Westport area. See Fig. 7 for location of The Hill samples.

Site	Material	NZ No.	Date, yr B.P.
Cape Foulwind (Grant-Taylor & Rafter 1971)	Wood	732	42 400 ±3400
	Peat	733	>46 800
	Peat	1086	34 100 ± 1200
	Peat	1087	>49 000
	Wood	1088	32 600 ± 1450
	Wood	1089	38 600 ± 1000
	Pretreated wood	1090	35 000 ± 1350
	Pretreated wood	1091	37 400 ±2450
	Pretreated wood	1092	39 700 ± 1300
Martins Quarry	Wood	2709	37 100 $\pm^{2300}_{1800}$
	Peat	2708	33 300 ± 1900
The Hill (74/4)	Organic clay	3168	31 600 $\pm^{1700}_{1500}$
	Sandy peat	3169	15 950 ± 350
	Peat	4047	17 950 ± 250
	Peat	4046	18 650 ± 250
	Organic sand	4409	12 200 ± 200
The Hill (69/12)	Peat	1675	19 100 ± 400
The Hill (not associated with pollen diagram)	Peat	1753	18 900 ± 400
	Peat, treated NaOH	1753	17 800 ± 500
	Peat, treated HCl	1753	19 900 ± 400
	Peat	1617	30 700 ± 1300
	Wood	1618	38 300 ±3300
	Organic sand [1]	3986	7 790 ± 110

[1]T. L. Grant-Taylor in litt.

Age of sea level maximum		*Height differences (m) from 125 000 yr max.* Stearns (1976)	Matthews (1973)
134 000 / 118 000	Commonly known only as 125 000	0	0
103 000		−8	−21
82 000		−6	−19
60 000		−21	−34

The question of the height of the 125 000-yr sea level relative to that of the present was not critical to Stearns' argument or to that of Broecker *et al.* (1968) who, followed by Matthews (1973), accepted it as + 6 m. Stearns (1976) pointed out that "... best estimates will come from coasts with low average rates of uplift", and although the rate in the Westport area is moderate (*c.* 0.3 m/1000 yr) rather than low, Stearns' and Matthews' values are useful in trying to judge the ages of the Virgin Flat and Waites Formations.

Their altitudes are:

Virgin Flat Formation: Westport, 40 m; Hokitika, 55 m.

Waites Formation: Westport, 30 m; Hokitika, 45 m.

The following points help one to judge the likely age of the two formations:

(i) Both formations are assigned to one (Oturi) interglacial period because, where the relations of glaciations to marine cliffs and deposits are clear in the Hokitika area, a glaciation (Waimea) is known to have preceded the earlier cliff and none is known or inferred between the formation of the two cliffs and associated marine deposits (Suggate 1965).

(ii) Transition from interglacial to Otira glacial conditions is known from the Sunday Creek peat (over 50 000 years old) that rests on the younger marine deposits (Dickson 1972).

(iii) The altitude difference between the older and younger marine deposits is 10 m, so that as the region is one of uplift, the actual sea level difference will have been <10 m; this rules out the 60 000-yr level for the Waites Formation.

(iv) One factor affecting the likelihood of a preservation of a marine terrace deposit and its associated cliff is the capability for their destruction during a younger high sea level, so that younger ones have a rather greater probability of being preserved than the older ones; the greatest probability is that the Waites Formation represents the 82 000-yr high sea level which, having been

Table 7 Published radiocarbon dates of late Otiran sites, all dominated by grassland vegetation, from northern South Island.

Site (Grid ref.: NZMS 1)	Reference	Radiocarbon date	
		NZ No.	Date, yr B.P.
Kamaka (S44:901909)	Suggate 1965	116	22 300 ±350
Totara Flat (S45:081039)	Suggate & Moar 1970	891 737	18 600 ±290 18 750 ±180
Pensini Creek (S32:471695)	Nathan & Moar 1973	1154	20 200 ±300
Buller Bridge gravel pit (S26:056786)	Suggate 1973[1]	1254	18 100 ±370
Station Creek (S26:063788)	Suggate 1965	444	16 600 ±390
Handysides Stream (S54:037723)	Suggate 1965	532	14 100 ±220
Wroxham (S62:362260)	Suggate 1965	706	20 900 ±260

[1]In "Guidebook for Excursion 5" IX INQUA Congress, Christchurch. Ed. R. P. Suggate.

higher than that of 103 000 yr, could well have destroyed evidence of the older one.

(v) Comparably, a 118 000-yr high sea level could have destroyed evidence of a 134 000-yr level.

