The Tertiary of southeastern Australia : was it tropical?

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In the early part of the Tertiary, Australia was not in tropical latitudes but the climate was warmer and wetter, and the vegetation was mainly rainforest. Most of the vegetation is considered subtropical or warm temperate, but there are a substantial number of tropical taxa present throughout the Tertiary. There is an overall decline in temperature throughout the Tertiary. The mid-Late Miocene was a turning point in the Australian Tertiary as it marks the demise of widespread rainforest and the beginning of the development towards aridity. Today, about one third of Australia lies within tropical latitudes but a large proportion of this area is arid. Remnants of the once widespread rainforest are found in disjunct areas along the northern and eastern coastal strip, including Tasmania.

Key-words—Tertiary, Tropical, Palaeovegetation, Spore/pollen, Dinoflagellates (Australia)

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साराँश

दक्षिण-पूर्वी ऑस्ट्रेलिया का तृतीयक कल्प : क्या यह उष्णकटिबन्धीय था?

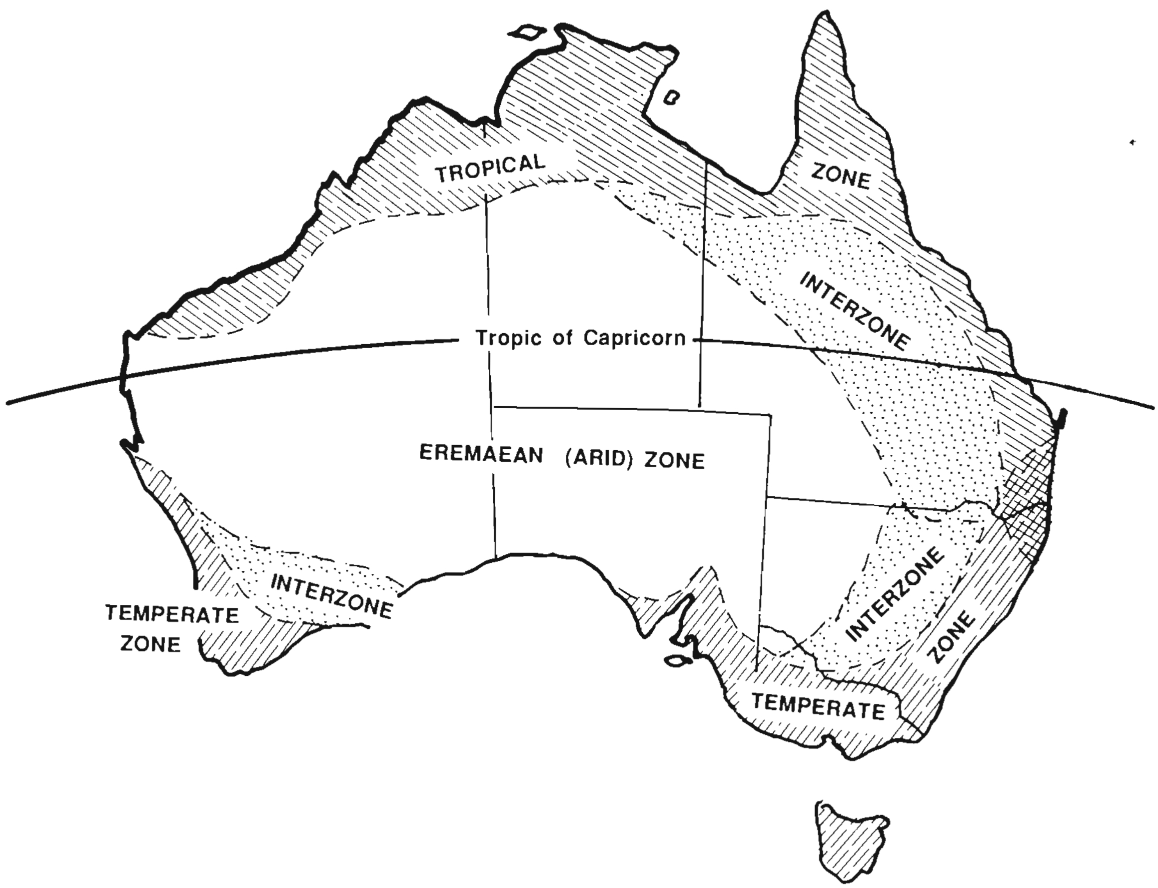
ऐंच० ए० मार्टिन

तृतीयक कल्प के प्रारम्भ में आस्ट्रेलिया उष्णकटिबन्धीय अक्षांशों पर नहीं था बल्कि यहाँ जलवायु नम तथा गर्म थी और वनस्पति मुख्यतया वर्षा-वनों के रूप में विद्यमान थी। अधिकाँश वनस्पति उपोष्ण अथवा उष्ण-शीतोष्ण मानी गई है परन्तु सम्पूर्ण तृतीयक कल्प में उष्णकटिबन्धीय वर्गकों की पर्याप्त संख्या थी। समस्त तृतीयक कल्प में तापमान में गिरावट आती चली गई। मध्य-अनंतिम मध्यनूतन काल आस्ट्रेलिया के तृतीयक कल्प में एक ऐसा परिवर्तनशील बिन्दु है जहाँ से कि वर्षा-वनों का पतन तथा जलशून्यता का प्रारम्भ इंगित होता है। आज ऑस्ट्रेलिया का लगभग एक-तिहाई भाग उष्णकटिबन्धीय अक्षांशों पर विद्यमान है। विस्तृत वर्षा-वनों के अवशेष तस्मानिया सहित उत्तरी एवं पूर्वी तटीय पट्टी के साथ-साथ वियोजित क्षेत्रों में पाये जाते हैं।

