A Quaternary Vegetation History of Northeastern Queensland from Pollen Analysis of ODP Site 820

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9. A QUATERNARY VEGETATION HISTORY OF NORTHEASTERN QUEENSLAND FROM POLLEN ANALYSIS OF ODP SITE 820[1]

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ABSTRACT

Pollen and charcoal analyses of Ocean Drilling Program (ODP) Site 820 on the continental slope, about 60 to 80 km off the northeastern Queensland coast, provide a continuous record of vegetation through the last 1.5 m.y. that complements and extends Quaternary records from the adjacent mainland. Through most of the record, the gross composition of the vegetation, indicated by pollen of drier and wetter rainforests, open sclerophyll vegetation, freshwater swamps and mangroves, changed little although fluctuations did occur that may relate to cyclical changes in climate and sea level. In addition, a reduction in temperatures within the middle Pleistocene might have caused a change in mangrove composition and an increase in higher-altitude taxa, particularly ferns. Evidence exists for the disappearance or reduction in range of a number of gymnosperms throughout the record. Earlier disappearances were probably caused by increased climatic variability and correspond with those elsewhere in Australia. The replacement of araucarian drier forest by open sclerophyll vegetation and the extinction of a species of *Dacrydium* may relate to an increase in burning caused by the activities of Aboriginal people. The initiation of this change is dated between ~150 and 100 k.y. ago, well before the date for a similar change in terrestrial records from the region. However, the date is in line with that from Lake George in southeastern Australia and adds substantially to the evidence of a very early time of arrival of Aborigines and for their impact on the Australian landscape.

INTRODUCTION

Site 820 was selected for palynological study to enhance our understanding of vegetation and its associated environmental changes within a region of substantial biogeographic interest where a great deal of research has already been undertaken on the present-day vegetation and its history. More specifically, the study was designed (1) to help resolve debate over the degree of incursion of southeastern Asian rainforest taxa into northeastern Australia since continental contact during the late Tertiary (Truswell et al., 1987), (2) to attempt correlation with adjacent onshore records and, if successful, (3) to provide a firmer time scale for these records beyond the limit of radiocarbon dating, and (4) to assess the regional extent of vegetation changes during the late Pleistocene, noted from terrestrial records that are considered to have resulted from burning by Aboriginal people (Kershaw, 1986).

GEOGRAPHICAL SETTING

Site 820 lies about 60 to 80 km off the coast of one of the most diverse parts of Australia (Fig. 1), much of which is included in the Wet Tropics World Heritage area. The dominant floristically and structurally complex rainforest ranges from true tropical lowland through submontane to montane on the Eastern Highlands, which include the highest peaks in Queensland, and extends over the basaltic Atherton Tableland. Rainfall, which can attain values in excess of 4000 mm/yr on the coastal plains and mountains, decreases sharply inland and, around the 1500 mm isohyet, 20 to 60 km from the coast, rainforest is replaced by open sclerophyll forest and woodland, dominated by *Eucalyptus* and Casuarinaceae with a grassy understory. A variety of swamp communities, including palm forest, *Melaleuca* woodland, and sedgeland, replace rainforest on the poorly drained lowland plains, while mangroves can be extensive in sheltered estuaries between tidal limits. Saltmarsh is largely absent from these wet, saline environments.

Previous palynological studies have focused on volcanic crater-lake and swamp sites on the Atherton Tableland (Chen, 1988; Goodfield, 1983; Grindrod, 1979; Kershaw, 1975, 1986; Kershaw, Baird, et al., 1991; Walker and Chen, 1987), with some limited research on modern and fossil pollen samples within lowland swamps and mangroves (Crowley et al., 1990). Most fossil records are Holocene, although two sites, Lynch's Crater (Kershaw, 1986; Kershaw, Baird, et al., 1991) and Strenekoff's Crater (Kershaw, Baird, et al., 1991), extend back through at least two glacial cycles and one, Butcher's Creek, provides evidence of late Tertiary or early Quaternary vegetation (Kershaw and Sluiter, 1982).

The region is drained by two major river systems, the Barron River and the Mulgrave/Russell rivers. These discharge into the sea close to the Grafton Passage, which probably carried flow from either or both of these systems across the continental shelf during times of low sea level and may presently provide a focus for sediment transport. Consequently, Site 820 is ideally placed to reflect changes in the range of vegetation within the region, if significant amounts of pollen have been carried in these flows and deposited on the continental slope.

METHODS

The 5-cm³ samples for analysis were provided by the shipboard scientists at ~10-m intervals through the 400-m cored sequence. These were processed at the palynological laboratory of the New South Wales Geological Survey. Samples were initially disaggregated in 30% hydrochloric acid and then left overnight in 30% hydrofluoric acid. After repeated washings in distilled water, they were sieved on an 8-μm screen with the aid of an ultrasonic needle. The residue then was further concentrated by using a heavy liquid zinc bromide solution with a 2.1 specific gravity. Residues were mounted in Eukitt.