It is not justified to assume a uniform rate of uplift throughout the whole period to the present day. This can be exemplified by the height of the post-glacial (*c*. 5000 yr) bench along the coast, which varies from *c*. 7 m in the Hokitika area to 9 m at Greymouth and 3 m at Westport, without any proportional differences in the Oturi interglacial terraces which generally decline northwards by 10–15 m. Nor is it possible, by assuming constant rates of uplift, and using either Matthews' or Stearns' heights, to calculate altitudes that clearly indicate which high sea levels are represented by the Waites Formation. However, it should be noted that if Matthews' values are applied to the Westport–Hokitika region, the Waites Formation would be more uplifted than the older Virgin Flat; this is not necessary with Stearns' values.

Accordingly it is assumed that the Virgin Flat Formation represents the 118 000-yr high sea level and the Waites Formation the 82 000-yr level.

Ages of Otiran and Aranuian Sites

The ages for the late Otiran and Aranuian sites are generally all within the range of the radiocarbon method, are internally consistent, and, with the possible exception of the oldest dates, are accepted as being approximately accurate (Table 6). It is unfortunate that not all dated Otiran samples have been subjected to pollen analysis and that the profiles from which some samples were obtained have been destroyed. However, comparison with pollen diagrams and field data makes correlation of most samples possible. Thus, there is good correlation between The Hill samples NZ 4046 (18 650 ±250 yr B.P., 74/4), NZ 1675 (19 100 ± 400 yr B.P., 69/12), and NZ 1753 (18 900 ± 400 yr B.P.); treatment with NaOH and HCl does not materially affect the dates (Table 6).

There is a discrepancy in the dates for peat (NZ 1617, 30 700 ±1300 yr B.P.) and wood (NZ 1618, 38 300 ±3300 yr B.P. collected at the same level near the base of a profile, now destroyed, at The Hill site some metres west of 74/4 (Fig. 7). The wood date is so old that it could have resulted from very minor contamination of undateable material and if so the peat date may also be unreliable. However, the peat date is similar to that from profile 74/4 (NZ 3168 $31\ 600\pm^{1700}_{1500}$ yr B.P.), and the similarity of the dates suggests that the two samples are coeval and perhaps not much affected by contamination. The tree or shrub from which the wood sample was taken may have been rooted in the underlying Oturi sands which could account for the difference in age between the wood and the peat. On present evidence, particularly using dates from Blue Spur Road, it is considered that the mid-Otiran interstadial ended *c*. 26 000 years ago and peat accumulation began earlier than 31 000 years ago.

At Wilsons Lead Road grassland was dominant from *c*. 26 000 yr B.P. until the post-glacial spread of forest *c*. 12 000 yr B.P. When judged by other late Otiran sites, a grassland phase lasting thousands of years occurred in many parts of central and northern South Island (Table 7). The available data clearly place the Ohikanui section (p. 379) within this period and on stratigraphical grounds within the range of the later Kumara 2 ($K2_2$) advance.

