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Pollen transport and deposition in riverine and marine environments within the humid tropics of northeastern Australia

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Abstract

Mechanisms of pollen transport in the humid tropics region of northeastern Australia were investigated to support the interpretation of a long Quaternary pollen record from ODP Site 820 located on the adjacent continental slope. Pollen analysis of surface sediment samples from the channels of two major river catchments demonstrated internal consistency in pollen spectra and little fluvial pollen sorting in relation to sediment variation. Differences in modern pollen spectra between catchments reflect existing variation in vegetation cover that, in turn, reflects climatic differences between catchments. Recent pollen spectra from top samples of the ODP core have sufficient in common with the riverine samples to suggest that the rivers are contributing a major pollen component to the offshore sediments, but these have been size sorted by marine action. Recent pollen samples from core tops taken from the Grafton Passage on the continental shelf that was thought to be the major passage for pollen transport to ODP Site 820 show significant differences to both riverine and ODP samples and suggest that pollen are dispersed across the continental shelf and through the outer Great Barrier Reef system in a more complex way than anticipated.

Keywords: pollen transport; pollen deposition; marine palynology; tropics; northeastern Australia

1. Introduction

Understanding of the mechanisms of pollen transportation and deposition (i.e., pollen representation) to a site is crucial for the interpretation of the fossil pollen record from that site, particularly in a marine setting (Stanley, 1966; Heusser, 1978; Kershaw, 1994; van der Kaars, 2001). There are two major mechanisms of pollen transportation, aeolian and waterborne (including fluvial and marine).

The influence that fluvial transportation may have on pollen representation is still far from completely understood with debate over the way in which fluvial transport affects pollen deposition and preservation and, therefore, pollen representation in a fossil record.

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Studies on fluvial transport have largely been undertaken in North America. Brown (1985), Catto (1985) and Fall (1987) indicate that fluvial pollen transport has a tendency to sort pollen with separation of sand-sized and silt-sized components. In these studies, the sand-sized pollen association is composed largely of Cyperaceae, Chenopodiaceae, Lycopodiaceae and Ericaceae linked with high-energy settings, while the silt-sized pollen association, correlated with low-energy settings, is biased towards *Picea*, *Betula*, *Alnus* and Poaceae. These findings are consistent with the Brush and Brush (1972) model of pollen transport in a sediment-laden channel. Other studies, such as those of Campbell and Chmura (1994), Chmura and Liu (1990), Hall (1989) and Smirnov et al. (1996), have concluded that sorting of pollen grains with fluvial transport is not a significant factor, and that fluvial transported pollen grains faithfully reflect nearby plant communities. These findings from investigations on the Mississippi and Atchafalya Rivers have been supported by the results from other studies conducted in North America (Brush and Defries, 1981; Mudie, 1982).

Transport of pollen grains by marine processes may also affect the "environmental" signal. Some of the first Quaternary marine pollen studies observed that pollen grains tended to be deposited with fine silt particles generally derived from terrigenous sediments; in contrast, marine-derived sediments (coarse particles) contained much lower pollen concentrations (Muller, 1959; Koreneva, 1964; Stanley, 1966). Subsequent research has highlighted the importance of aggregation of pollen in faecal pellets and filamentous algal masses to facilitate sinking as pollen grains are considered too

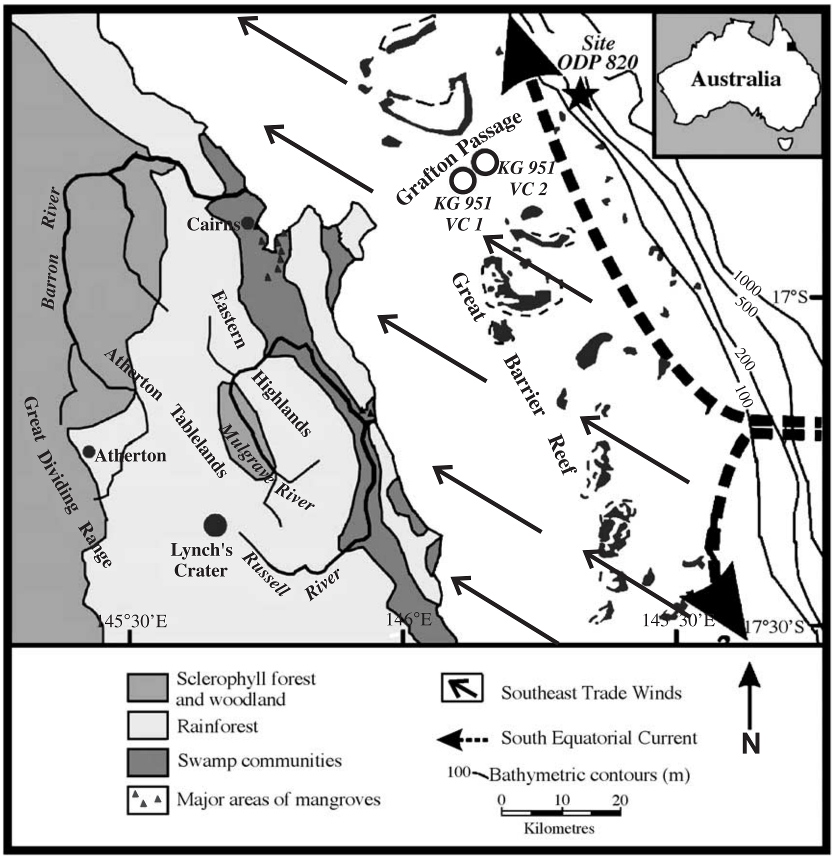

Fig. 1. Location of study area in relation to the present vegetation of the humid tropics, the southeast trade winds and major marine current flows.

small and light to have effective sinking velocity in ocean waters by themselves (Hooghiemstra, 1988a, 1996; Dupont, 1999).