THE VIEW has long been held that Australia was once "more tropical" than it is today. Fossil leaves found by the early settlers and travellers were larger and broader than the leaves of the local floras, and more like the rainforests along the coast, thus giving the impression of tropicality.

Much of the early work on the identifications of Tertiary fossil leaves still requires revision. Leaving aside the question of identification, leaf size and other leaf characteristics may be used as indicators of climate, regardless of identification. Generally, larger leaves are found in warmer climates, but available moisture also influences leaf size (Dolph & Dilcher, 1980). In a physiognomic classification of Australian rainforests (Webb, 1959), leaf size is one of the main characters. This classification is used by palaeobotanists to interpret fossil leaf floras. For example, the sizes of the Maslin Bay Eocene leaf flora suggests affinities with modern tropical and sub-tropical rainforests (Christophel & Blackburn, 1978). Maslin Bay, in South Australia is within the Temperate Zone today (Text-fig. 1). Such a comparison, however, is likely to inflate the degree of tropicality. Webb's (1959) physiognomic classification is based upon the size of the sun leaves, the smallest of the mature leaves. In fossil assemblages, however, the smaller sun leaves and the larger shade leaves are mixed together and palaeobotanists should make allowances for this. Even without this allowance, the Tertiary fossil leaf floras undoubtedly suggest rainforests and warmer climates, but as Herbert (1933) points out, rainforests are not necessarily tropical.

Palynology relies on spores and pollen which may be identified with a parent taxon, but they give no indication of climate in the way that leaves do.



Text-figure 1—The phytogeographic zones of Australia (from Burbidge, 1960).

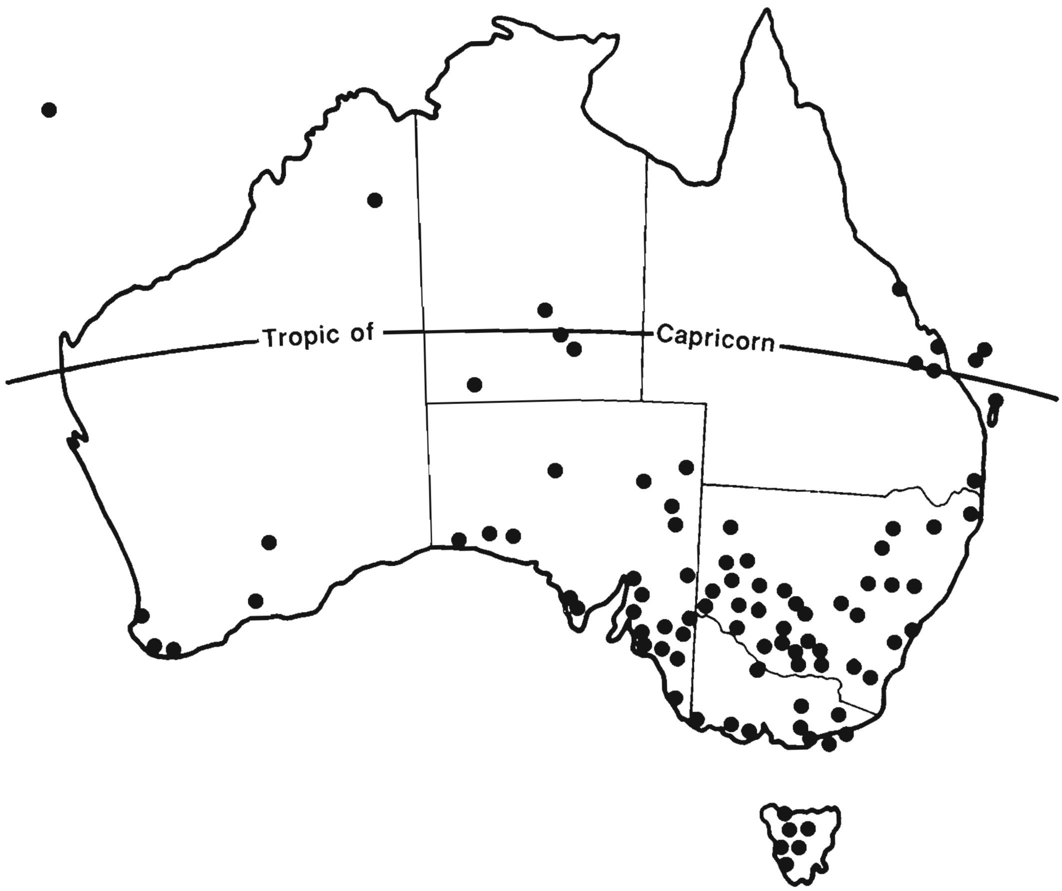
The fossil pollen taxon may be identifiable with a living species, but more often it is only identifiable with a genus or family. This variable level of identification may cause difficulties in determining what is tropical, as a genus or family may contain tropical and extra-tropical species. Tertiary palynology in Australia is concentrated in the south eastern part of the continent: well outside the tropical region (Text-fig. 2). Unfortunately, little is known about the Tertiary palynology in the region which is tropical today.