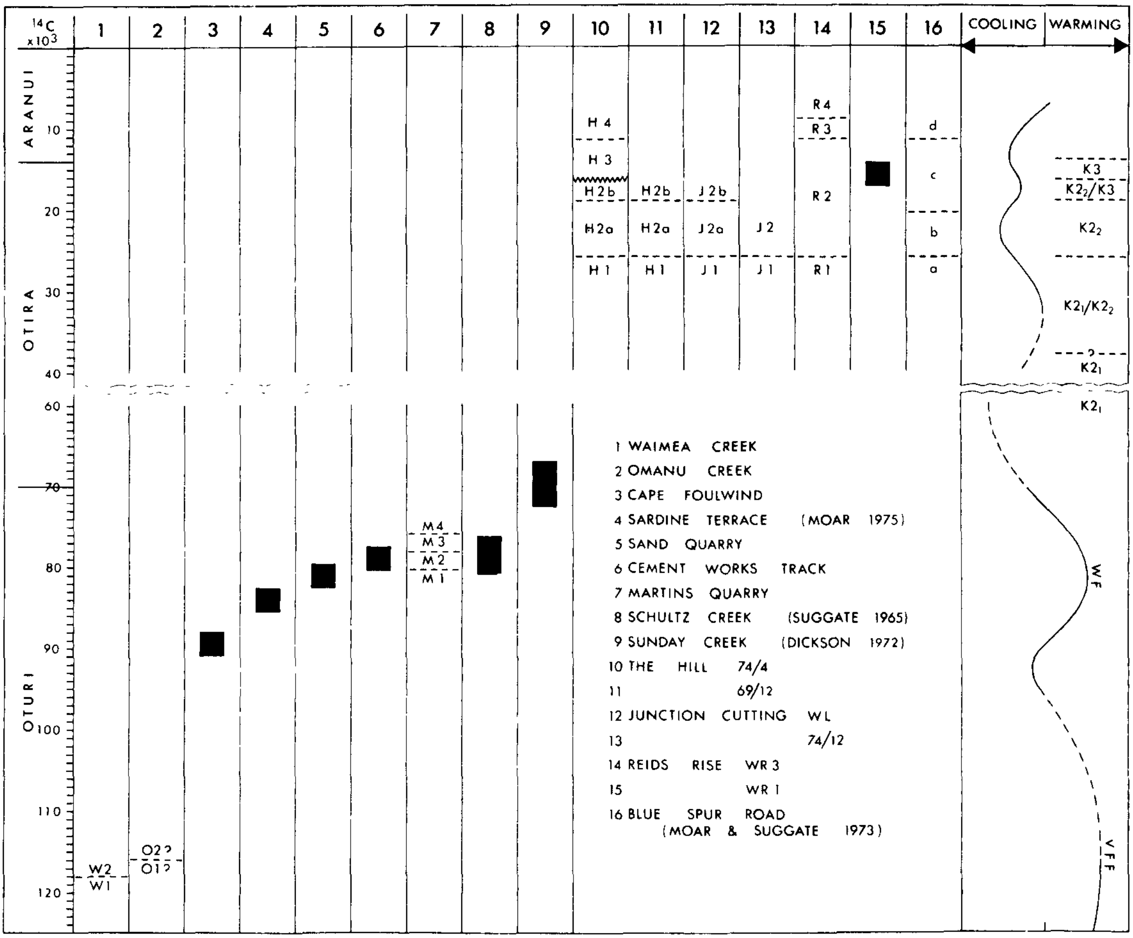

Fig. 14 Correlation of sites in Westport area and in Westland. The curve at the right indicates warming and cooling trends and is based on data presented here. The broken line is an assumed trend not supported by fact and is staggered at the break between 40 000 and 60 000 yr B.P. to avoid the inference that there was no early Otiran interstade.
K = Kumara, WF = Waites Formation, VFF = Virgin Flat Formation.

The spread of Aranuian forest began slightly later than 12 000 yr B.P. and therefore earlier than in any South Island district so far studied. Podocarp forest at Bell Hill, 30 km inland from Greymouth, spread *c.* 9000 yr B.P. (Moar 1971), at Springs Junction, 16 km from Lewis Pass, earlier than 9800 yr B.P. (Moar loc.cit.), at Gillespies Beach, South Westland, later than 11 700 yr B.P. (Moar 1973b), and *c.* 10 000 yr B.P. in Otago (McIntyre & McKellar 1970). Although the timing at Westport is early for the South Island, *Dacrydium cupressinum* was already well established 12 000 years ago in the Tongariro region, North Island (McGlone & Topping 1973, 1977). Because data are so scanty there is clearly need for more detailed investigation, with radiocarbon control, of early Aranuian vegetation in north-west South Island.

CORRELATION OF SITES

Although the relationships of the various sites discussed have been briefly indicated an attempt at a more detailed correlation is desirable. Because of the limitations of radiocarbon assay only the Otiran and Aranuian sites are dated securely and that depends mainly on dates from The Hill profile, 74/4. Correlation between sites therefore depends largely on bio-stratigraphic data and on the assumption that similar events recorded in sites close to each other will be more or less synchronous (Fig. 14).

The Oturian sites fall into three groups. The Omanu and Waimea Creek sites are included within the early Oturian Virgin Flat Formation, the Cape Foulwind site at the base of the Waites Formation, the Sand Quarry and the Cement Works Track sites within Waites Formation, and Martins Quarry near the upper boundary of Waites Formation. Of the two early Oturian sites, Waimea Creek may be younger than the Omanu Creek site since it is closer to the aggradation surface of the Virgin Flat Formation. As has been pointed out already, however, the pollen diagrams indicate that the sites can be slightly different in age only if they represent overlapping phases in a period of transition. If this is so, the Omanu Creek site may be the younger and the sequence illustrated by combining both sites represents a slight upward warming.

There are no data for comparison with the Cape Foulwind site which is placed between the older and younger Oturian sites. The Sand Quarry and Cement Works Track sites are correlated with Waites Formation and are coeval with the deposits in Martins Quarry. According to Nathan (1975) the Sardine 2 Terrace of south Westland is a correlative of the younger Oturian (Waites Formation) terrace at Westport, so that the Ship Creek and the Martins Quarry pollen diagrams represent events within the same period. The diagrams are dissimilar, but if the Ship Creek diagram implies warming during the early stages of the sub-cycle (Moar 1975) and the Martins Quarry diagram (Fig. 6) a trend away from the optimum, then the differences can be reconciled. The Schultz Creek samples (Dickson 1972), containing about equal amounts of *Nothofagus, Dacrydium cupressinum,* and *Metrosideros* pollen, are correlated with zones M2 and M3 of Martins Quarry.