The relative importance of transport mechanisms from land to oceans varies from region to region. For instance, aeolian pollen transport is the major way in which pollen is transported to marine sites off northwest Africa, the Mediterranean Sea and southeastern Indonesian waters (Bottema and van Straaten, 1966; Hooghiemstra, 1988a,b; Hooghiemstra and Agwu, 1988; Hooghiemstra et al., 1986; Koreneva, 1971; van der Kaars, 2001). In contrast, fluvial systems are more significant in pollen transportation in the northeastern Pacific and northwestern Atlantic, and the pattern of pollen transport in these regions is partly a function of distribution by surface currents (Balsam and Heusser, 1976; Heusser, 1983, 1983/84, 1988; Heusser and Balsam, 1977). In both instances, the selective nature of marine pollen transport may decrease the diversity of pollen types in marine cores compared with terrestrial sites and may distort the "environmental" signal. In addition, bioturbation, oxidation and diagenetic processes may also be more pronounced in marine sediments (Heusser, 1978). Therefore, these processes have to be taken into account when interpreting pollen records from marine settings. However, a recent investigation into pollen distribution in marine sediments reports a good representation of individual pollen taxa and major vegetation types in southeastern Indonesian waters despite complex wind and ocean current patterns (van der Kaars, 2001), while marine pollen assemblages off the western coasts of North Africa and Western Australia have been shown to capture major changes in vegetation and climate over a broad latitudinal range (Hooghiemstra, 1988a; Hooghiemstra et al., 1986; van der Kaars and De Deckker, 2003).

This paper investigates processes of modern pollen transportation and deposition in marine and fluvial settings within northeastern Australia. Results from surface pollen samples taken from lowland riverine and estuarine sediments are compared with recent pollen sequences from the adjacent continental shelf and from ODP Site 820 on the continental slope (see Fig. 1). The study was designed to help interpret the pollen record from ODP Site 820 (Moss, 1999; Moss and Kershaw, 2000; Moss and Kershaw, unpublished data) in general and specifically to test the propositions of Kershaw et al. (1993) that the record will be composed of a high proportion of fluvially transported pollen. This proposition is based on the proximal position of the ODP Site 820 record to high rainfall terrestrial environments supporting large river discharges and the fact that the region experiences onshore southeasterly winds derived predominantly from the Pacific Ocean rather than adjacent land. It was further suggested that, due to impedance of the Great Barrier Reef system, pollen would be channeled onto the continental slope through a major gap, the Grafton Passage.

2. Regional setting

The humid tropics region (Fig. 1) is characterized by substantial topographic variation that is reflected in the climate and vegetation cover. Rainforest dominates the region, extending from the coast and low coastal ranges to the eastern highlands that rise to above 1500 m in altitude, the Atherton Tableland, averaging about 700 m in altitude and Great Dividing Range. In general terms, the forest varies from mesophyll vine forest (or tropical lowland rainforest) on the coast and low coastal ranges to microphyll vine forest and thicket (submontane rainforest) at highest altitudes and grades from 'complex' to 'simple' (Webb, 1968), as rainfall decreases inland from in excess of 3000 mm per annum in southern coastal regions to about 1500 mm in the west (Tracey, 1982). Rainforest is replaced abruptly by sclerophyll woodland dominated by *Eucalyptus* and, in places Casuarinaceae, to the west of the Great Dividing Range and in fire-affected patches within the rainforest areas, e.g., Mulgrave River Valley (see Fig. 1). Swamps, palm forests and *Melaleuca* open forest or woodlands are found in areas of impeded drainage along the coastal plain. Mangroves are found in low-energy coastal environments.

The climate of the region is largely controlled by the easterly movements of the subtropical high-pressure belt with its anticyclonic cells tracking 37 to 38°S in summer (November to April) and 29 to 32°S in winter (May to October; Sturman and Tapper, 1996). The trade winds (Fig. 1), which blow in a southeasterly direction on the north side of the anticyclonic cells, form the predominant winds in the area throughout the year. The trade winds are responsible for most of the precipitation within the region, which occurs mainly during the summer (Gentilli, 1972). The summer precipitation is enhanced by the occasional southward swing of the intertropical convergence zone (ITCZ), with the degree of penetration varying from year to year (Gentilli, 1972). Furthermore, the trade winds are modified by the occurrence of tropical cyclones that develop in the Coral Sea and heat depressions over Central Queensland (Sturman and Tapper, 1996).

Much of the region, east of the Great Dividing Range, is drained by two large river systems, the Barron and the Russell/Mulgrave Rivers that discharge onto the extensive continental shelf that is bordered by islands of the Great Barrier Reef. The edge of this shelf, some 60 km from land, then slopes steeply from about 100 m to in excess of 1000 m to the bed of the Coral Sea (Johnson and Searle, 1984). Marine currents (Fig. 1) in the area relate to the circulation of the Coral Sea. Of greatest note is the South Equatorial Current that impinges on the barrier reef system usually between 16° and 19° south latitude (Andrews and Clegg, 1989; Brinkman et al., 2001). On contact with the continental slope, it bifurcates northward and southward to generate persistent long-shore current over the slope and shelf. The southern branch continues south, down the whole of the eastern coast of Australia, as the East Australian Current.

The focus of this study is on surface samples from the lower reaches and estuaries of the Barron (16°50′S, 145°40′E) and Russell/Mulgrave (17°14′S, 145°58′E) rivers that have the potential to contribute substantial amounts of pollen to the sediments of ODP Site 820. Recent pollen spectra from two cores taken within the Grafton Passage on the midcontinental shelf—KG 951 VC 1 (60 m water depth, 16°44′S, 146°11′E) and VC 2 (60 m water depth, 16°44′S, 146°08′E)—as well as spectra from the topmost section of the ODP Site 820 marine core (water depth 280 m, 16°38′S, 146°18′E), which are examined to allow some assessment of the degree and nature of pollen transport from the coastal river systems to the continental slope.

3. Methods

For assessment of fluvial transport, 29 samples of river margin and channel surface sediments were taken with a drop sampler: nine from the Barron River, six from the Mulgrave River, seven from the Russell River and seven from Mutchero Inlet (Fig. 2). The Barron River samples were taken along three transects across the river, each containing a sample from each margin and one sample from the centre of the river. Surrounding vegetation varies between mangrove, rainforest and deforested grassland. Samples from the Russell and Mulgrave Rivers and their combined estuarine outlet, Mutchero Inlet, were taken from various open water locations. Mangroves bordered most of the Mutchero and Russell locations while most of the Mulgrave samples were bordered largely by sugar cane fields. Some rainforest encroaches onto both river margins in some places. Of the samples collected, I4–I6 (Mutchero Inlet), R6 (Russell River) and B3C (Barron River) consisted of coarse sands unsuitable for pollen analysis and were excluded from pollen preparation.