Pollen identification was assisted by the extensive pollen slide collection of northeastern Queensland plants within the Centre for Palynology and Palaeoecology, Monash University. Poor preservation in a number of samples together with the use of a fixed mounting medium prohibited the thorough examination of many grains necessary for identification or allocation to refined taxonomic groups. Consequently, most grains were identified only to family or genus
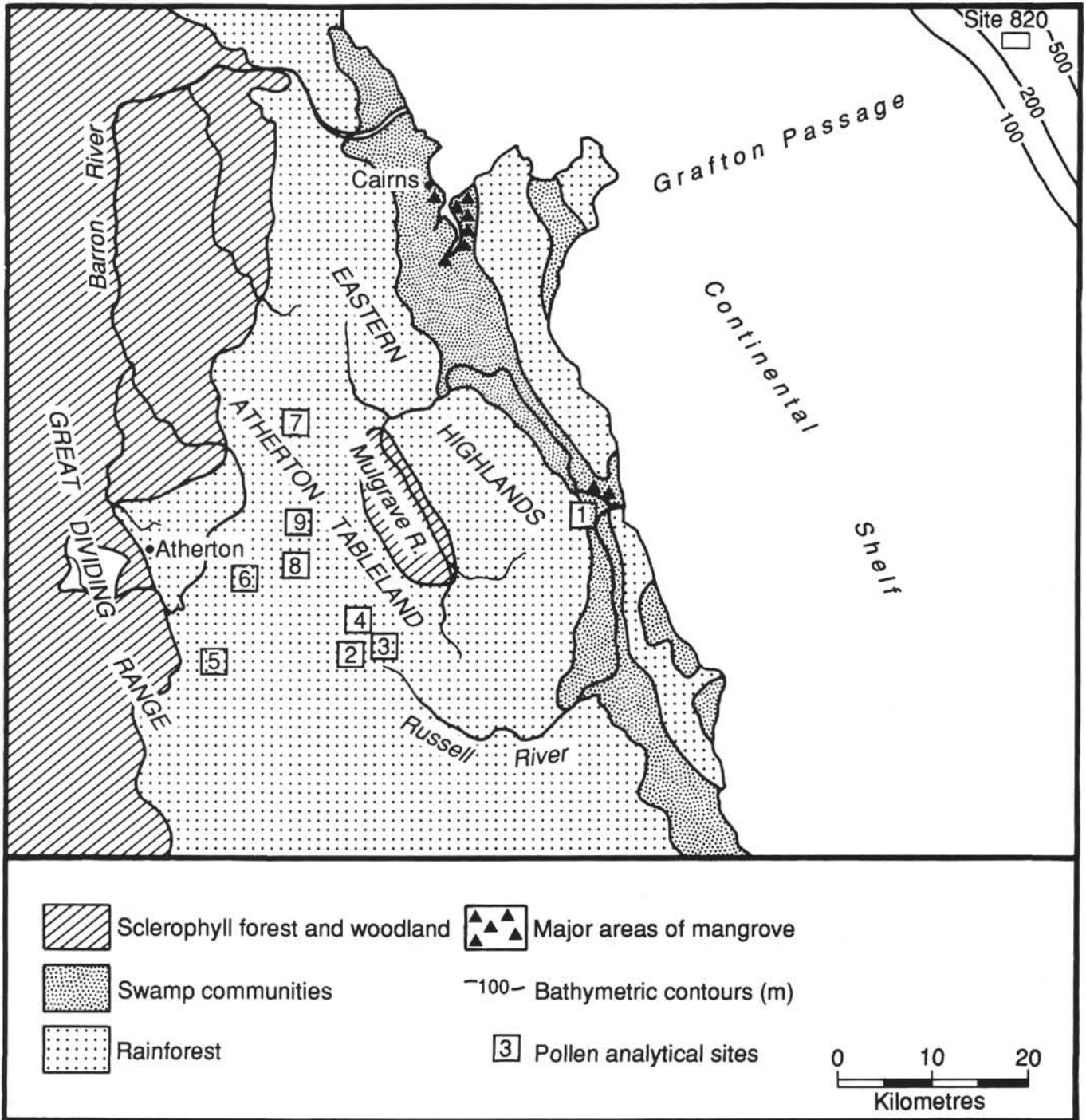
Figure 1. Location of Site 820 in relation to the adjacent mainland, terrestrial pollen sites, and major vegetation types. Pollen sites: (1) Mulgrave River Valley (Crowley et al., 1990); (2) Lynch's Crater (Kershaw, 1986); (3) Strenekoff's Crater (Kershaw, Baird, et al., 1991); (4) Butcher's Creek (Kershaw and Sluiter, 1982); (5) Bromfield Swamp (Kershaw, 1975); (6) Quincan Crater (Kershaw, 1975); (7) Lake Euramoo (Kershaw, 1975); (8) Lake Barrine (Chen, 1988; Walker and Chen, 1987); and (9) Lake Eacham (Goodfield, 1983; Grindrod, 1979).

level, while many angiosperms, and ferns that had lost their exosporia, were left as unidentified pollen and monolete or trilete fern spores, respectively. The term "comp" is appended to taxon names where the grains compare well with the given group but a relationship with another taxon is a possibility. The term "type" is reserved for taxa that compare well with extant species, but ones not now living in this region. All identifications are with botanical taxonomic units, except

for *Tubuliflorides pleistocenicus,* a fossil species (Martin, 1973), whose relationship with an extant taxon is uncertain.