The question must be asked: What is tropical? Today, approximately one third of Australia lies in tropical latitudes, but this has not been the case throughout most of the Tertiary. Text-figure 3 shows the position of Australia in Mid-Eocene time, compared with today (Crook, 1981). Clearly none of it was within tropical latitudes then. Thus the latitudes were not tropical throughout most of the Tertiary.

It may be said that a climate is tropical. Tropical places are usually warm and wet. The Tertiary climate of Australia was certainly warmer and wetter than that of today. The light regime in the Early Tertiary when Australia was in higher latitudes would have been different, regardless of temperature and precipitation. The summer days would have experienced almost continuous light and there would have been the long polar winter twilight. Growth rings in Palaeocene wood found in the Monaro Region of southeastern Australia reflect this light regime (Taylor *et al.*, 1990).

It may be said that the vegetation is tropical. The vegetation in the warm, wet tropics is usually a rich, diverse rainforest of mainly evergreens, although deciduous trees are often common. Most of the species have large broad leaves. Some taxa may be considered tropical in that their distribution is tropical. Text-figure 1 shows the phytogeographic zones of Australia and the Tropical Zone in the north. Much of the area north of the Tropic of Capricorn, i.e., in tropical latitudes, however, is occupied by the Eremaean or Arid Zone (Burbidge, 1960).

This paper examines the vegetation and climate of the Tertiary and those aspects which may be considered tropical.



Text-figure 2—Location of sites studied for Tertiary palynology. There are very few in the tropical region.