For examination of marine transport of pollen grains over the continental shelf, results from the topmost sections of cores KG 951 VC 1 and VC 2 collected from under 60 m of water by a vibrocorer from the James Cook University research vessel ‘The James Kirby’ were used. The cores were taken from a former estuarine setting, which have also provided a record of mangrove development on the continental shelf during the early Holocene marine transgression (Grindrod et al., 1999, 2002). The carbonate sediments examined here accumulated after the mangrove facies and represent the period since stabilization of sea levels about 6000 years BP (Gagan et al., 1994). The last 4000 years of the pollen record from ODP Site 820 (Moss and Kershaw, 2000) collected from beneath 280 m of water were taken to represent pollen deposition on the continental slope. The constancy in composition of the pollen spectra suggests that neither catchment vegetation nor transport and depositional processes have altered greatly over this period.

Surface sediments and ODP Site 820 samples were prepared for pollen analysis using the technique developed by van der Kaars (1991) for extracting pollen from marine sediments. This method involved using sodium pyrophosphate to disaggregate the sediments, which were then further processed by acetolysis to darken the pollen grains and aid their visibility under a light microscope. Sodium polytungstate (with a specific gravity of 2.0) was then used to

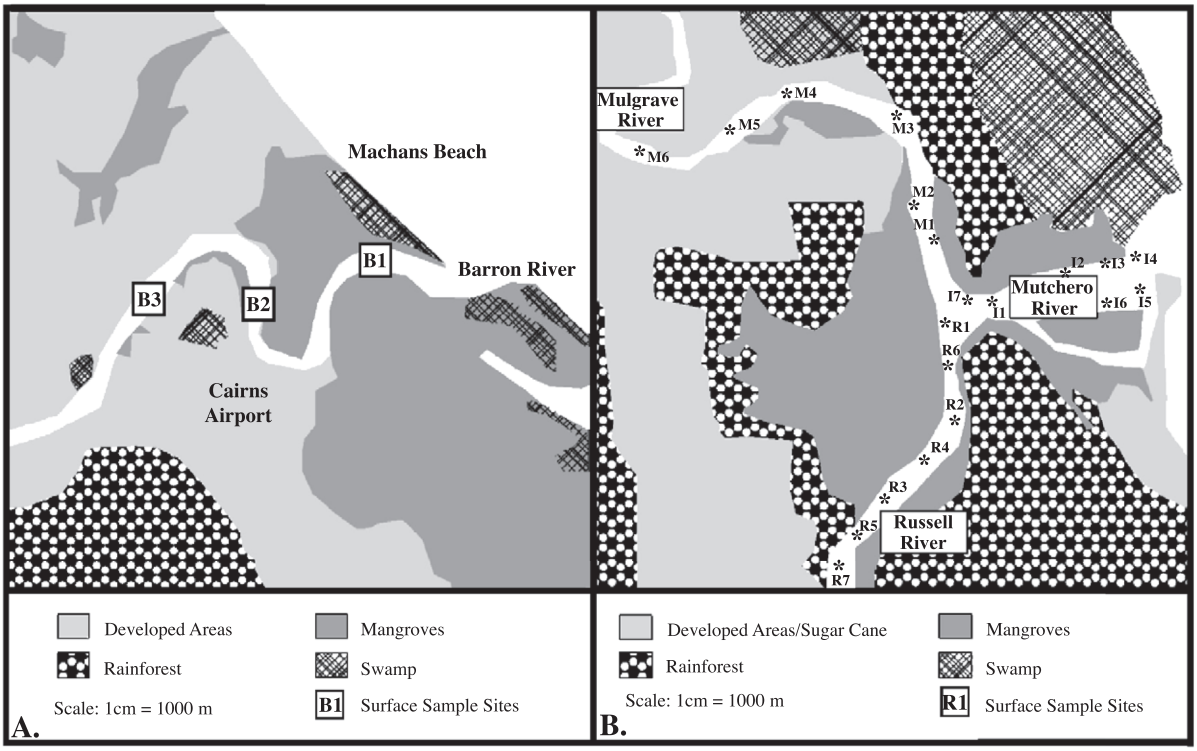

Fig. 2. Location of the Barron River and Russell/Mulgrave surface samples and major modern-day vegetation types in northeastern Australia. For the Barron River samples (Fig. 3A), transect 1 (B1) and transect 2 (B2) consist of three samples sites each, B1A, B1B, B1C and B2A, B2B, B2C, respectively, while transect 3 (B3) consists of two sample sites, B3A, B3B. For the Russell/Mulgrave Rivers (Fig. 3B), seven surface samples were taken from the Russell River (R1 to R7), six from the Mulgrave River (M1 to M6) and seven from Mutchero Inlet (I1 to I7;Fig. 3B).

float the lighter organic fraction (including pollen) from the heavier minerogenic components. The Grafton Passage core samples were subjected to standard preparation techniques (Faegri and Iversen, 1989) of hydrochloric acid to remove carbonates, hydrofluoric acid to remove silicates and acetolysis to dissolve excess organic matter, as well as to darken the grains. All prepared samples were then mounted in silicon oil and pollen identification, and counting was undertaken using a light microscope at ×650 magnification. At least 300 identifiable grains (or the number of grains recorded on four completely traversed slides) were counted for the modern samples, while at least 100 identifiable grains (or the total on four slides) were counted from the marine cores. All predominantly dry land taxa (rainforest taxa, sclerophyll trees and shrubs and herbs) make up the pollen sum on which percentages of all taxa are based.