Counting along spaced transects at 400 magnification on individual slides continued until at least 50 identifiable dryland grains had been recorded. Total counts of pollen and pteridophyte spores varied from 98 to 243/sample. Charcoal particles greater than about 10 μm long were counted along three transects on each sample slide. The

results of analyses are presented in two diagrams. The first (Fig. 2) includes a summary of the ratios of major pollen and spore groups, with indeterminate pollen included in the dryland pollen category and monolete and trilete spores included within pteridophyte spores. Also shown are estimates of the pollen concentration of each sample and its charcoal content. To present a realistic impression of fire activity, charcoal values are expressed as percentages of identifiable dryland pollen on the assumption that the influx of this component was relatively constant through time.

The second diagram (Fig. 3) displays all identifiable taxa that occur above trace values in at least two spectra as percentages of the dryland pollen sum.

POLLEN REPRESENTATION

Pollen has derived from a broad range of vegetation types, including rainforest, sclerophyll communities, swamp, and mangroves. The conifers Araucariaceae and *Podocarpus* dominate the rainforest pollen component. Parent trees of both taxa occur as canopy or canopy emergent species in suboptimal rainforest types throughout the region. This habit, combined with relatively high pollen production and wind dispersal, allows high representation, but not to the extent shown on the diagram, at least for Araucariaceae. At present, this family is represented almost entirely by the genus *Agathis*, which does not achieve percentages higher than 10% in any pollen diagram from the region. The other genus, *Araucaria*, has been restricted to small isolated patches. However, *Araucaria* can occur as the dominant of drier rainforest (Webb, 1967), which has been shown to have been much more important within the area in the past (see Fig. 4). Many of the Araucariaceae pollen grains in the core can be assigned to *Araucaria* and the sharp decrease in this Araucariaceae component near the top of the core probably represents the regional decline in *Araucaria*.

It is unlikely that the bulk of gymnosperm pollen was derived by wind transport. The site is a long distance from land, during high sea-level phases at least, and the heavy, wingless Araucariaceae grains are seldom recorded far beyond parent plants within the sediments of enclosed basins (Kershaw, 1973). Also, the predominant winds are from the northeast to southeast, which provides little opportunity for offshore pollen dispersal. Thus, it is likely that most grains were water-transported, a conclusion supported by the relatively large number of fern spores, whose plants are often concentrated along drainage lines.

Other gymnosperms, all within the Podocarpaceae, have limited pollen representation and none exist within Australia today. It is possible that their pollen was derived by long-distance wind transport from areas where they exist at present (i.e., *Dacrydium cupressinum* type from New Zealand, *Dacrycarpus* from New Guinea or New Zealand, and *Dacrydium guillauminii* type from New Caledonia), but more likely they derived from the adjacent mainland. All have had a long history in Australia, and all except *Dacrydium cupressinum* type have been recorded from the Atherton Tableland in the late Tertiary/early Quaternary (Kershaw and Sluiter, 1982) with *Dacrydium guillauminii* type surviving into the late Pleistocene (Fig. 4). Their representation probably reflects the presence of parent plants in the wet, cooler parts of the highlands and tablelands of the region.

In contrast to the gymnosperms, no rainforest angiosperms are well represented. This is also in contrast to terrestrial diagrams (e.g., Fig. 4), where a number of taxa, including Cunoniaceae, Elaeocarpaceae, *Eugenia* complex of the Myrtaceae, and *Nothofagus* in earlier times, have values that, on average, compare with those for the gymnosperms. The almost complete absence of these taxa, excluding *Nothofagus*, which are now widely distributed in the rainforests of the region, is probably due to the small size of their pollen grains; either they have been deposited elsewhere or, more likely, passed through the 8-μm sieve used for sample preparation. *Nothofagus* may have had very limited distribution within the region during the recorded period. The most consistently recorded angiosperms are *Trema*

and *Olea*, which are generally associated with disturbed lowland and drier rainforest assemblages, respectively. However, it was not possible to separate consistently *Olea* from the mangrove taxon *Avicennia*, so that it is difficult to assess the significance of this taxon. A range of other rainforest taxa have scattered occurrence similar to the pattern in terrestrial records and consistent with the limited pollen production and dispersal capabilities of most rainforest angiosperms. The sclerophyll component is dominated by Casuarinaceae and Poaceae, although both taxa have representatives in other groups. Presently, one Australian rainforest species is seen within the Casuarinaceae that exists in small patches to the north of the region, but a larger rainforest component may have been present in the past. As a canopy dominant of a number of sclerophyll communities producing large amounts of wind-dispersed pollen, the high representation of Casuarinaceae similar to the conifers is expected. The major source of Poaceae is likely to be from the extensive open sclerophyll woodlands, although a swamp grass component may be significant. The present dominant of sclerophyll vegetation, *Eucalyptus*, included within the Myrtaceae category, has surprisingly low representation.