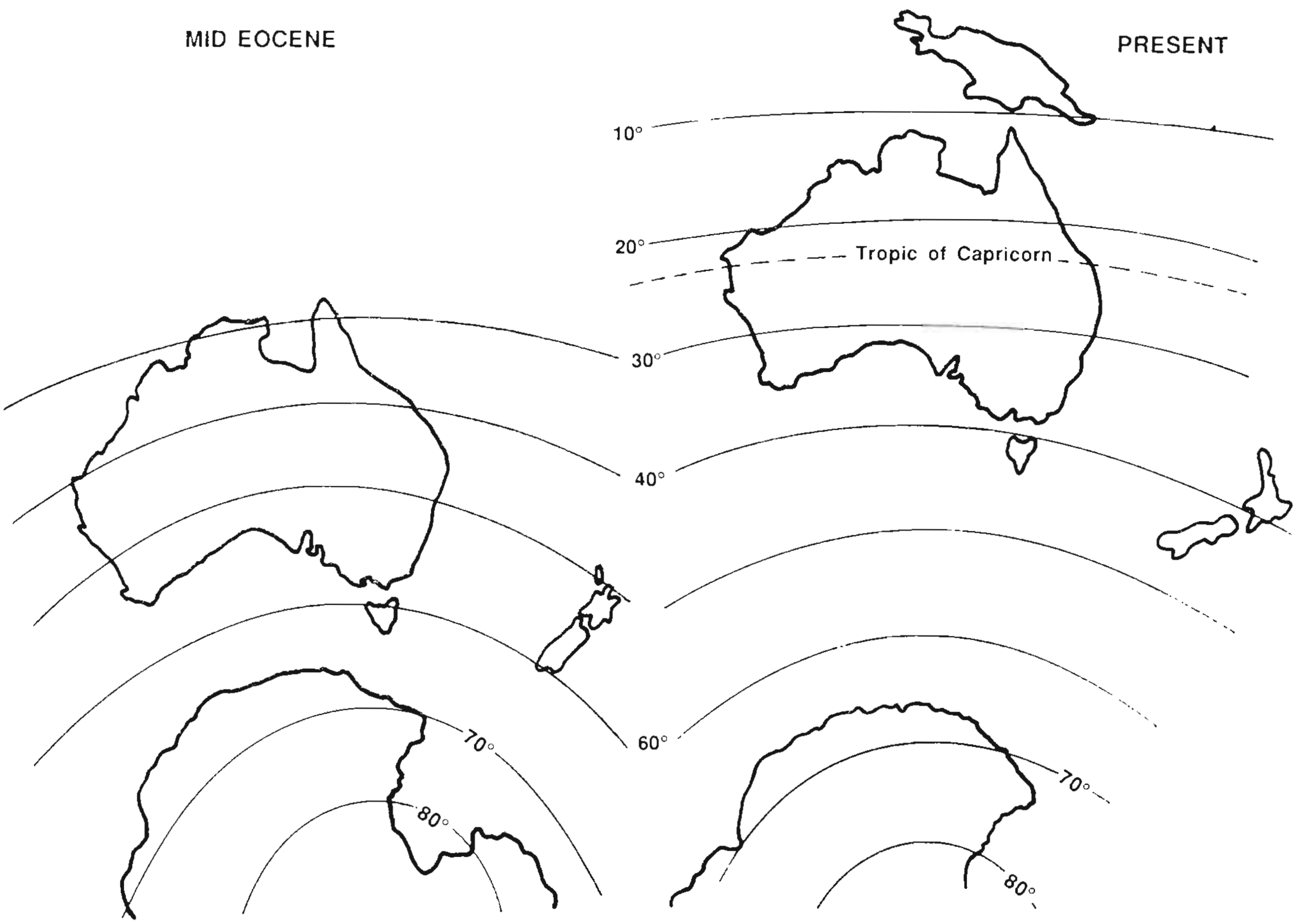
THE TERTIARY FLORA AND VEGETATION

The palynofloras in the tropical region are too few to present any coherent picture of the floras and vegetation. Those in Queensland are undoubtedly related to those in the southeast and comparisons will be discussed later. The Lachlan River Valley in New South Wales has been studied intensively and has the most continuous record. There are some good studies on palynofloras of the earliest part of the Tertiary, but these are not as well known as those from Late Eocene and younger. Gymnosperms are relatively more abundant in the Palaeocene, and angiosperms increase in diversity and abundance. The early and Mid-Eocene has a great diversity of angiosperm types. *Nothofagus* is present (it first appears in the Late Cretaceous), but only in low percentages. Casuarinaceae may be relatively abundant. In the Mid-Eocene, *Nothofagus* becomes the most abundant pollen group.

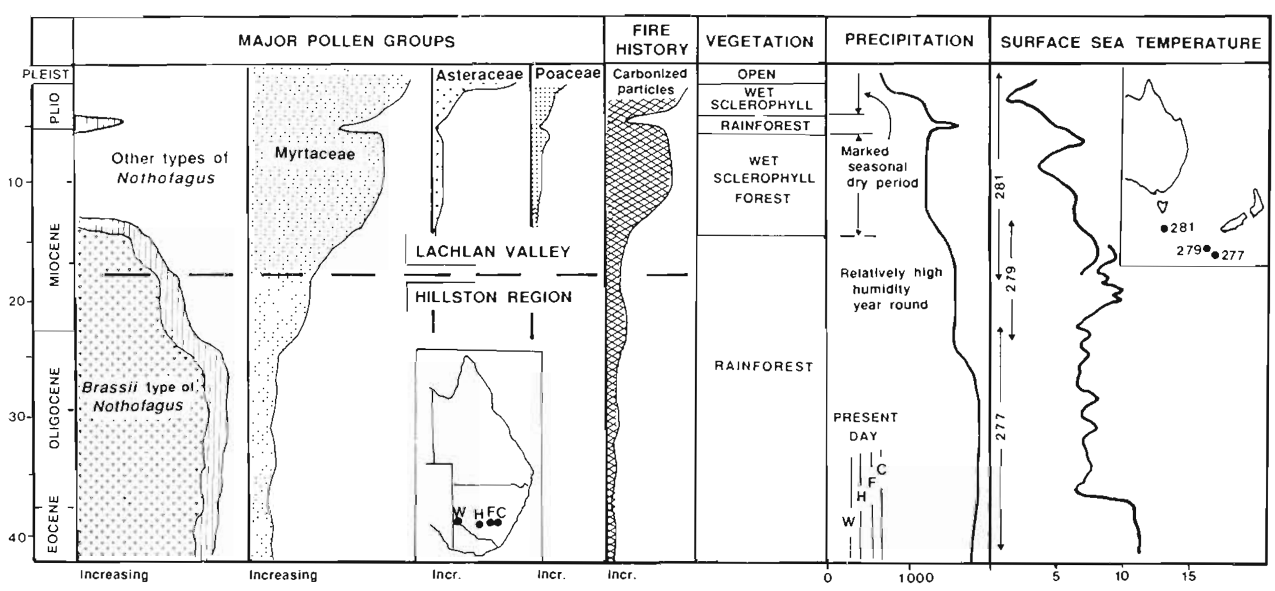
Text-figure 4 presents a diagrammatic summary, constructed from numerous bores, of the major pollen groups, the fire history, interpretations of vegetation and climate (Martin, 1987). From Mid-Eocene to Mid-Miocene, the dominant pollen group is *Nothofagus* with usually 40-60 per cent of the total count (Text-fig. 4). The *brassii* type accounts for most of it and the *fusca* and *menziesii* types are normally only a small proportion. Gymnosperms are usually present, as are Myrtaceae, Casuarinaceae and a wealth of other angiosperm pollen types, each of which is usually only 1-5 per cent of the palynofloras. The vegetation was undoubtedly rainforest throughout the whole time.