4. Results

4.1. Surface pollen samples from the Barron River

There is marked similarity between all spectra with good representation of five major taxon groups, rainforest, sclerophyll arboreal taxa, herbs, pteridophytes and mangroves (Fig. 3). The major dryland arboreal taxa are all sclerophyll trees with *Melaleuca*, *Eucalyptus* and Casuarinaceae occurring in relatively equal frequencies. By contrast, the contributions of rainforest taxa are all minor with only Sapotaceae, Sapindaceae, *Syzygium*, Euphorbiaceae and *Macaranga* occurring in all samples. Pollen spectra from mangroves are dominated by the Rhizophoraceae taxa, *Rhizophora* and *Ceriops*/*Brugeira,* with only low representation of other taxa, while monolete fern spores, the majority of which had lost their exosporia and could not be identified further, and, to a lesser

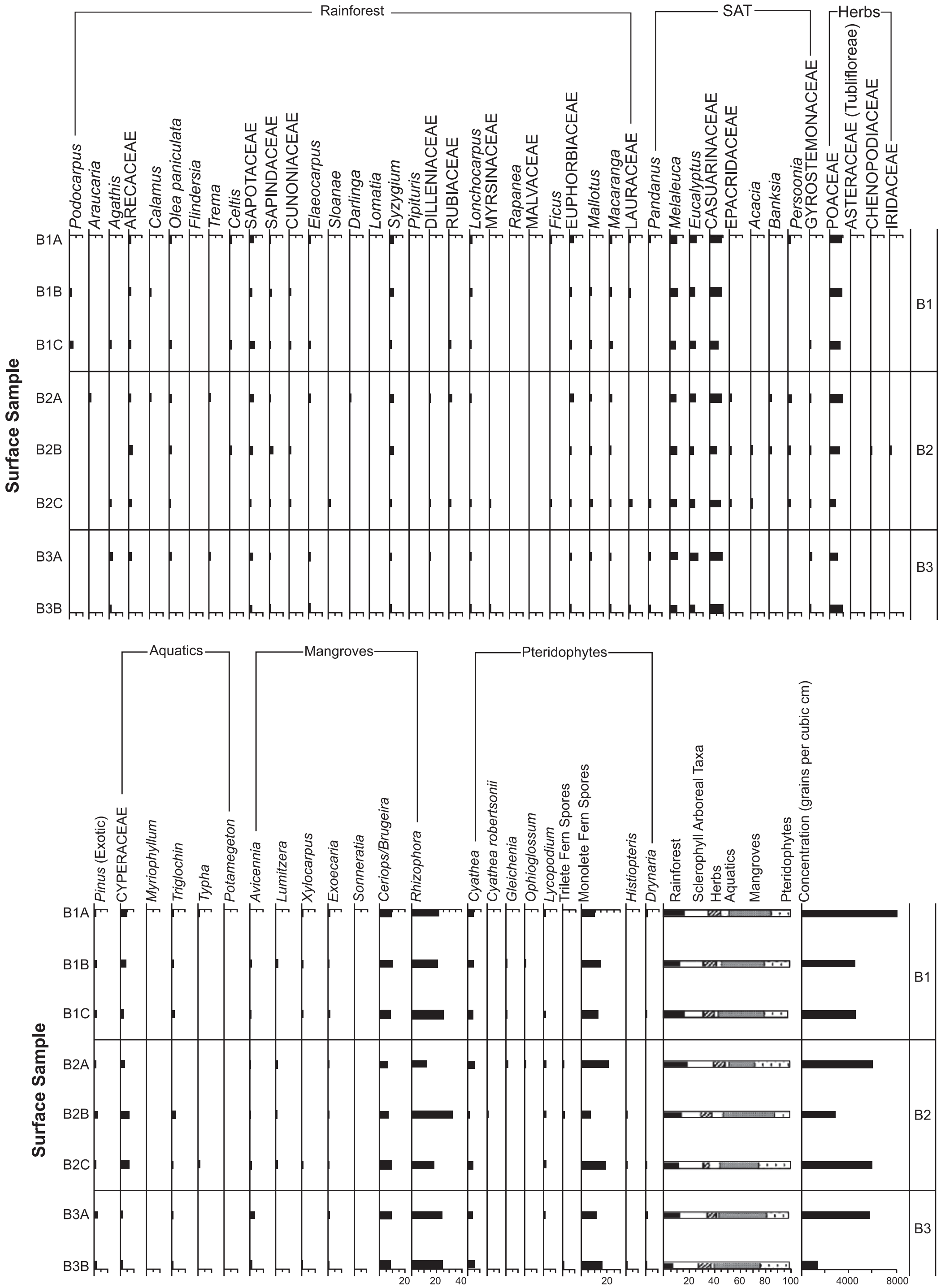

Fig. 3. Pollen percentage diagram for the Barron River surface samples, northeastern Australia. B1—transect 1; B2—transect 2; B3—transect 3. SAT—sclerophyll arboreal taxa.

degree, the tree fern *Cyathea*, make up most of the pteridophyte component. Poaceae percentages are highest in almost all samples from dryland herb vegetation. Aquatics, mainly represented by Cyperaceae, and identifiable exotics, represented by *Pinus*, are the minor components present. In total, 64 identifiable taxa were recorded with little variation in number between samples.

Overall, pollen concentrations are low. They vary between about 1500 and 8000 grains/cm^3, but most

