# 23. PALYNOLOGY OF SELECTED NEOGENE SAMPLES FROM HOLES 594 AND 594A, CHATHAM RISE<sup>1</sup>

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#### ABSTRACT

This chapter presents the results of preliminary palynologic analyses of 132 samples from Holes 594 and 594A from Deep Sea Drilling Project Leg 90. Palynomorph abundance, diversity, and preservation vary, with minimum concentration in the late early to middle Miocene nannofossil chalk. In the upper part of the late Miocene foraminifer-bearing nannofossil ooze, pollen concentration rises close to the maximum amounts (~400 grains/cm<sup>3</sup>) found in the Pliocene, Pleistocene, and Quaternary hemipelagic silts and clays.

Pollen spectra in all samples are mainly arboreal pollen. Early Miocene pollen assemblages are dominated by *Nothofagus brassi*, with subsidiary podocarpaceous pollen. In mid-Miocene samples, *N. fusca* is the major type of beech pollen present. Late Miocene, Pliocene, and Quaternary pollen assemblages show decreasing representation of extinct Tertiary pollen types and evidence of climatic fluctuations.

## **INTRODUCTION**

The purpose of this preliminary survey of palynomorphs in cores recovered from DSDP Holes 594 and 594A on the Chatham Rise in the southwest Pacific east of South Island, New Zealand, is to evaluate the stratigraphic, paleogeographic, and paleoclimatic potential of the marine pollen record from Site 594. Although few papers discuss pollen in marine sediments near New Zealand (Koroneva, 1968), pollen analyses of marine sediments in fjords of western South Island (Harris, 1964; Mildenhall, 1978d) demonstrate the stratigraphic and ecologic usefulness of marine pollen. Elsewhere in the Antipodes, Kemp (1975, 1981; Kemp and Harris, 1975) used pollen from deep-sea cores to reconstruct Antarctic and Australian Tertiary vegetation and climates. Pollen analyses of samples from DSDP sites near western North American (Fournier, 1981; Heusser, 1982) and in the Black Sea (Koroneva and Kartashova, 1978; Traverse, 1978) provide age determinations, palynostratigraphic zonations, and floral and climatic information about nearby land masses.

New Zealand Tertiary and Quaternary pollen stratigraphy and vegetation/climatic history are well known from pollen analyses of late Cenozoic shallow-water marine and nonmarine deposits, work begun by New Zealand palynologists such as Cranwell (Cranwell and von Post, 1936), Couper (1951a, b), and Moar (1958). Tertiary pollen zonations are usually related to the exceptionally complete and well-correlated New Zealand Tertiary marine sequence. Paleoclimatic interpretations of late Cenozoic pollen assemblages are based on detailed studies of present relationships between pollen and vegetation distributions in New Zealand (e.g., McGlone, 1982; Moar, 1970; Pocknall, 1980).

### SETTING

The plants of New Zealand (South Island and, to a lesser extent, North Island) are the primary source of pollen in sediments of Site 594. Vegetation of these mountainous islands can be simplistically divided into two plant formations, forest and tussock grassland, the first widely distributed in both islands, and the second well-developed in South Island east of the forest-covered Southern Alps (Cockayne and Phillips-Turner, 1967). Two broad categories of temperate, board-leaved evergreen forests are recognized: lowland, conifer-broadleaf forest (including podocarps such as *Podocarpus, Dacrydium*, and *Phyllocladus*, hardwoods such as *Weinmannia*, and tree ferns like *Cyathea*), and subalpine *Nothofagus* (southern beech) stands (including *N. fusca* and *N. solandri;* Wardle et al., 1983).

Present distribution of plant associations in New Zealand is related to climatic patterns, controlled by latitude, oceanic environment, and relief, as well as to historical factors (Wardle et al., 1983). Located between  $\sim 34^{\circ}$  and 47°S, the long, narrow (<300 km) land mass lies in the convergence of atmospheric pressure systems (subtropical high and Southern Ocean low) and oceanic water masses (subantarctic, temperate, and warm subtropical) (Griggs, et al., 1983). Precipitation is high, with strong, circumpolar westerly winds and high relief causing marked differences in average annual rainfall (from 6250 mm on the west coast of South Island to <600 mm in the east). Moderate mean annual temperatures range from 8°C on South Island to 13°C on North Island (Allan, 1961; Moar and Suggate, 1979).