It is difficult to assess the relative abundance of *Nothofagus* in the vegetation from these pollen counts. *Nothofagus*, being wind pollinated, is a heavy pollen producer and would be over represented. It was probably common in the forests but it may have been no more abundant than some of the other species which, if insect pollinated, would produce little pollen and be under represented in the palynofloras. *Nothofagus* is not generally regarded as a tropical taxon although the *brassii* type is found today in the montane regions of New Guinea. These forests are probably best regarded as sub-tropical or warm temperate.

The mid-Late Miocene was a time of profound



Text-figure 3—The position of Australia in the Mid Eocene compared with that of today.



Text-figure 4—Diagramatic representation of the major pollen groups, fire history, vegetation and precipitation of the Tertiary of the Lachlan River region (from Martin, 1987). The surface sea temperatures are from oxygen isotope temperatures of deep sea cores for latitudes 40-50 degrees south (from Shackleton & Kennett, 1975). Present day precipitation is for W. Wentworth; H. Hillston; F. Forbes; C. Cowra. These locations are shown on the insert map. The Lachlan Valley extends from Forbes to Cowra.

change. *Nothofagus* disappeared and Myrtaceae became the most abundant pollen group. The family Myrtaceae is ecological heterogeneous and contains taxa of the rainforest, open sclerophyll (eucalypt) forests and species which grow in the arid and semi-arid parts of Australia. The charcoal particle count, however, increases whenever Myrtaceae increases (Text-fig. 4); showing that burning was more common when Myrtaceae is abundant. Rainforests do not burn easily, hence these myrtaceous palynofloras do not represent predominantly rainforest. There are, however, a number of rainforest taxa present in these palynofloras, e.g., *Quinitia, Tasmannia, Dacrydium, Dacrycarpus,* etc. (see Table 1) and *Cyathea* spores may be abundant. The features of these palynofloras best fit wet sclerophyll forest (tall open forest) which has a canopy of eucalypt species, a shrubby/small tree understorey containing some rainforest species and tree ferns (*Cyathea*) may be abundant in gullies and sheltered habitats. Wet sclerophyll forests are regarded as intermediate between rainforests and dry sclerophyll forests: in the latter, eucalypts are dominant and rainforest species are absent. Moreover, wet sclerophyll forests are subjected to burning at regular intervals (Ashton, 1981). Wet sclerophyll forests are generally regarded as temperate.

There was a brief resurgence of rainforest in the Late Miocene-Early Pliocene of the Western Slopes of the Eastern Highlands. This rainforest, however, contains a fraction of the taxa found in the Early Tertiary. The most notable absence is the *brassii* type of *Nothofagus*, and these rainforest are thus quite different to those of the Early Tertiary (Martin, 1991). The *brassii* type of *Nothofagus* probably remained in small relict areas of the Eastern Highlands until the Pleistocene. McEwen Mason (1989) has recorded it from the Late Pliocene-Pleistocene of Lake George.

The Late Pliocene-Early Pleistocene was also a time of major change. The rainforest taxa disappeared, at least from this inland location of the Lachlan River Valley and Asteraceae and Poaceae became abundant (Text-fig. 4). The vegetation became more open, i.e., woodlands and/or grasslands/herbfields. The vegetation was not truly tropical at any time during the Tertiary. There were, however, some tropical taxa present in the Tertiary vegetation and this topic is discussed later.

THE TERTIARY CLIMATE

The precipitation shown in Text-figure 4 has been deduced from the parameters of present day vegetation (Martin, 1987). Briefly, it was very wet,

Table 1—Tropical taxa in the Australian Tertiary

Botanical affinity	Fossil name(s)	Present distribution	Australian fossil distributions	Age
Angiosperms				
ALANGIACEAE				
Alangium ? chinense type C	*Alangipollis* sp. 1, 15	Central Africa	NE Australia 1, 19 Inland SE Australia 6, 12	Late Eocene 1, Oligocene 6, 12, Mid-Miocene 19
Alangium villosum type	*Alangipollis* sp. cf *A. villosum*	NE coast Qld to N coast NSW	SE Australia	Late Eocene-?Miocene 12, 21
ANACARDIACEAE				
?Anacardiaceae	*Tripcolporites paenestriatus* 16 *Tricolporopollenites substriatus* 8	Tropical Zone, E coast Qld to N coast NSW	SE Australia 12 NE Australia 3	early-Mid Tertiary 12
AQUIFOLIACEAE				
Ilex	*Ilexpollenites anguloclavatus* 16	Northern Australia	Widespread in Australian Tertiary 9A	Late Cretaceous 16 to Late Miocene 11
cf. *Sphenotemon* sp.	cf. *Sphenotemon* sp. 18	NE-E Qld	Inland SE Australia 7, 18	Mid-Miocene 18
ARALIACEAE				
Araliaceae	Araliaceae 5	Tropical Zone, N & E Qld to N coast NSW. Two genera in S. central coast NSW, one to Tas.	SE Vic 5	Mid-Miocene

Contd.