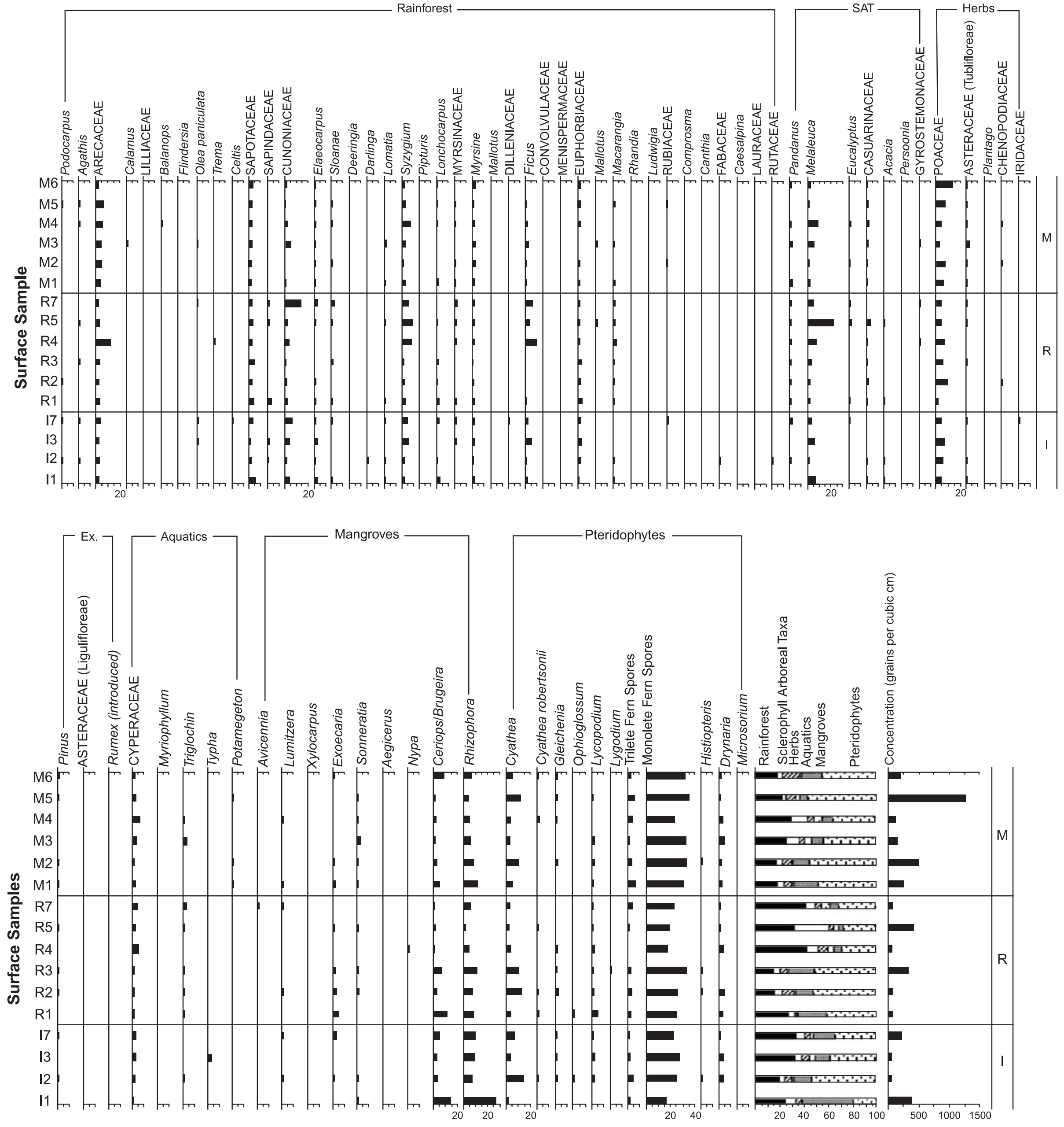

Fig. 4. Pollen percentage diagram for the Russell/Mulgrave surface samples, northeastern Australia. M—Mulgrave River samples; R—Russell River samples; I—Mutchero Inlet samples. SAT—sclerophyll arboreal taxa; Ex—exotic taxa.

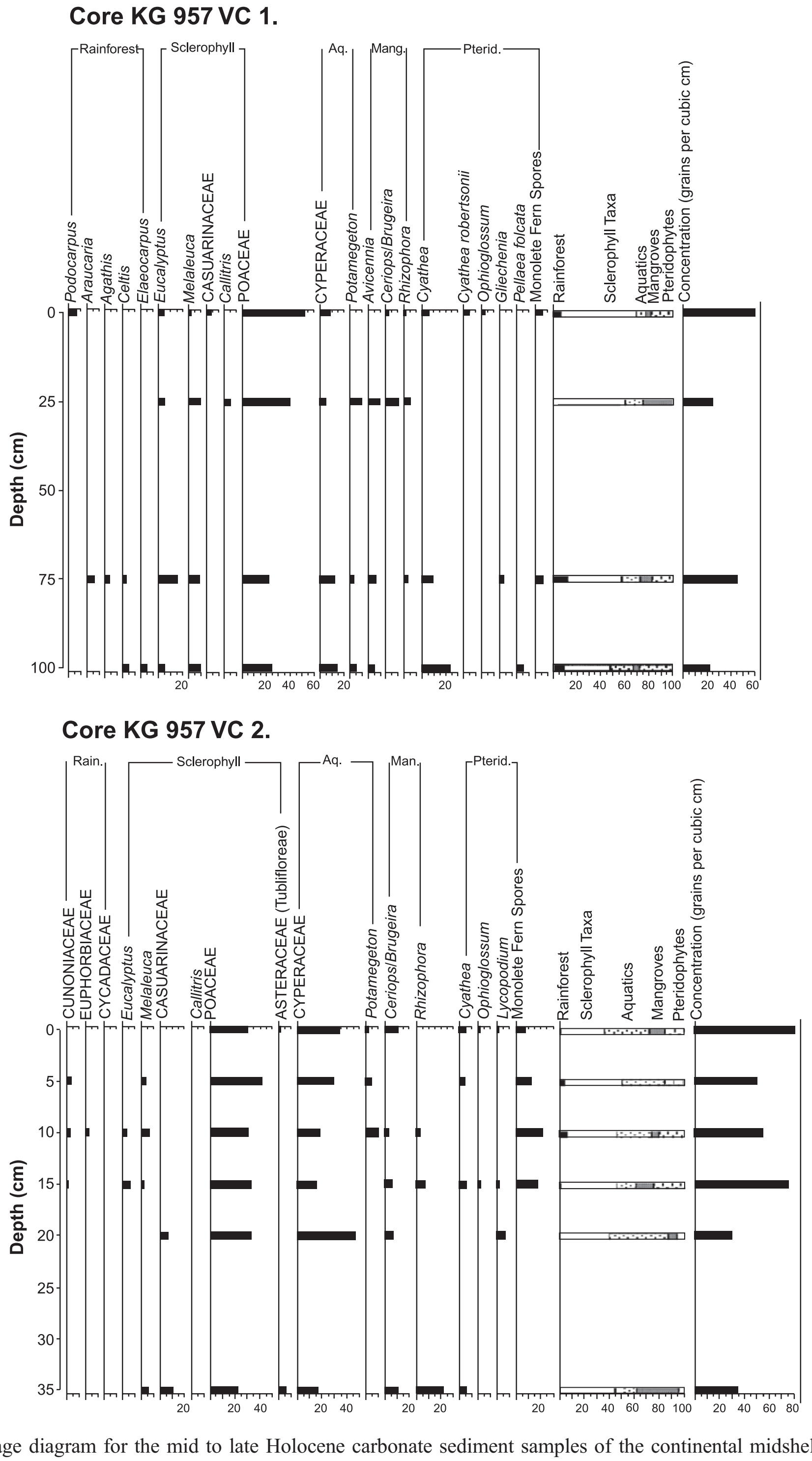

Fig. 5. Pollen percentage diagram for the mid to late Holocene carbonate sediment samples of the continental midshelf cores KG 951 VC 1 (Fig. 6A) and VC 2 (Fig. 6B), northeastern Australia. Rain—rainforest taxa; Aq—aquatic taxa; Mang.—mangrove taxa; Pterid.—pteridophytes.

samples contain around 3000 to 5000 grains/cm^3. Samples noted as having a high sand fraction, particularly B2B and B3B, have lower pollen concentrations than samples composed predominantly of silt-sized sediments.