#### METHODS

For this preliminary survey, two to three samples were taken from each core from Holes 594 and 594A (Table 1). Sampling intervals ranged from 3 to 10 m. In all, 132 samples were processed, 94 from Hole 594 and 38 from Hole 594A. Sample size ranged from 10 cm<sup>3</sup> to 20 cm<sup>3</sup> wet sediment. Preparations involved mechanical and chemical extraction techniques described in Heusser and Stock (1984). Palynomorphs were identified using a reference collection made from plants

 <sup>&</sup>lt;sup>1</sup> Kennett, J. P., von der Borch, C. C., et al., *Init. Repts. DSDP*, 90: Washington (U.S. Govt, Printing Office).
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# Table 1. Samples analyzed for pollen from Holes 594 and 594A.

# Table 1. (Continued).

	Depth below			Naga ta kusta	Depth below		
Sample (interval in cm)	Seafloor (m)	Lithology	Age	Sample (interval in cm)	Seafloor (m)	Lithology	Age
Hole 594				Hole 594 (Cont.)			
1-2, 43-47	1.95	Unit I	Quaternary	34-2, 43-47	314.05		
1-4, 43-47	4.95	Alternating bluish gray	1170 ES	34-4, 43-47	317.05		
2-2, 43-47	7.85	foraminifer-bearing		35-2, 43-47	323.65		
2-4, 43-47	10.85	nannofossil ooze and		35-4, 43-47	326.63		
2-0, 43-47	15.85	fossil bearing claum		36-4 43-47	336 25		
3-2, 43-47	17.45	silt		38-2, 43-47	352.45		
3-4, 43-47	20.45	1511121 (		39-2, 43-47	362.05		mid Miocene
3-5, 43-47	21.45			40-2, 43-47	371.65		
3-6, 43-47	23.45			40-4, 43-47	374.65		
4-2, 43-47	27.05			41-2, 43-47	382.25		
4-4, 43-47	30.05			41-4, 43-47	385.25		
4-6, 43-47	33.05			42-2, 43-47	391.85		
5-2, 43-47	30.05			45-2, 43-47	420.65		
5-6. 43-47	42.65			46-2, 43-47	430.25		
6-2, 43-47	46.25			47-1, 43-47	438.35		
6-4, 43-47	49.25			48-2, 43-47	449.45		
7-2, 43-47	55.85			49-2, 43-47	459.05		
9-2, 43-47	75.05			49-4, 43-47	462.05		
9-4, 43-47	78.05			50-2, 43-47	468.65	Cochoonit IID	
9-6, 43-47	81.05			51-1, 43-47	4/0./5	Subunit IIB Very light gray pappofossil	
11-2, 43-47	94.05			52-2, 45-41	407.05	chalk with occasional	
11-4, 43-47	97.25					interbeds of olive gray	
11-6, 43-47	100.25					silt-bearing clayey	
12-2, 43-47	103.85					nannofossil chalk	
12-4, 43-47	106.85						
13-2, 43-47	113.45			Hole 594A			
13-4, 43-47	116.45			1 2 42 47	42.26	Linit I	Quaternary
14-2, 43-47	123.05		Inte Diocene	1-2, 43-47	43.25	Alternating bluich grav	Quaternary
15-2, 43-47	132.65		late r nocene	1-6, 43-47	49.25	foraminifer-bearing	
15-4, 43-47	135.65			2-2, 43-47	52.85	nannofossil ooze and	
15-6, 43-47	138.65			2-4, 43-47	55.85	greenish gray nanno-	
16-2, 43-47	142.25			2-6, 43-47	58.85	fossil bearing clayey	
16-4, 43-47	145.25			3-2, 43-47	62.45	silt	
18-2, 43-47	161.45		early Phocene	3-4, 43-47	65.45		
18-6 43-47	167.45			3-0, 43-47	72.05		
19-2, 43-47	171.05	Subunit IIA		5-2, 43-47	81.65		
19-4, 43-47	174.05	Light to very light gray		5-4, 43-47	84.65		
19-6, 43-47	177.05	foraminifer-bearing		5-6, 43-47	87.65		
20-2, 43-47	180.65	nannofossil ooze to		6-2, 43-47	91.25		
20-4, 43-47	183.65	nannofossil ooze		10-2, 43-47	129.65		late Pliocene
21-2, 43-47	190.25		late Miocene	10-4, 43-47	132.65		early Phocene
21-6, 43-47	195.25			11-2 43-47	199.85	Subunit IIA	late Miocene
23-2, 43-47	209.45			11-4, 43-47	202.85	Light to very light gray	
23-4, 43-47	212.45					foraminifer-bearing	
23-6, 43-47	215.45					nannofossil ooze to	
24-2, 43-47	219.05					nannofossil ooze	
24-4, 43-4/	222.05			13-2, 43-47	507.05	Subunit IIB	mid-Miocene
24-0, 43-47	223.05			13-4, 43-47	513.05	chalk with occasional	
25-4, 43-47	231.65			14-2, 43-47	516.65	interbeds of olive gray	
26-2, 43-47	238.25			14-4, 43-47	519.65	silt-bearing clayey	
26-4, 43-47	241.25			15-2, 43-47	526.25	nannofossil chalk	
27-2, 43-47	247.05			16-2, 43-47	535.85		
27-4, 43-47	250.85			16-4, 43-47	538.85		
28-2, 43-47	257.45			10-0, 43-47	545.45		
29-2, 43-47	267.05			17-2, 43-47	548.45		
29-4, 43-47	270.05			20-1, 10-14	572.42		
29-6, 43-47	273.05			20-2, 43-47	574.25		
30-2, 43-47	276.65			21,CC	584.34		early Miocene
30-4, 43-47	279.65			22,CC	592.45		
30-6, 43-47	282.65			23-1, 127-130	611 91		
31-4, 43-47	289.25			24-1, 110-112	621.31		
31-6, 43-47	292.25			26-1, 32-34	630.23		
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collected in New Zealand by the author, C. J. Heusser, and L. B. Moore; from reference slides and photographs graciously lent by L. M. Cranwell; and from illustrations and descriptions published by Cookson, 1959; Couper, 1953c; Cranwell, 1938-1963. Hanks and Fairbrothers, 1976; Harris, 1955; and Truswell 1982b, 1983. Poor preservation and the presence of numerous opaque (pyrite ?) particles often made identification difficult; therefore, many groups were not differentiated and classifications should be regarded as tentative, pending further detailed study. For example, Dacrydium kirkii-biforme-bidwilli types were not differentiated and may be included in the Podocarpus group or mistakenly assigned to Dacrydium cupressinum (Mildenhall, 1978c). Tertiary bisaccate grains with small sacci placed in the Phyllocladus group may include Phyllocladites mawsoni (Couper, 1953c; Tulip, et al., 1982), and some small, trisaccate grains may represent Microcachrys, Microstrobus (Pherosphaera) species, Microcachryidites, or possibly Acmopyle pancheri and A. alba from New Caledonia (Cranwell, 1961; personal communication, 1983).