Table 1 *Contd.*

ARECACEAE				
Nypa	*Spinozonocolpites prominatus* 13	NE Qld	SE Australia 14	Early Eocene 14, 16
Palmae	?Palmae	Tropical Zone, E coast Qld to N coast NSW	Inland SE Australia 12	?Oligocene-mid* Miocene 12
BOMBACACEAE				
Bombax type	*Bombacidites bombaxiodes* 16	Tropical Central and S America	SE Australia 16	early-Mid Eocene 16
CAESALPINIACEAE				
Caesalpinia type	*Margocolporites vanwijhei* 2	N & NE Australia	Inland SE Australia 12, 18	early-Mid Miocene 12, 18
CONVOLVULACEAE				
Merrimia	*Perfotricolporites digitatus* 2	Tropical Zone	Inland SE Australia 6, 12, 17, 18, 19	Late Eocene 7, Early Miocene 19, early-Mid Miocene 6, 12, 17, 18 Pliocene 12
ELAEOCARPACEAE	*Elaeocarpus* comp 5, cf. Elaeocarpaceae 6	Tropical Zone, E coast and mountains to Tas.	SE Australia 5, 6, 11	Oligocene 6, Pliocene 12
EUPHORBIACEAE				
Austrobuxus/ Dissiliaria	A. *Malvacipollis diversus/subtilis* 16 B. *Polyorificites oblatus* 9 (= *Heliciiporites astrus* 16)	Tropical Zone, E Qld to N Coast NSW	In most reports of Tertiary palynology Miocene 5, 12	A. Palaeocene-mid Miocene 5, 16 B. Mid-Eocene 16-mid Miocene 11
Macaranga-Mallotus	*Triporopollenites endobalteus* 9	Tropical Zone, E. coast Qld & S to Central NSW	Qld 1, inland, SE Australia 12	Late Eocene 1, 12-Pliocene 11
Coelebogyne (= *Alchorina*)	*Psilatricolporites operculatus* 2, 9	Coastal E Qld & NE NSW	Qld 3, inland NSW 11, 12	Oligocene-late Miocene 11, 12 Pliocene 3
Omalanthus	*Omalanthus* comp 5	Tropical Zone and E Coast to Vic (?Tas)	SE Australia 5	Mid-Miocene 5
MALPIGHIACEAE				
Malpighiaceae	cf. *Perisyncolporites pokornyi* 2	NE Qld	Inland SE Australia 6, 7, 12	early-Mid-Miocene 6, 12
MALVACEAE				
Malvaceae	*Malvacearumpollis estelae* 3 *Malvacearumpollis* sp. 18 *Malvacearumpollis mannanensis* 19	Australia wide	Qld 3, 19. Inland SE Australia 6, 12, 17, 18	mid-Late Eocene 1 Miocene (3, 6, 17, 18, 19)
MIMOSACEAE				
Mimosaceae	*Polyadopollenites* cf. *P. granulosus* 7	?	Inland NSW 7	Late Eocene-Early Miocene 7.
Acacia	*Polyadopollenites myriosporites* 16	Australia wide	Southern Australia 11, 16	Early Miocene-Pleistocene
MORACEAE				
Moraceae	Moraceae comp 5	Tropical Zone and central E. coast. One genus, N Eremaean Zone	SE Australia 5	Mid-Miocene 5

Contd.