Moderate values for Asteraceae and Chenopodiaceae would have derived mainly from open sclerophyll and coastal communities, with the Chenopodiaceae component augmented by any saltmarsh representation within the area. Other sclerophyll taxa either have poor pollen dispersal or are not common within the region and have low and scattered values, similar to those from terrestrial sites.

Domination of the mangrove component by Rhizophoraceae is consistent with studies within mangroves and offshore in tropical regions of Australia (e.g., Crowley et al., 1990, 1992; Grindrod and Rhodes, 1984; van der Kaars, 1991) and elsewhere (e.g., Grindrod, 1988; Muller, 1959; van Campo, 1986). Rhizophoraceae which includes the genera *Rhizophora, Bruguiera,* and *Ceriops*, composes the bulk of mangrove vegetation and produces large quantities of pollen that is well dispersed by wind and water (Muller, 1959). Variations in abundance may have been caused by the changing extent of mangrove forest or by changing proximity to the coring site due to variations in sea level. Other significantly represented mangroves are *Avicennia* and, surprisingly, *Camptostemon*. This latter taxon has not been recorded previously from studies in northeastern Queensland and is presently confined to more northerly latitudes, extending only to 12°31'S along the eastern Australian coastline (Busby and Bridgewater, 1986). It occurs on well-drained sites along tidal waterways (Wells, 1982).

A limited number of ferns have been identified. Of these, the tree fern, *Cyathea*, has the highest representation, followed by the largely epiphytic Polypodiaceae/Davalliaceae. The presence of *Cyathea robertsonii*, a tree fern restricted to cooler rainforests, indicates that higher altitude vegetation is represented in the core although few pollen indicators of this environment are recorded.

VEGETATION AND ENVIRONMENTAL RECONSTRUCTIONS

Reconstructions are related to the limited results of core dating available to the authors. It is thought that the core covers the last 1.3 to 1.5 m.y. Selected dates for the upper part of the sequence are based on microfaunal age ranges and oxygen isotope data presented in Peerdeman and Davies (this volume).