## SITE 594 (45°31.41'S; 174°56.88'E)

Site 594 is located in the South Pacific Ocean at a depth of 1204 m on the southern margin of the Chatham Rise about 250 km east of South Island, New Zealand (Fig. 1). The site, downslope from Waitaki Canyon, is situated in a transitional area between ocean (subantarctic waters immediately south of the Subtropical Convergence) and terrigenous influences, particularly the Waitaki River drainage.

Holocene through lower Miocene sediments were recovered from three holes cored to a maximum sub-bottom depth of 639 m, with four unconformities detected (about 8.3-6.5 Ma, about 5.4-4.5 Ma, about 3.85-2.7Ma, and about 1.6-0.74 Ma). Both the Miocene/Pliocene boundary and the early/late Pliocene boundary fall within disconformities. Two lithostratigraphic units were defined (Table 1). Unit I (earliest Pliocene to Quater-



Figure 1. Location of Site 594 off South Island, New Zealand.

nary age) consists of an alternating sequence of greenish gray hemipelagic and bluish gray pelagic lithofacies separated from the lower units by a gradational contact. Unit II (late early Miocene to earliest Pliocene age) is a pelagic facies consisting mainly of light gray foraminifer-bearing nannofossil ooze (Subunit IIA, middle Miocene to earliest Pliocene age), and light gray nannofossil chalk with occasional interbeds of olive gray silt-bearing nannofossil chalk (Subunit IIB, late early to middle Miocene).