4.2. Surface pollen samples from the Russell/Mulgrave river system

There are some but little significant variation in the pollen spectra that are all dominated by rainforest (see Fig. 4). Conspicuous rainforest components include Arecaceae (palms), Sapotaceae, Sapindaceae, Cunoniaceae, *Elaeocarpus*, *Syzygium*, *Rapanea*, *Ficus* and Euphorbiaceae with many other taxa having low values. The pteridophytes, which are almost exclusively derived from rainforest (with perhaps some contribution from sclerophyll vegetation growing on poorly drained soils and from the mangrove fern *Acrostichum*), are the second most abundant group with *Cyathea* and monolete psilate spores being the major types but with *Gleichenia*, *Lycopodium* and *Drynaria* also conspicuous in many samples. The sclerophyll trees and shrubs component is composed largely of *Melaleuca* with consistent but low values of *Eucalyptus* and *Casuarinaceae*. Poaceae accounts for almost all herb taxa, and Cyperaceae pollen represents the bulk of aquatics. *Pinus* is the only certain exotic, occurring in low values. In addition, single grains of Asteraceae (Liguliflorae) are likely to represent introduced taxa. There is a range of mangrove taxa represented in the relatively low mangrove count. Rhizophoraceae are the major recorded mangrove taxa, but there are also notable percentages of *Exoecaria* and *Sonneratia*. Overall, the pollen spectra display high diversity with a total of 80 taxa identified.

Pollen concentrations are low, ranging between about 100 and 1200 grains per cm^3. Variation between samples can be related largely to the proportion of sand in the sediment.

4.3. Late Holocene pollen sequences from the Grafton Passage

Considering the modest pollen counts resulting from pollen concentrations consistently less than 100 grains per cm^3, the pollen spectra display a great deal of similarity within cores (see Fig. 5). KG 951 VC 2 shows codominance of Poaceae and Cyperaceae with relatively high percentages of monolete fern spores in the top four samples. Mangroves are represented only by members of the Rhizophoraceae family. High values in the basal sample may be a legacy of the noted presence of mangroves over this site during the Holocene marine transgression (Grindrod et al., 2002). Values for both the predominant regional vegetation components, rainforest and sclerophyll trees and shrubs, are low, with the former also displaying surprisingly low diversity. Core KG 951 VC 1 shows a similar predominance of Poaceae and an aquatic component composed of Cyperaceae and *Potamogeton* type, although the Cyperaceae values are lower than in core KG 951 VC 2. All other groups have similar representations to those in core KG 951 VC 2, although individual taxa proportions tend to be different. In the mangroves, *Avicennia* is in competition with Rhizophoraceae, in the fern group, *Cyathea* predominates over monolete spores, while there are no rainforest taxa in common between the diagrams. Casuarinaceae tends to be the best represented sclerophyll woody taxon in both diagrams with both *Eucalyptus* and *Melaleuca* present.

4.4. Late Holocene record from ODP Site 820

Despite the low pollen concentrations, which are consistently between 1000 to 2500 grains per cm^3, intersample variability is very low both in terms of taxa represented and their abundance (see Fig. 6). Rainforest diversity is relatively high with Cunoniaceae clearly dominant and *Elaeocarpus* having significant representation. A large proportion of other rainforest taxa, namely, the conifers *Araucaria*, *Agathis* and *Podocarpus*, and angiosperms, *Trema*, *Celtis*, Arecaceae, *Ficus*, *Macaranga*/*Mallotus*, are present in all or most samples. Sclerophyll trees and shrubs have more moderate representation with highest values for *Melaleuca* and especially *Eucalyptus*, while other taxa, including Casuarinaceae, occur only at low levels. Poaceae has the highest percentages in the diagram and is the only notable representative of an otherwise poorly represented herb group. Other groups are poorly represented although a few individual taxa, including *Triglochin* and *Potamogeton* of the aquatics and *Cyathea* and monolete fern spores of the pteridophytes are consistently present. Mangrove