The composition of the vegetation changed little through much of the recorded period. Drier rainforest, with substantial Araucariaceae and some *Podocarpus*, probably dominated the terrestrial vegetation in those areas that experienced less than ~1500 mm annual mean rainfall. Considering that we are presently in a high rainfall phase, the area receiving low rainfall may have been much more extensive than today during much of the period. Araucarian forest also may have colonized exposed continental shelf areas during times of lower sea level, as presently remnant araucarian communities frequently occur on continental shelf islands. Some drier areas, especially on poorer
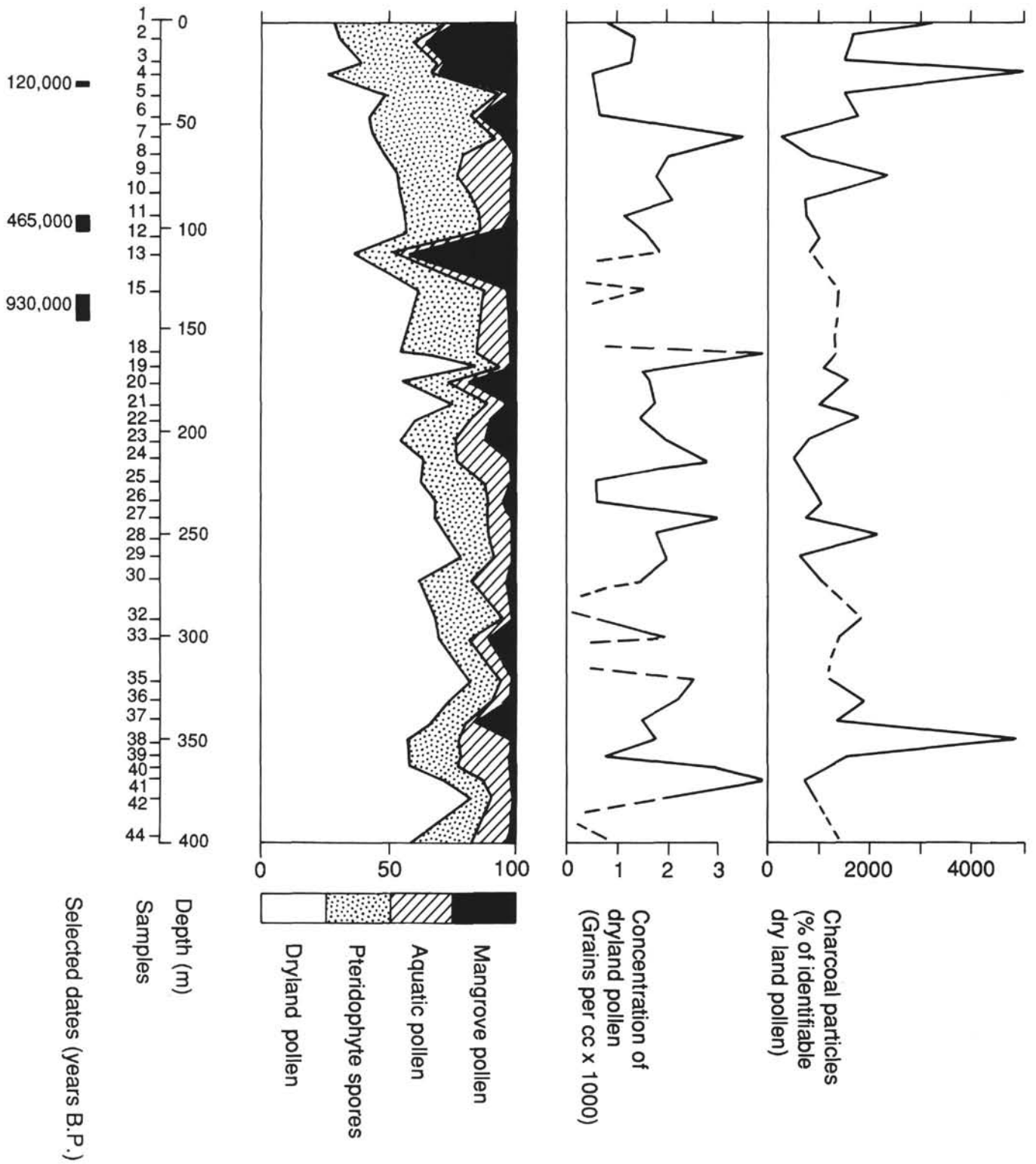
Figure 2. Pollen diagram showing ratios of major pollen and spore groups, dryland pollen concentrations, and charcoal particle content of the sequence from Site 820. Dates are from Peerdeman and Davies (this volume).
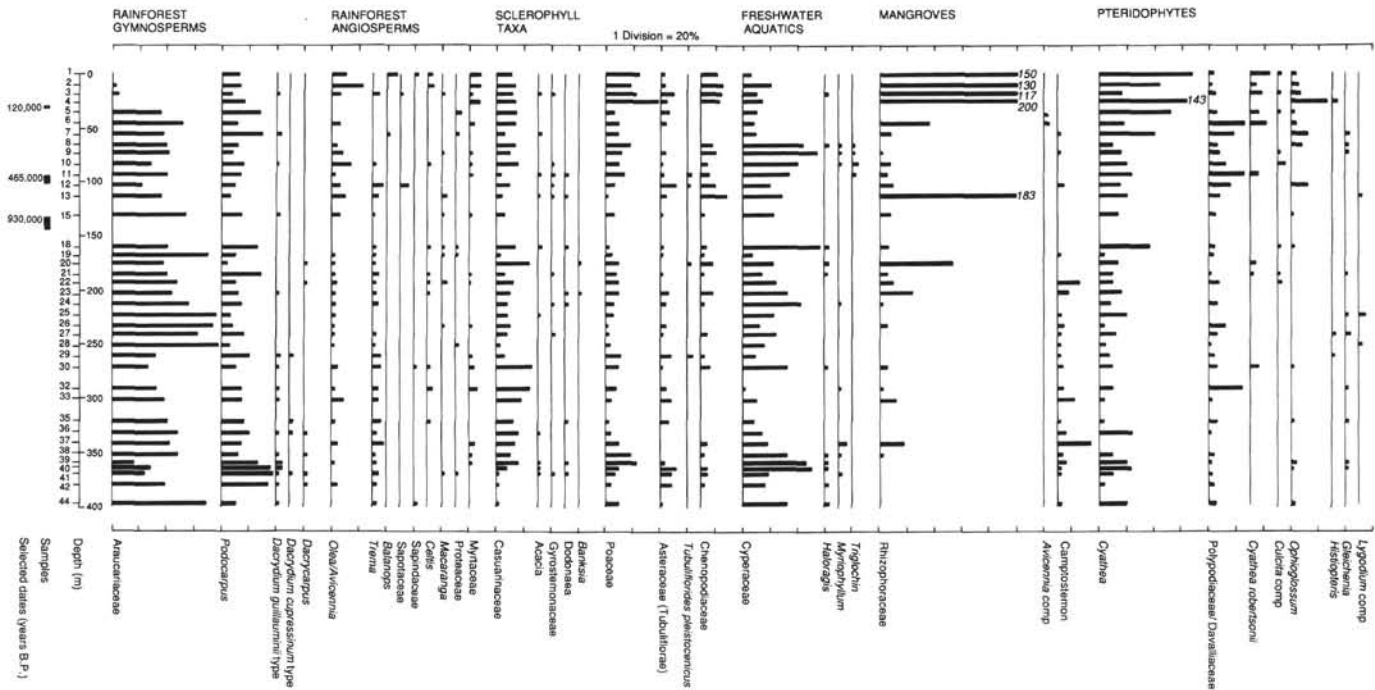
Figure 3. Diagram of pollen taxa from Site 820. Percentages of all taxa are based on the sum of all identifiable dryland pollen taxa. Dates are from Peerdeman and Davies (this volume).

soils, would have supported sclerophyll communities, probably with Casuarinaceae, rather than *Eucalyptus,* as the major canopy dominant and with a predominantly grassy understory. Support for the presence of a significant amount of sclerophyll vegetation is provided by the charcoal curve that indicates the occurrence of regular burning. Fire is not a common feature of rainforest vegetation, whereas many sclerophyll communities require fire for their maintenance.