Table 1 *Contd.*

OLACACEAE				
Anacolosa	*Anacolosidites* sp 13	Tropical Africa, Indomalaysian, Pacific	SE Australia 13 NE Australia 1, 3	Eocene (SE Australia) 12, 13 ?Eocene-Early Miocene, (NE Australia) 1, 3
RUBIACEAE				
Canthium	cf. *Canthiumidites oblatus* 6	Widespread in Tropical Zone & N part of Eremaean Zone	Inland SE Australia 18	Oligocene-Mid-Miocene 6
Gardenia	*Triporotetradites* sp. 18	Tropical Zone, N-NE-E Qld to N coast NSW	Many reports in SE Australia	Late Oligocene-Mid Miocene 18
Gardenia (= "*Randia*") *chartacea* type	*Triporopollenites bellus* 16	Tropical Zone, N-NE-E Qld to N cost NSW	Many reports in SE Australia	Mid-late Miocene 16
Guettarda	cf. *Guettardidites* 7	NE Qld	Inland SE Australia 7	Mid-Miocene 7
SANTALACEAE				
?Santalum	*Santalunudites cainozoicus* 20	?Pacific Islands	Many reports in SE and NE Australia	Eocene 16
SAPINDACEAE				
Cupanieae	*Cupanieidites*	Tropical Zone and E spp. 16	In most reports of Australia to S-central coast NSW	Early Eocene-Pleistocene Australia palynology 16, 12
Dodonaea spp.	*Dodonaea sphaerica* 8	Australia wide	Inland NSW 10, 11, 12	Late Eocene-Pleistocene 12
Dodonaea tripuetra type	*Nuxopollenites* sp. 18	Coastal SE Australia	Central Australia, inland SE Australia	Mid-Eocene 4 early-Mid Miocene 12, 17, 18 Pliocene 12
SAPOTACEAE	*Sapotaceoidaepollenites rotundus* 16	Tropical Zone, W. Qld N. coast NSW	In many reports SE Australia Qld 1, 19	Mid-Eocene 1, 16- Mid-Miocene 5, 19
SYMPLOCACEAE				
Symplocos	*Symplocoipollenites austellus* 16	E. coast of Australia	Many reports in SE Australia	Mid-Miocene 16 Pliocene 12
VITACEAE				
Vitaceae	Vitaceae 5	Mainly Tropical Zone, E coast & Dividing R to E Vic, one genus SW coast WA	SE Australia 5	Mid-Miocene 5
Ferns				
PTERIDACEAE				
Pteris cf. *P. mohaisensis*	*Polypodiaceoisporites retirugatus* 1	?	Qld 1, 3, 19 Inland NSW 7	Mid-Eocene-Mid-Miocene 1, 3, 7, 19
?	*Asseretospera* sp. 1	?	Qld 1 Inland NSW 7	Mid-Eocene 1
SCHIZAECEAE				
Lygodium cf. *L. microphyllum*	*Crassoretitriletes vanraadshooveni*	Tropical Zone, NE coast NSW	Qld 1, 3, 7 Inland NSW 7, 12	Mid-Eocene-Mid-Miocene 1, 3, 7, 12
Dinoflagellate				
Pyrodinium bahamense	*Polysphaeridium zoharyi*	North Australian waters 22	Inland NSW 12	early-Mid Miocene

References: 1, Foster (1982); 2, Germeraad *et al.* (1968); 3, Hekel (1972); 4, Kemp (1976); 5, Luly *et al.* (1980); 6, Macphail (1987); 7, Macphail and Truswell (1989); 8, Martin (1973); 9, Martin (1974); 9a, Martin (1977); 10, Martin (1978); 11, Martin (1987); 12, Martin (unpubl.); 13, Muller (1981); 14, Partridge (1976); 15, Reitsma (1970); 16, Stover and Partridge (1973); 17, Truswell (1987); 18, Truswell *et al.* (1985); 19, Wood (1986); 20, Cookson and Pike (1954); 21, M. K. Macphail (pers. comm.); 22, McMinn (1990); Present distributions are from Willis (1966) and Burbidge (1963) unless specified otherwise. Distributions outside of Australia are given only if the taxon is not found in Australia. For phytogeographic zones and place names, see Text-figure 1.

from Late Eocene, with a decrease in the Late Oligocene-Early Miocene and in the Mid-Miocene. This latter decrease was critical for it reduced precipitation to a level which could not support widespread rainforest. There was a brief increase in the Late Miocene-Early Pliocene and further decreases subsequently. The precipitation has been deduced from the palynofloras and the nature of the sediments supports these deductions. Lignites are common in the Late Eocene-Early Oligocene. Carbonaceous clays predominate until the Mid-Miocene, after which the carbon content is less. However, in the Late Miocene-Early Pliocene, carbonaceous clays are common once again.

Oxygen isotope temperatures from deep sea cores are shown for surface seas of latitudes 40-50°S, in Text-figure 4 also (Shackleton & Kennett, 1975). Briefly, they show a peak in the early-Mid Miocene, much lower temperatures in the mid-Late Miocene with a rise in the Late Miocene-Early Pliocene, before further declines. Thus the higher temperatures coincide with times of widespread rainforest and wetter climates.

TROPICAL TAXA IN THE AUSTRALIAN TERTIARY

There are some tropical taxa in the Australian Tertiary and these are listed in Table 1. Much hinges on the definition of "tropical taxa". For this exercise, those taxa listed as tropical, mostly tropical and sub-tropical in Willis (1966) are included here. There are some anomalies, e.g., Willis lists *Dodonaea* as tropical and sub-tropical, but it is found over practically the whole of Australia, including Tasmania (Burbidge, 1963). *Dodonaea triquetra*, readily identified from its distinctive pollen, is found today in the southern half of the east coast strip (West, 1984), and thus falls within the Temperate Zone (see Text-fig. 1). As a second example, Malvaceae is listed as tropical and temperate (Willis, 1966) and is widespread in Australia (Burbidge, 1963), but the fossil taxon—*Malvacearumpollis* (= *Echiperiporites*) *estelae* (Germeraad, Hopping & Muller, 1968; Hekel, 1972) is almost certainly tropical. There are two other forms of *Malvacearumpollis* (Truswell *et al.*, 1985; Wood, 1986). Clearly, the variable level of identification, i.e., whether a pollen type has been identified to the family, the generic or some other level, has a bearing on this problem. A very liberal interpretation of tropical has been adopted here.