Two major tectonic episodes are recorded in sediments of Site 594. The clay turbidites of Subunit IIB provide evidence of an early tectonic pulse about 17 Ma, which coincides with strike-slip motion along the Alpine Fault sector of the Indian/Pacific plate boundary (site chapter, this volume). At 6 Ma, the first late Neogene influx of hemipelagic sediments dates the beginning of the Kaikoura Orogeny and the emergence of a fairly substantial, continuous, northeast-to-southwest-trending landmass (site chapter, this volume; Nelson, this volume; Suggate, 1978). In the upper 200 m below the seafloor, 25 major hemipelagic depositional episodes are recorded. Shipboard investigations indicate that this sequence of alternating dark hemipelagic and light pelagic biogenic sediments of latest Miocene to Pleistocene age is related to climatic change: warm climates (interglacials) and high sea levels are associated with pelagic sediment containing warm planktonic foraminifer faunas, and cold climates (glacials) and low sea levels are associated with pelagic sediments containing much biosiliceous material and cold planktonic foraminifer faunas (site chapter, this volume). High-resolution carbonate and isotope stratigraphies provide detailed confirmation of the correlation between sedimentary parameters and late Quaternary climatic changes, and provide a correlation between New Zealand Quaternary records and fluctuations of northern hemisphere ice sheets (Nelson, Hendy, et al., this volume).

### RESULTS

The results presented in this preliminary report cannot do justice to the paleoecological potential of the pollen record in the sediments of Site 594. Palynomorphs in samples from Holes 594 and 594A (Table 1) are Nothofagus fusca type, Nothofagus menziesii type, Nothofagus brassi type, Podocarpus types, Dacrydium types, Phyllocladus type, Michrocachrys type, inaperturate cupressaceous types, Myrtaceae, Coprosma types, Ericaceae, Gramineae, Cyperaceae, Compositae, Chenopodiaceae, Polypodiaceae, and Lycopodiaceae. Dinoflagellates, microforaminifers, and recycled pollen and spores are frequently present. Pollen types identified, but not tabulated, include Haloragacidites (al. Triorites) harrisii and H. trioratus, extinct species probably belonging to the Haloragaceae or Betulaceae (Couper, 1953a-c; Mildenhall and Harris, 1970), Proteacidites, and members of the Umbelliferae, Rosaceae, Loranthaceae, Cupressaceae, Proteaceae, and Cunoniaceae (Allan, 1961; Moore and Edgar, 1970).

Pollen spectra from samples from Sites 594 and 594A are not correlated with New Zealand stratigraphic units because rare diagnostic forms (Couper, 1951–1960; Couper and McQueen, 1954; Couper and Harris, 1960; Mildenhall, 1972–1980. Moar and Suggate, 1979) were not often identified. Future preparation of larger samples from cores taken at Site 594 to isolate diagnostic pollen types may prove useful for late Cenozoic correlations; however, Mildenhall and Suggate (1981) suggest that palynological subdivision using extinct species may be of only local value in the upper Pliocene and basal Quaternary. In deep-sea sediments, rare extinct or extant pollen types must be interpreted with caution because of the increased possibilities for contamination by long-distance transport or the addition of recycled pollen.

Palynomorphs were recovered from both lithostratigraphic units (Unit I, and Subunits IIA and IIB). Early Pliocene-Quaternary samples from the interbedded hemipelagic and pelagic facies of Unit I and late Mioceneearly Pliocene Samples 594A-11-2, 43-47 cm and 594-21-6, 43-47 cm through 594-19-2, 43-47 cm from Subunit IIA were generally more productive than the nannofossil ooze of Subunit IIB, with the exception of turbidite samples 594A-17-2, 43-47 cm, 594A-17-4, 43-47 cm, and 594A-20-1, 10-14 cm. Pollen concentration is low (<400 pollen grains/cm<sup>3</sup>), and shows no apparent correlation with the detailed changes in sedimentary properties of the Quaternary pelagic and hemipelagic oozes at Site 594 described by Nelson (Nelson et al., this volume). Preservation and pollen diversity vary: more pollen groups are identified in well-preserved assemblages with relatively high pollen counts (50 to 100 grains), samples which often, but not always, have high pollen density.