The Sunday Creek site represents the transition from the Oturi Interglacial to the Otira Glacial. There then follows a long interval for which there is no information until the middle Otiran interstade from Wilsons Lead Road and Blue Spur Road. The suggested correlations for this and later periods are indicated in Fig. 14 and when all sites are taken into account there is a continuous series of events from the mid-Otiran through into the mid-Aranuian. The Blue Spur Road diagram (Moar & Suggate 1973) correlates reasonably well with the Westport data although transitions are not marked and the general impression is of gradual cooling until the post-glacial spread of forest.

In the sequences discussed here the period between *c.* 26 000 and *c.* 12 000 yr B.P. shows only minor changes and the early Aranuian shrubland of other South Island sites is absent. Thus, comparison in terms of vegetation succession and climate is not always clear and further work is needed to understand these differences; at Wilsons Lead Road the coastal situation may have been significant.

The late Otiran sequence compares fairly well with the principal glacial advances and retreats inferred by Suggate (1965). The $K2_1/K2_2$ interstade and the $K2_2$ stade are clearly represented, but there is no great change in the interval between this period and the early Aranuian. However, the minor changes apparent have been used to indicate the $K2_2/K3$ interstade and the K3 stade (Fig. 14).

CONCLUSION

The data presented offer some insight into the vegetation and climate history of the Westport area since the Oturi Interglacial. They provide a basis for future work and emphasise the complexity of vegetation patterns throughout the period under review. The presence of *Nestegis* pollen during the milder phases of the Oturi Interglacial provides a means of distinguishing Oturian from Aranuian sediments.

Suggate & Moar (1970) concluded that the later Kumara 2 ($K2_2$) glacial advance began before 22 300 yr B.P. and that it ended *c.* 18 000 yr B.P. The Wilsons Lead Road data confirm this conclusion and provide reasons for supposing that the $K2_1/K2_2$ interstade began before 31 600 yr B.P. and ended *c.* 26 000 yr B.P. The effects of the glacial advances and retreats of Kumara 3 time and the early Aranuian are not so clearly recognised although there are changes in the pollen diagrams which may imply minor climatic shifts associated with the distant glaciers.

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REFERENCES

ALLAN, H. H. 1961: "Flora of New Zealand". Vol. I. Government Printer, Wellington. 1085 pp.

BOWEN, F. E. 1964: Sheet 15, Buller. (1st edition) "Geological map of New Zealand, 1: 250 000". DSIR, Wellington, New Zealand.

BROECKER, W. S.; THURBER, D. L.; GODDARD, J.; KU, T. L.; MATTHEWS, R. K.; MESOLELLA, K. J. 1968: Milankovich hypothesis supported by precise dating of coral reefs and deep-sea sediments. *Science 159:* 297–300.

CHAPPELL, J. 1974: Geology of coral terraces, Huon Peninsula, New Guinea: A study of Quaternary tectonic movements and sea-level changes. *Geological Society of America Bulletin 85:* 553–70.

DICKSON, MICHELE 1972: Palynology of a late Oturi Interglacial and early Otira Glacial sequence from Sunday Creek (S51), Westland, New Zealand. *N.Z. Journal of Geology and Geophysics 15:* 590–8.

GRANT-TAYLOR, T. L.; RAFTER, T. A. 1971: New Zealand radiocarbon age measurements — 6. Ibid. *14:* 364–402.

HOLLOWAY, JOHN T. 1954: Forests and climates in the South Island of New Zealand. *Transactions of the Royal Society of New Zealand 82:* 329–410.

KU, TEH-LUNG; KIMMEL, MARGARET A.; EASTON, WILLIAM H.; O'NEIL, THOMAS J. 1974: Eustatic sea level 120 000 years ago on Oahu, Hawaii. *Science 183:* 959–62.

LINTOTT, W. H.; BURROWS, C. J. 1973: A pollen diagram and macro-fossils from Kettlehole Bog, Cass, South Island, New Zealand. *N.Z. Journal of Botany 11:* 269–82.

MCGLONE, M. S.; TOPPING, W. W. 1973: Late Otiran/early Aranuian vegetation in the Tongariro area, central North Island, New Zealand. Ibid. *11:* 283–90.