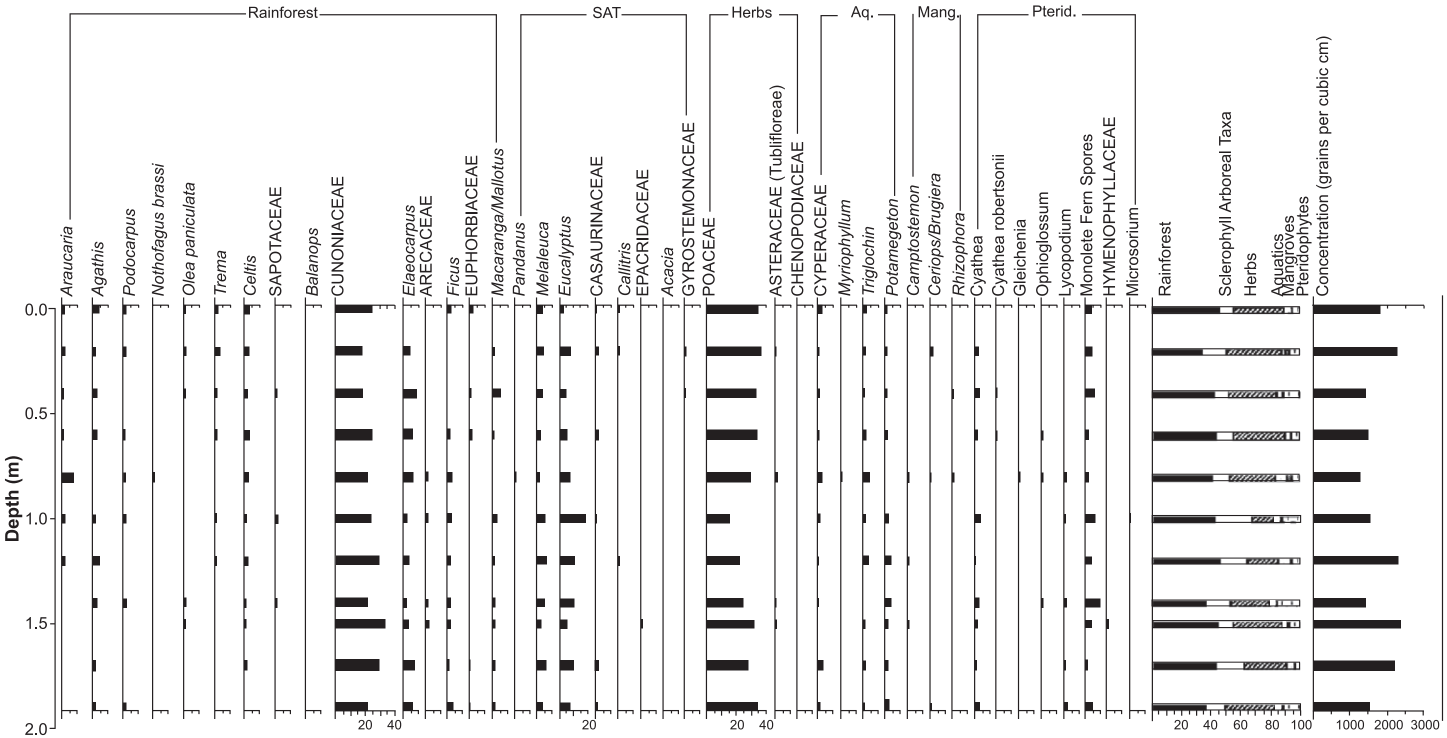

Fig. 6. Pollen percentage diagram for the mid to late Holocene samples of the ODP Site 820 marine core, northeastern Australia. SAT—sclerophyll arboreal taxa; Aq—aquatic taxa; Mang.—mangrove taxa; Pterid.—pteridophytes.

values are very low. One interesting feature is the presence of the mangrove *Camptostemon* that does not presently occur on the adjacent Queensland coast.

5. Environmental reconstruction

5.1. The pollen signal from surface riverine samples

The pollen spectra of the Barron and Russell/Mulgrave river sediments (Figs. 3 and 4) reveal marked differences between the two river systems. The local settings provide some explanation, and interpretation is assisted by results of modern deposition within a variety of swamp and dryland communities previously undertaken within the region that included sites in the vicinity of Mutchero Inlet (Crowley et al., 1994). The Russell/Mulgrave system experiences much higher rainfall resulting in a naturally greater extent of rainforest that is more diverse than that around the Barron estuary. This rainforest component is represented by both rainforest and pteridophyte taxa. Although the rainforest component is much less in the Barron samples, disturbance or drier rainforest taxa, such as *Olea paniculata*, *Trema*, *Celtis* and *Macaranga* are as well represented here, consistent with a drier climate and more broken rainforest cover (see Moss and Kershaw, 2000). As can be predicted from the drier conditions in the Barron River catchment (compared with the Russell/Mulgrave catchment), sclerophyll taxa are more important in the Barron samples. Higher values of *Eucalyptus*, Casuarinaceae and possibly Poaceae are indicative of the extent of open woodland in the drier Barron area, while the predominance of *Melaleuca* in the Russell/Mulgrave is a reflection of more extensive areas of swamp forest or woodland in areas of impeded drainage. The higher representation of Arecaceae derived from palm forests is also indicative of poorly drained environments. Poaceae values may be increased by representation in freshwater swamps (Crowley et al., 1994) and also by human impact, especially the transformation of much of the Russell/Mulgrave area to cane fields. However, percentages are still lower than those recorded in the offshore Holocene sequences, suggesting that human modification could be having minimal influence on pollen spectra or preferential deposition of Poaceae pollen is occurring in the shelf sediments. The pattern of mangrove distribution is interesting. In the Russell/Mulgrave system, there is some variation that relates to the proximity of the samples to mangrove vegetation and its extent, with highest values in Mutchero Inlet and lower reaches of the Russell River and, to some degree, the Mulgrave River, but representation is significant beyond the major extent of these communities. In the Barron River, there is little difference between samples. This could result from some aerial pollen transport but is perhaps best explained by tidal transport, as all samples are within tidal influence.

On a more regional scale, there is evidence of pollen transport from beyond the coastal plain. In the Russell/Mulgrave samples, several well-represented taxa or taxa restricted to these spectra, including Cunoniaceae, Rapanea and *Cyathea robertsonii*, are most indicative of higher altitude rainforest, and as the rivers drain higher and moister reaches of the eastern highlands, the taxa could have been largely river transported from this source. The predominance of southeasterly winds make a significant aeolian source less likely. The higher levels of *Rapanea* pollen in the Mulgrave River samples are perhaps an indication that the Mulgrave embraces much of the higher altitude catchment. It is more difficult to separate lowland and higher altitude contributions to the pollen spectra of the Barron River because most of the large catchment is composed of sclerophyll and drier rainforest vegetation that shows little differentiation with altitude. Any potential contribution from high-altitude source areas may also have been retained by Lake Tinaroo, an artificial lake on the Atherton Tableland formed through a dam built across the middle reaches of the Barron.

5.2. Pollen representation in marine sequences

The Grafton Passage and ODP Site 820 records indicate that processes of pollen deposition and presumably vegetation distributions have not altered substantially over the mid–late Holocene period. This is consistent with results from individual pollen records from the region (Hiscock and Kershaw, 1992) that indicate the attainment of conditions similar to the present day within the last 4000 to 3000 years. However, there are marked differences between pollen representation in the two areas and with the surface samples from the river mouth areas.

All three cores have low pollen concentrations. This can partially but not wholly be explained by distance from terrestrial pollen sources as, taking into account sediment accumulation rates, pollen influx has been consistently lower in the Grafton Passage cores. One explanation is that pollen is no longer channeled along the Grafton Passage as it was during the early Holocene lower sea-level phase. Another possibility is that pollen is transported through the passage, but that currents prohibit deposition on the shelf. This latter explanation is perhaps improbable as the carbonate sediments suggest quiet depositional conditions, as opposed to a turbulent environment, that would tend to favour terrestrial sediment deposition. The composition of the pollen assemblages does not help resolve the issue, as the two best represented taxa, Poaceae and Cyperaceae, have been considered to have a bias towards deposition under low-energy and high-energy conditions, respectively. (Brown, 1985; Catto, 1985; Fall, 1987).