Pteridophyte spores (Filicopsida and Lycopsida) and redeposited pollen and spores occur in all three sedimentary units. A few grains identified as *Sphagnum* appear at the base of Subunit IIA. Dinoflagellates are commonly present and frequently abundant in samples from Unit I and Subunit IIA, and are rare in Subunit IIB. Units I and II contain microforaminifers, ranging from abundant in Unit I to absent in Subunit IIB. Other components of the organic residue include fungal spores, blackened and degraded plant fragments, amorphous organic material (<5  $\mu$ m), and algal fragments.

# **Early Miocene**

In the six early Miocene samples, pollen assemblages are dominated by *Nothofagus*, primarily *N. brassi* with lesser *N. menziesii*. *Nothofagus fusca* is present in small amounts. Podocarp and *Microcachryidites*-type pollen occurs throughout. *Haloragacidites harrisii* and *Proteacidites* are present, along with recycled pollen and spores. Herb and shrub pollen is essentially absent (one Gramineae grain was identified), and no dinoflagellates or microforaminifers were found.

# **Mid-Miocene**

Pollen concentration is very low in most mid-Miocene samples. Eight samples are barren and four other samples have <10 pollen grains. Samples 594A-20-1, 43-47 cm, 594A-13-6, 43-47 cm, 594-49-2, 43-47 cm, 594-46-2, 43-47 cm, and 594-45-2, 43-47 cm, are very productive, with >50 pollen grains identified from each sample. Nothofagus fusca is the most important arboreal pollen type, and replaces N. brassi in prominence. N. menziesii, podocarpaceous pollen, and Microchachryidites-types are present, along with representatives of the Gramineae, Compositae, Chenopodiaceae, and Cyperaceae. Pteridophyte spores, including Cyathea-types, increase in abundance upwards, Dinoflagellates are present in each sample, and recycled palynomorphs, microforaminifer cysts, and a few Sphagnum-like grains occasionally appear.

# Late Miocene

Basal late Miocene Samples 594-38-2, 43-47 cm, through 594-31-4, 43-47 cm are relatively unproductive. Pollen becomes more numerous in Samples 594-31-2, 43-47 cm, through 594-28-2, 43-47 cm, with 65 grains identified in Samples 594-28-4, 43-47 cm. Podocarpaceous pollen types (including Dacrydium cupressinum) are more numerous than Nothofagus types. Fern spores and dinoflagellate are frequent, microforaminifers appear occasionally, and lycopod spores occur in a few samples. Between 250 and 212 m (Samples 594-27-4, 43-47 cm through 594-23-6, 43-47 cm), podocarps (Dacrydium cupressinum, Podocarpus dacrydiodes, and trisaccate types) outnumber Nothofagus types (N. fusca, N. menziesii, and N. brassi, in order of prominence). Fern (polypod) spores and dinoflagellates are consistently abundant. Nonarboreal pollen, lycopod spores, and microforaminifers appear occasionally.

The podocarp/Nothofagus ratio reverses in pollen-rich (>100 pollen grains/sample), younger late Miocene samples (594-23-4, 43-47 cm, through 594-21-2, 43-47 cm, 594A-11-4, 43-47 cm, and 594A-11-2, 43-47 cm), with Nothofagus fusca the leading arboreal pollen group. Compositae pollen is present in each sample, and Coprosma, Chenopodiaceae, Gramineae, and Cyperaceae pollen are occasional components of these pollen assemblages. Pteridophyte spores (polypod and lycopod) are more prominent than dinoflagellates and microforaminifers. Microcachryidites is present. A few grains of Haloragacidites harrisii and Protaecidites were identified, apparently marking the last appearance of these grains.