———1977: Aranuian (post-glacial) pollen diagrams from the Tongariro region, North Island, New Zealand. Ibid. *15:* 749–60.

MCINTYRE, D. J.; MCKELLAR, I. C. 1970: A radiocarbon dated post glacial pollen profile from Swampy Hill, Dunedin, New Zealand. *N.Z. Journal of Geology and Geophysics 13:* 346–9.

MCPHERSON, R. I. 1967: Westport Ilmenite deposits. *N.Z. Department of Scientific and Industrial Research Geological Survey Report 21.*

MATTHEWS, R. K. 1973: Relative elevation of Late Pleistocene high sea level stands: Barbados uplift rates and their implications. *Quaternary Research 3:* 147–53.

MOAR, N. T. 1971: Contributions to the Quaternary history of the New Zealand flora 6. Aranuian pollen diagrams from Canterbury, Nelson, and north Westland, South Island. *N.Z. Journal of Botany 9:* 80–145.

———1973a: Late Pleistocene vegetation and environment in southern New Zealand. *In* Bakker, E. M. van Zinderen (Ed.) "Palaeoecology of Africa and of the Surrounding Islands and Antarctica". Vol. 8 Balkema, Cape Town. Pp. 179–98.

———1973b: Contributions to the Quaternary history of the New Zealand flora 7. Two Aranuian pollen diagrams from central South Island. *N.Z. Journal of Botany 11:* 291–304.

———1975: Pollen analyses from the Sardine Terraces. *In* Nathan, Simon. Late Quaternary terraces between Ship Creek and the Whakapohai River, South Westland, New Zealand. *Journal of the Royal Society of New Zealand 5:* 313–27.

MOAR, N. T.; GAGE, MAXWELL 1973: Interglacial deposits in Joyces Stream (S74), Waimakariri Valley, Canterbury. *N.Z. Journal of Geology and Geophysics 16:* 321–31.

MOAR, N. T.; SUGGATE, R. P. 1973: Pollen analysis of late Otiran and Aranuian sediments at Blue Spur Road (S51), north Westland. Ibid. *16:* 333–44.

MOORE, LUCY B.; EDGAR, ELIZABETH 1970: "Flora of New Zealand". Vol. II. Government Printer, Wellington. 354 pp.

NATHAN, SIMON 1975: Late Quaternary terraces between Ship Creek and the Whakapohai River, South Westland, New Zealand. *Journal of the Royal Society of New Zealand 5:* 313–27.

———1976: Sheet S23/9 and S24/7 Foulwind and Westport (1st edition). "Geological map of New Zealand 1: 25 000". DSIR, Wellington, New Zealand.

NATHAN, SIMON; MOAR, N. T. 1973: Age and correlation of late Quaternary terraces in the lower Inangahua Valley, West Coast, South Island, New Zealand. *Journal of the Royal Society of New Zealand 3:* 409–14.

NEW ZEALAND METEOROLOGICAL SERVICE 1973: Summary of climatological observations to 1970. Government Printer, Wellington, New Zealand.

RIGG, HELEN H. 1962: The pakihi bogs of Westport, New Zealand. *Transactions of the Royal Society of New Zealand (Botany) 1:* 91–108.

STEARNS, C. E. 1976: Estimates of the position of sea level between 140 000 and 75 000 years ago. *Quaternary Research 6:* 445–9.

SUGGATE, R. P. 1965: Late Pleistocene geology of the northern part of the South Island, New Zealand. *N.Z. Department of Scientific and Industrial Research Geological Survey Bulletin n.s. 77:*1–91.

SUGGATE, R. P.; MOAR, N. T. 1970: Revision of the chronology of the late Otira Glacial. *N.Z. Journal of Geology and Geophysics 13:* 742–6.

VAN DER LINGEN, G. J.; ANDREWS, PETER B. 1968: Grain size parameters and sedimentary structures of a last interglacial marine sand body, near Westport, New Zealand. *N.Z. Journal of Marine and Freshwater Research 2:* 447–71.

WARDLE, P. 1964: Facets of the distribution of forest vegetation in New Zealand. *N.Z. Journal of Botany 2:* 352–66.

———1965: A comparison of alpine timber lines in New Zealand and North America. Ibid. *3:* 113–35.

WARDLE, P.; CAMPBELL, A. D. 1976: Seasonal cycle of tolerance to low temperatures in three native woody plants, in relation to their ecology and post-glacial history. *Proceedings of New Zealand Ecological Society 23:* 85–91.

ZOTOV, V. D. 1938: Some correlations between vegetation and climate in New Zealand. *N.Z. Journal of Science and Technology 19:* 474–87.