High levels of Cyperaceae suggest the presence of extensive lowland swamp environments through the recorded period, although little information has been provided for the woody component of these swamps. Mangroves were consistently present.

Fluctuations in abundance of taxa might relate to changing sea levels and/or climate, but the sample interval is too coarse to identify any cyclical changes. The consistently high mangrove values in the top four samples, which span the last glacial/interglacial cycle (Peerdeman and Davies, this volume), suggest that no simple relationship exists between this component and the proximity of the coast to the core site.

Through the sequence there is a gradual loss from the rainforest of members of the Podocarpaceae, which because of their present absence from Australia are considered to represent local extinctions. The likely reason for the extinction of *Dacrycarpus* and *Dacrydium cupressinum* is increasing climatic variability, as both disappear within the early Pleistocene, when the amplitude of global climatic oscillations is considered to have increased. The critical factor may have been either low precipitation during cool periods or increased temperatures during "interglacials," possibly enhanced by the continued movement of the Australian continent into lower latitudes. The survival of *Dacrydium guillauminii* into the late Pleistocene, in some places in abundance (Kershaw, Baird, et al., 1991), suggests that climatic variability was not the dominant factor in its demise.

The early Pleistocene also witnessed a change in mangrove representation, with a decline in *Camptostemon* and an increase in both frequency and abundance of Rhizophoraceae, and possibly also *Avicennia.* The decline in *Camptostemon,* now restricted to lower latitudes, may have been caused by a reduction in temperature. In contrast

to the situation with the conifers, the experience of lower temperatures during glacial periods may have been the critical factor. The increase in Rhizophoraceae values may indicate an expansion of mangroves beyond river estuaries, with the development of a protective barrier reef system (Davies, 1992).

Some support for generally lower temperatures in the period represented by the upper part of the record is provided by a significant increase in pteridophyte spores, whose parent plants are most abundant in cooler forests and, more specifically, by representation of the high-altitude forest indicators *Cyathea robertsonii* and *Balanops.* The increase in Chenopodiaceae may represent an expansion of salt marsh, indicating the development of drier as well as cooler conditions.

The major change within the sequence occurs between samples 5 and 4 and falls within the later part of oxygen isotope stage 5 or the earlier part of stage 6 (see Peerdeman and Davies, this volume) between ~100 and 150 k.y. ago. Here, the dramatic decline in *Araucaria* and increases in Myrtaceae and Poaceae indicate the regional replacement of drier araucarian rainforest by open sclerophyll vegetation and probably, more specifically, eucalypt woodland. The sharp increase in charcoal at this change, followed by the maintenance of relatively high values, strongly suggests that an increase in burning was responsible for the change and that relatively high burning levels have been sustained, preventing any recovery of the fire-sensitive drier rainforests. The wetter forests, existing under mean annual rainfall levels in excess of ~1500 mm, were probably little affected, being capable of maintaining a sufficiently humid microclimate to exclude most fires. However, *Dacrydium guillauminii,* which appears to have been a component of wetter forests on the Tablelands (Kershaw, 1986), died out within this period, and it is possible that some taxa were lost as a result of substantial range contraction at the height of the last glacial period. The disappearance of the mangrove *Camptostemon* might also have been climate-related. Conditions during the last or penultimate glacial stage may have become too cold for the species' survival at these latitudes.