# **Pliocene-Quaternary**

Plio-Pleistocene samples are characterized by large fluctuations in pollen density, changing from 400 to 5 grains/ cm<sup>3</sup> in one sample interval. Nothofagus fusca is the leading pollen type, and Nothofagus types usually occur more frequently than podocarps, although some levels do have larger numbers of conifer pollen. Nonarboreal pollen is always less numerous than arboreal pollen; only 2 samples (594-5-6, 43-47 cm and 594A-2-6, 43-47 cm) have >25% herb pollen. As in older samples, fern spores are more abundant than lycopod spores. Dinoflagellates and microforaminifers vary in relative frequency of total palynomorphs, the latter increasing in the upper 36 m below the seafloor. Characteristic older Tertiary types, N. brassi and trisaccate conifers, gradually decrease in younger sediment. Sample 594-18-2, 43-47 cm (161 m sub-bottom depth) marks the last fairly continuous appearance of N. brassi, although (?recycled) pollen grains

which appear to be N. brassi occur occasionally in younger sediments up to 43 m sub-bottom depth (Sample 594-1-2, 43-47 cm).

### DISCUSSION

Pollen concentration (<400/cm<sup>3</sup>) in all samples analyzed from Site 594 is unexpectedly low, although larger than concentration values of marine pollen in piston cores taken off North Island, New Zealand (Koroneva, 1968). In similar marine sedimentary environments adjacent to North America and Japan (continental slope at  $\sim 40^{\circ}$  latitude near large river systems draining temperate vegetation), pollen concentrations are 2 to 20 times greater than in sediments east of New Zealand (Heusser, 1983; Heusser and Balsam, 1977; Heusser, L. E., unpublished data). Perhaps the relatively small area from which pollen is derived (both the present surface area of North and South Island and the even smaller area capable of supporting vegetation in the Tertiary; Walcott, 1984) accounts for the low amount of pollen in cores from Holes 594 and 594A. Sedimentation and preservation are also important determinants in pollen concentration in sediments from Chatham Rise. Dilution by terrigenous and pelagic sedimentary components may account for the scarcity of pollen at Site 594. Oxidation and winnowing related to vigorous current action may have differentially destroyed or removed pollen (Heusser and Balsam, 1977), and oxidizing depositional environments are noted for poor pollen preservation (Tschudy and Scott, 1969). Pollen concentration is broadly correlated with intervals of terrigenous influx, with greatest pollen influx in the Plio-Pleistocene hemipelagic sequence (Samples 594-1-2, 43-47 cm through 594-11-2, 43-47 cm, and 594A-1-2, 43-47 cm through 594A-6-2, 43-47 cm), and in basal Miocene turbidites (Samples 594A-20-1, 10-14 cm and 594A-25-1, 100-102 cm). Lowest pollen influx, in middle Miocene nannofossil oozes (Sample 594-49-4, 43-47 cm through 594-28-2, 43-47 cm) is associated with pelagic carbonates and virtual lack of terrigenous input (site chapter, this volume). The sparseness of pollen in these mid-Miocene samples may also be related to the increased corrosiveness of Pacific Ocean bottom waters associated with Antarctic glaciation and the formation of Antarctic Bottom Water (Shackleton and Kennett, 1975).

Broad changes in marine plankton in the pollen concentrate of samples analyzed from Sites 594 and 594A, an absence of dinoflagellate and microforaminifer cysts in the lower Miocene, and abundance variations in younger sediments probably relate to the paleoceanographic changes (i.e., changes in sea surface temperature and salinity, sediment supply, current velocity, and glacioeustatic sea level). Increased numbers of dinoflagellates in the upper Miocene may be associated with development of the Subtropical Convergence at this time (site chapter, this volume). In the northeast Pacific Ocean, late Miocene dinoflagellate abundance and diversity indicate changes in surface waters of the California Current (Ballog and Malloy, 1981). Further south off Mexico, Fournier (1981) related dinoflagellate abundance to water depth and turbulence: high dinoflagellate density is associated with low sea level in shallow depositional sites.