It is highly likely that the pollen assemblages are strongly influenced by the significant westward oceanic inflow from the Coral Sea onto the continental slope and shelf (Andrews and Clegg, 1989; Brinkman et al., 2001). While the cross shelf component of this flow is poorly understood, it is considered that this component is responsible for marine flushing of the continental shelf by the Coral Sea. This strong oceanic influence is likely to have to influenced pollen deposition at shelf and ODP sample locations by preventing river plumes from spreading from near-shore to the outer shelf, obliterating focused tidal transport from inner to outer shelf locations and ensuring a broad latitudinal mix of pollen types in train at any time in the marine water column on the continental shelf and slope. In view of this general circulation model, it is not surprising that the Grafton Passage pollen spectra do not clearly reflect a Barron or Russell/Mulgrave river source. High Poaceae values are more consistent with a Barron source, while high Cyperaceae values and significant representation from *Cyathea* and monolete fern spores are more consistent with spectra from the Russell/Mulgrave river system. The differences in floral composition between the Grafton Passage cores and the two river systems though, either individually or combined, are sufficiently great to consider factors other than simple mixing of pollen from these two sources. The majority of rainforest pollen types represented in the Grafton Passage cores have been recorded as long distance components in the pollen spectra from inland sites to the west of the humid tropics (Kershaw, 1976), suggesting that a predominance of wind transport is a possibility. However, unfavourable wind directions and particularly the low values for the sclerophyll trees, *Eucalyptus* and Casuarinaceae, that have demonstrated high wind dispersal potential relative to rainforest taxa (Kershaw and Bulman, 1994) make this suggestion very questionable.

In contrast to the Grafton Passage cores, which are dominated by herbaceous taxa, the ODP Site 820 record has a more diverse pollen flora, and one that appears more representative of the broader, rainforest-dominated humid tropics vegetation. This is consistent with a greater admixture of terrigenous material in the marine carbonate sediments of the ODP core. A bias towards Poaceae is still evident but, in combination with low Cyperaceae values, suggest a more regional than local swamp source, as Poaceae has a much more substantial representation in dryland communities. Relatively low mangrove values support a regional picture of pollen representation in that mangrove communities, relative to rainforest and sclerophyll vegetation, have restricted distribution at the present day. An alternative or additional suggestion is that mangrove pollen has limited dispersal beyond source areas as suggested by, for example, Muller (1959) and Hooghiemstra et al. (1986). However, this is not a universal phenomenon as deep oceanic basins in the Indonesian region distant from existing shorelines show high values of mangroves during glacial–interglacial marine transgressions when mangrove vegetation was more extensive in the region than it is today (Grindrod et al., 1999, 2002). High representation of Cunoniaceae within the rainforest component is surprising considering that the greatest expansion of the taxon occurred during the early Holocene within the region (Hiscock and Kershaw, 1992) and its preference for high-altitude forests. It perhaps suggests optimal depositional conditions within the marine environment for small pollen grains, especially as the equally small pollen of *Elaeocarpus* also has reasonable percentages. It is unlikely that they indicate wind transport as neither demonstrates great aerial dispersal ability away from rainforest (Kershaw, 1976), and the major wind transported taxon, Casuarinaceae, has very low values. It is surprising that the pteridophytes have such low values as high representation is characteristic of marine records in other parts of the northern Australian–Indonesian region (Kershaw et al., 2002) and are considered to be largely water transported (Hooghiemstra et al., 1986). It is possible that many fern spores are transported beyond this core location as they are proportionately better represented than pollen in marine samples with increased distance from land (van der Kaars, 2001). It has also been noted that offshore water turbulence can complicate distribution patterns of fern spores in offshore sediments (Hooghiemstra et al., 1986).

Although generally reflecting the vegetation of the humid tropics region, there is some evidence of long-distance aeolian pollen transport in the ODP record. *Araucaria* is consistently present in the top part of the sequence, yet this dominance of drier rainforest appears to have been largely eliminated from the region during the last glacial period (Kershaw, 1976) and occurs only in a few remnant patches today. The representation of araucarian forest is greater to the north and south of the humid tropics, including on continental islands from where the pollen is most likely derived, most probably by wind transport considering the predominance of current movement northwards and southwards from this study area. There is a slight possibility that *Araucaria* pollen represents reworking of older sediments on this inherently unstable continental slope. However, radiocarbon dating of late Quaternary part of the ODP core (Peerdeman and Davies, 1993) provided no evidence of sediment disturbance. A northern source is more certain for those grains of *Nothofagus*, subsection *Brassospora*, which have been recorded throughout the late Quaternary ODP record (Moss, 1999). This taxon is presently restricted to New Guinea, and the pollen type has not been recorded in the humid tropics of northeastern Australia in numbers sufficient to indicate the presence of the plant since the late Tertiary/early Quaternary (Kershaw and Sluiter, 1982; Kershaw, 1994). Strong northwesterly winds occurring during autumn, winter and spring mornings (Bureau of Meteorology, 1988) or summer cyclones may be possible mechanisms by which this taxon reached ODP site 820. A similar explanation may be given for representation of pollen of *Camptostemon* as this mangrove is only found to the north of the study area at the present day.

6. Conclusions

Surface pollen samples from the lower reaches of two major river systems have revealed consistent signals of within site similarity and between site differences that reflect the vegetation and climate of the humid tropics region of northeastern Australia. Pollen spectra from recent core sequences from the Grafton Passage within the Great Barrier Reef on the adjacent continental shelf were very different to those in the riverine samples showing marked overrepresentation of herbaceous taxa relative to forest taxa. This poor reflection of regional vegetation fails to support the proposition that pollen was channeled through the passage to the continental slope (Kershaw et al., 1993). However, recent pollen spectra from the ODP Site 820 pollen record located on the continental slope do provide a realistic picture of the regional vegetation. It is tentatively concluded that riverine pollen transport from the humid tropics of northeastern Australia is the major source of pollen to ODP Site 820, but that pollen is probably diffused over a large area rather than being channeled through the Grafton Passage to the site, a suggestion supported by knowledge of major marine current movements. The importance of aerial pollen transport is difficult to assess with our limited number of sites but, due to the predominance of onshore winds through the year and the relatively small proportion of pollen from the extensive sclerophyll vegetation dominated by wind-dispersed taxa, is probably relatively minor.

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