The other major change between samples 5 and 4 is the massive and sustained increase in pollen of Rhizophoraceae. This probably
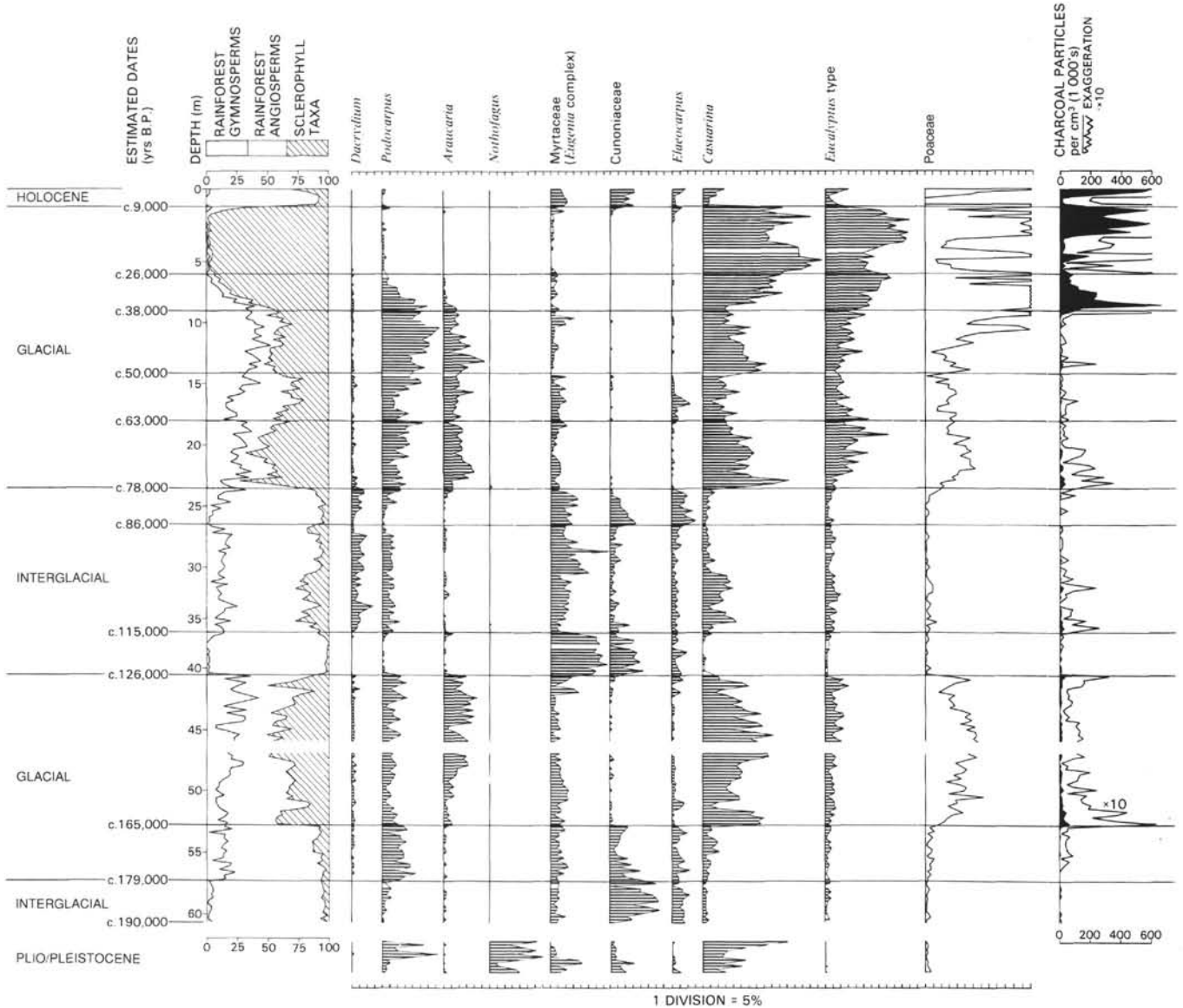
Figure 4. Selected information from the pollen diagrams from Butcher's Creek (Pliocene/Pleistocene) and Lynch's Crater (late Quaternary, ~190–0 k.y.), Atherton Tableland (from Kershaw, 1992).

reflects an expansion of suitable habitat, perhaps resulting from an increase in coastal sedimentation with the change in terrestrial vegetation cover. A rainforest cover would have limited runoff and catchment erosion; however, both these processes are likely to have increased substantially under sclerophyll vegetation and frequent firing. The Rhizophoraceae, much more than any other group, would have been advantaged by an expansion of the mangrove fringe.

REGIONAL COMPARISONS

The small degree of variation in the components of dryland vegetation through the early and middle Pleistocene indicates that the increasing magnitude of Quaternary climatic fluctuations had little impact on gross floristic composition. This accords with other parts of Australia, where information exists (Kershaw et al., 1992). There is also no evidence for arrivals from the southeastern Asian region, although many invasions from this source may have occurred prior to the recorded period. The only identifiable changes are the extinctions of the podocarpaceous taxa *Dacrycarpus* and *Dacrydium cu-*

pressinum type, and perhaps also *Nothofagus* subgenus *Brassospora*. This latter taxon, which is now restricted in its distribution to New Guinea and New Caledonia, was recorded only twice, in samples within the early Pleistocene. All these taxa were widespread within Australia during the later part of the Tertiary and, considering the broad range of latitude encompassed by the continent, some component of precipitation (either increasing variability or periods of very low rainfall) rather than temperature, must have been the critical causal factor in their demise. In southeastern Australia, these taxa had probably disappeared by the very earliest Pleistocene, with extinction possibly assisted by a change there from a summer to winter rainfall regime (Bowler, 1982). Consequently, they probably survived longer in northeastern Australia.