Pollen spectra from marine sediments of Site 594 can be interpreted only in relation to late Cenozoic pollen assemblages found on land (New Zealand) because there are no comprehensive studies relating New Zealand vegetation and pollen deposition in marine environments offshore. In comparing marine pollen assemblages from DSDP cores taken on Chatham Rise with pollen assemblages from South and North Island, differences in pollen source and sedimentation should be noted. Pollen from most peats, lignites, or nonmarine sediment is largely wind-transported short distances from small plant communities and rapidly deposited in lakes and bogs, environments with excellent pollen preservation. Pollen from shallow-water marine sediments (the fjords of South Island, or the mudstones and siltstones of the Wanganui Series) is derived from large vegetation formations, and shows effects of differential sorting and preservation during aerial and fluviomarine transport before final deposition in high-energy environments. Pollen and spores in deep-water marine sediments reflect vegetation of broad regions, as well as eolian and fluviomarine transport and deposition (Heusser, 1983; Heusser and Balsam, 1977).

Late Cenozoic pollen assemblages from Site 594 are dominated by arboreal pollen: *Nothofagus* (southern beech), the most common Cretaceous and Tertiary pollen type of New Zealand (Couper, 1951a), and representatives of the Podocarpaceae (conifers), including *Dacrydium, Podocarpus*, and *Phyllocladus* species (Allan, 1961). Pollen and macrofossils from these wind-pollinated trees are prominent in Tertiary marine and nonmarine sediments in the southern hemisphere, and relative differences in representation of beech and conifer pollen are criteria for stratigraphic assignments and climatologic interpretations of Tertiary and Quaternary polliniferous sediments from New Zealand, Australia, and Antarctica (Couper, 1951–60; Cranwell, 1969; Kemp, 1975; Mildenhall, 1978a, b).

Despite differences in source and sedimentation, late Cenozoic pollen spectra in samples analyzed from Site 594 are broadly correlative with pollen obtained from marine and nonmarine sediments on New Zealand. Early Miocene floras are characterized by the presence of numerous extinct pollen and spore types. The mid-Miocene marks a transition, with some older pollen types (N. brassi, Haloragacidites harrisii) continuing in a minor role and others (N. fusca) playing a major role. As on North and South islands, new groups (Compositae and Chenopodiaceae) appear in greater numbers. Upper Miocene and Pliocene marine samples show a gradual decline in extinct species, and no abrupt changes in floral assemblage appear between  $\sim 2.47$  and  $\sim 5.5$  Ma. On New Zealand, no evidence exists of exceptional climatic changes (Suggate et al., 1978), or of abrupt floral extinctions at the Miocene/Pliocene boundary or in latest Miocene (Kapitean) pollen sequences. Pliocene-Quaternary pollen assemblages also record an apparent gradual loss of extinct taxa, although a substantial number of extinct species make their last appearance in the Pliocene Taranaki Series (Suggate et al., 1978; Mildenhall and Suggate, 1981). The progressive extinction of Tertiary groups includes forms with interrupted ranges, such as the Nothofagus brassi group which appears in inter-

### L. E. HEUSSER

glacial deposits after absence in earlier glacial periods (Suggate et al., 1978).

In New Zealand, Quaternary pollen stratigraphic units are defined by climatic criteria supported by physiography, lithostratigraphy, and radioisotope and tephrochronology (Fleming, 1970; 1975; Moar, 1982). Generally, nonarboreal pollen assemblages are present in glacial intervals, and arboreal-dominated pollen assemblages are more prominent in interstadial or interglacial intervals. All Quaternary spectra in samples analyzed from Site 594 are dominated by arboreal pollen. Arboreal pollen dominates interglacial as well as glacial intervals, as defined by oxygen isotope stratigraphy of samples from the last ~400,000 yr. (Nelson, Hendy, et al., this volume). Samples 594-1-2, 43-47 cm and 594-1-4, 43-47 cm deposited during isotope Stage 2, the last glacial maximum, have a prominence of cool-temperate forest pollen.<sup>3</sup> Interstadial intervals are characterized by podocarp pollen in sediments from Site 594 and on North Island (Otamangakau interstadial; McGlone and Topping, 1983).

Climatic interpretations of pollen in samples analyzed from Site 594 are restricted to broad observations by the preliminary nature of the data. Early Miocene pollen assemblages from Chatham Rise probably represent subtropical (frost-intolerant) vegetation (trees similar to those now growing in New Guinea and New Caledonia-N. brassi group), as well as temperate and cool-temperate vegetation (trees now growing in lowland and montane parts of New Zealand). Rainfall estimates, based on requirements of modern species, range from 1800 mm/yr. (inferred from N. brassi) to as low as 400 mm/yr. (inferred from N. fusca) (Truswell, 1982a). Miocene pollen assemblages from Site 594 appear transitional between warm-temperate to subtropical early Cenozoic vegetation (Wardle et al., 1983) and temperate vegetation of the late Cenozoic glacial mode. Variations in key pollen types suggest that climate was not static during the Miocene. Using the prominence of conifers (podocarps) and southern beech (Nothofagus groups) as a general guide4 to climate suggests that in the late Miocene, a warm, moist interval preceeded cooler, drier conditions in which herbs and shrubs (vegetation of more open forests or shrublands and grasslands) developed. Miocene New Zealand apparently was ecologically and topographically diverse, with local montane and arid habitats (Wardle, 1978).

Pollen and spores deposited on Chatham Rise during the last 5 m.y. document the gradual disappearance of subtropical environments supporting *N. brassi*, and the expansion of temperate forests on both South and North Island. Changing climatic modes are suggested by variations in arboreal pollen in the upper 200 m taken from Site 594. Climatic interpretations of the broadly spaced pollen data appear to correlate with similar levels in the high-resolution sedimentary and geochemical data from the upper 80 meters of Site 594 (Nelson, Hendy, et al., this volume). Cool-temperature (glacial) pollen assemblages occur in hemipelagic ooze enriched in silt, with low carbonate content, high  $\delta^{18}$ O values and low  $\delta^{13}$ C values. Warm-temperate (interstadial and interglacial) pollen assemblages occur in pelagic oozes high in sand and clay, with high carbonate content, low  $\delta^{18}$ O values, and high  $\delta^{13}$ C values (Nelson et al., this volume).

### CONCLUSIONS

Preparation and preliminary analyses of 132 samples from Holes 594 and 594A produce the following results:

1. Pollen is present in low concentration (<400 pollen grains/cm<sup>3</sup> wet sediment) in both pelagic and hemipelagic facies. Preparation of large samples (on the order of 20 cm<sup>3</sup> is recommended for future pollen analyses.

2. Early Miocene samples are dominated by *Notho-fagus brassi* type pollen, along with other extinct Tertiary pollen types.

3. In mid-Miocene samples, pollen is scarce and N. *fusca* becomes more important than N. *brassi*.

4. Pollen concentration increases in late Miocene samples, which show fluctuations in the importance of conifers (podocarps) and beech (*Nothofagus*), suggesting vegetational and climatic changes on New Zealand.

5. Extinct Tertiary pollen types appear gradually to drop out of the record. Evidence for abrupt, major climatic change from late Miocene pollen assemblages in the samples analyzed from Site 594 is not apparent.

6. Pliocene/Quaternary samples show fluctuations in pollen concentration and in arboreal-dominated pollen assemblages. Climatic interpretations of changes in these arboreal pollen types appear to correlate with climatic changes indicated by oxygen isotope analyses of samples from Site 594.

7. Detailed analyses of pollen from Holes 594 and 594A will produce high-frequency stratigraphic and climatic information.

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<sup>&</sup>lt;sup>3</sup> The absence of herb-dominated pollen spectra from glacial sediments in Site 594 suggests that *Nothofagus* persisted in favorable sites on South Island during Plio-Pleistocene glaciations. This agrees with previous observations that scattered clumps of trees now present in South Island forests grew on the east coast of South Island during the last glaciation (Wardle, 1963, 1978; Wardle et al., 1983).

<sup>&</sup>lt;sup>4</sup> High values in the Podocarpus/Nothofagus ratio are interpreted as warm intervals and low values as cold intervals (Mildenhall, 1976). Although the ratio of conifers (Podocarpaceae) and southern beech (Nothofagus) pollen and macrofossils is used extensively in New Zealand Tertiary and Quaternary paleoclimatic reconstructions to indicate warmer and cooler conditions, recent ecological work in New Zealand stressing the variability of modern New Zealand forests questions the validity of such interpretations (Moar, 1973).

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