The ODP core appears to shed little light on the likely age of the Butcher's Creek sequence from the Atherton Tableland (see Fig. 4). Here, the spectra are dominated by *Podocarpus, Nothofagus,* and Casuarinaceae, with very low values for Araucariaceae. This suggests that the sequence is likely to be older than Pleistocene. However, no similar spectra are recorded from Site 815 that extends back to the

late Miocene (Martin and McMinn, this volume). It would appear that the Tableland area is not well represented in the offshore record. Furthermore, despite their broad regional pollen dispersal ability, the fact that none of the extinct taxa, and especially *Nothofagus,* which achieved high values at Butcher's Creek, has more than trace values in the offshore cores indicates that their distributions have been limited within the region during the later part of the Cenozoic. From a comparison of the Butcher's Creek sequence with both ODP cores, the age range would be from early Pliocene, when Poaceae, Cyperaceae, and Asteraceae became consistently present, to early Pleistocene, when the podocarps began to disappear from the record. This corresponds almost exactly with the original estimated age range proposed by Kershaw and Sluiter (1982). Within this period, the most likely age is the earlier part of the late Pliocene, which contains a small peak in *Nothofagus* (Martin and McMinn, this volume).

No clear correlation can be seen between the younger part of this ODP record and that from Lynch's Crater on the Atherton Tableland (Fig. 4). The clear, temporal pattern of vegetation variation on the Tableland is masked by the broad regional picture and coarse temporal resolution in the offshore core. The sustained dominance of Araucariaceae until its demise in the top four samples of the offshore core suggests that drier rainforests were widespread, even when replaced by wetter facies on the Tableland during interglacials. The most likely influx of Araucariaceae during these interglacials would have been from those areas now occupied by sclerophyll vegetation, west of the present wet rainforest massif. Pollen may have been transported onto the continental shelf predominantly by the Barron River.

The sharp decrease in Araucariaceae accompanied by a rise in charcoal particles near the top of both the ODP and Lynch's Crater records demonstrate that this was a broad regional feature, most likely induced by increased burning. However, the change appears to have taken place at different times, between 100 and 150 k.y. ago in the ODP core and ~38 k.y. ago around Lynch's Crater. It is possible that the Lynch's Crater date, close to the limit of radiocarbon, is too young and that it was a regionally synchronous event, but this is unlikely. The pattern of vegetation variation at Lynch's Crater suggests that the change took place a long time after the existence of conditions analogous to the Holocene, which is assumed to represent the last interglacial, and a similar change at nearby Strenekoff's Crater is dated closer to 20 k.y. ago, well within the dating limit of radiocarbon (Kershaw, Baird, et al., 1991).

It is possible that, in this relatively moist region, we are witnessing the latter part of a process of replacement of fire-sensitive forests by fire-promoting sclerophylls that has been operating on the Australian continent since the middle Tertiary, in response to increasingly drier and more variable climatic conditions (Kershaw et al., 1992). Here, some destruction of araucarian forests may have taken place during the height of the penultimate glacial period, ~140–130 k.y. ago, while the remaining forests succumbed toward the end of the last glacial period. However, the date for the initial impact (~150–100 k.y. ago) is remarkably similar to that for a sharp and sustained increase in burning accompanied by a marked change in vegetation at Lake George in southeastern Australia at ~130 k.y. ago (Singh and Geissler, 1985). At this site, the replacement of rainforest by more open vegetation had occurred much earlier, ~2.7 Ma (Kershaw, D'Costa, et al., 1991; McEwen Mason, 1991) and the later change was in the nature of sclerophyll vegetation. It was considered to have resulted from increased burning pressure by Aboriginal people, despite the lack of archaeological evidence for such an early presence of people. A similar explanation was also proposed for the change on the Atherton Tableland (Kershaw, 1975, 1986; Singh et al., 1981), where the date is more in line with the archaeological record. The evidence presented here suggests that the change in northeastern Queensland was very much time transgressive and initiated around the same time as that at Lake George. It very much strengthens the case for an early arrival time for Aborigines, and substantial impact on the landscape through burning practices.

SUMMARY

Pollen analysis of Site 820 provides a general picture of the vegetation within the most diverse part of the northeastern Queensland humid tropics from ~1.5 m.y. to the present. The vegetation appears to have changed little through much of the period with domination of the pollen record by the rainforest gymnosperms Araucariaceae and *Podocarpus* and the predominantly sclerophyll family Casuarinaceae, although a general increase is seen in representation of pteridophyte spores and mangroves from the middle part of the record. A change from *Camptostemon* to Rhizophoraceae domination of the mangrove component around this time may indicate lower temperatures during the height of glacial periods. Increased climatic variability may also have been responsible for the disappearance of the podocarpaceous taxa *Dacrydium cupressinum* type and *Dacrycarpus* that were major components of Australia's Tertiary rainforest flora and are now no longer present on the continent.

The major change within the sequence occurred between ~100 and 150 k.y. ago with the regional replacement of drier rainforest characterized by Araucariaceae by open sclerophyll vegetation. The timing of this change corresponds with a similar change from relatively fire-sensitive to fire-promoting vegetation at Lake George in southeastern Australia and adds substantially to the case for Aboriginal burning and an early date for human arrival in Australia.

The record is too coarse to allow for resolution of cyclical fluctuations in climate and sea levels. We propose that more detailed analyses be undertaken, particularly within the upper parts of the sequence, to reveal these fluctuations as a basis for correlation with, and firmer dating of, long terrestrial records from the adjacent mainland.

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