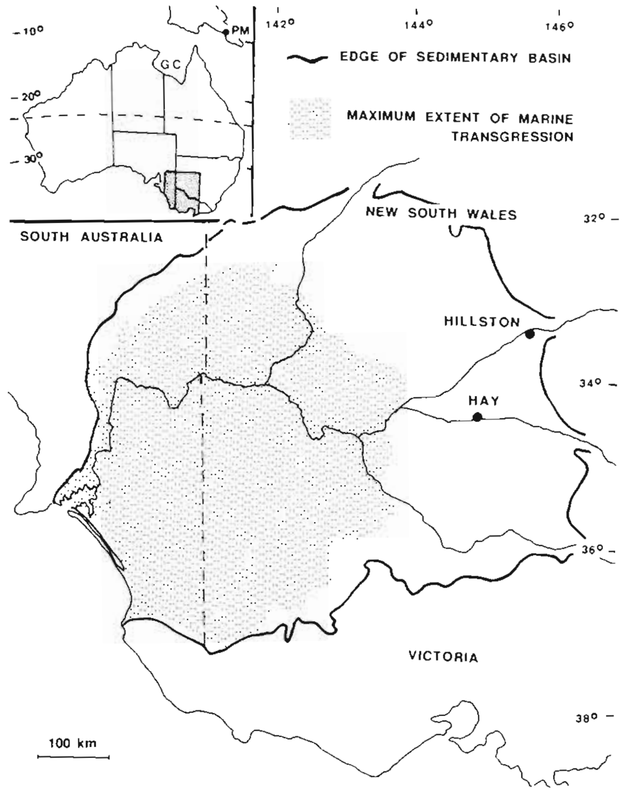
DISCUSSION

Table 1 shows that there is a significant representation of tropical taxa in the Tertiary vegetation of Australia. Some 18 families are represented and some of these have more than one fossil pollen type. Both Euphorbiaceae and Rubiaceae have four different fossil pollen taxa in the fossil record. Most of these taxa are found throughout the period under review.

The Miocene has a surprising number of tropical taxa, in keeping with the peak in palaeo-temperatures. The Late Eocene was warmer than the early-Mid Miocene, but the evidence does not reflect this in numbers of tropical taxa. It may be that the movement of Australia into lower latitudes compensated for the overall cooling trend of this period. The Late Eocene has a number of extinct taxa, hence it is not known whether they would have been more tropical. Whatever the relative tropicality during the Tertiary, southeastern Australia was certainly wetter and warmer than it is today.

The most conclusive evidence about the tropicality of the climate is found amongst the dinoflagellates. In the early-Mid Miocene, a time of high sea level, the shallow Murray Basin (Text-fig. 5) was flooded. Hay on the Murrumbidgee River would have been some 60 km from the accepted limits of the marine transgression, but the river estuary would have been flooded by a minor rise in sea level, as this area is very flat. The dinoflagellate assemblages at Hay contain some 94 per cent of the cyst *Polysphaeridium zoharyi*. The living stage of this cyst, *Pyrodinium bahamense* is well known in tropical regions today as it is toxic. A survey of dinoflagellates in surface sediments of estuaries and bays in eastern Australia shows comparable quantities of *P. zoharyi* in Port Morseby Harbour, New Guinea and the Gulf of Carpentaria today (McMinn, 1990). Hence for a brief interval in the early part of the Mid-Miocene, at least one part, south eastern Australia may have had a truly tropical climate.

Today, southeastern Australia has a variety of environments and ecosystems, and this would have been true for the Tertiary also. Macphail *et al.* (1991) report Late Oligocene-Early Miocene palaeofloras from the montane region of Tasmania. The pollen assemblages show a general similarity with those of the same age elsewhere in southeastern Australia. The leaf floras, however, are remarkable in that all leaves recovered are less than 3 cm long and most (88.5%) are less than 1 cm long, and a similar leaf-size spectrum occurs in at least one modern



Text-figure 5—*Polysphaeridium zoharyi*, the cyst stage of the toxic dinoflagellate *Pyrodinium bahamense* are found in the Mid-Miocene sediments of what would have been the estuary of the Murrumbidgee River at Hay. Today, comparable numbers of cysts are found in Port Moresby Harbour (PH) and the Gulf of Carpentaria (GC).

subalpine lake! (Macphail *et al.*, 1991). Thus while a tropical environment may have existed along the shoreline of the Murray Basin, the montane regions of Tasmania were sub-alpine.

The few reports of Tertiary palynology in northern Australia (Foster, 1982; Hekel, 1972; Truswell & Harris, 1982; Wood, 1986) record palynofloras generally similar to those of the south-east. These reports are too few in number to show geographic variation in the Tertiary flora and vegetation. Such variation must have existed during the Tertiary, just as it exists today. Where there is sufficient evidence, geographic variation may be mapped. For example, in the early-Mid Miocene, Myrtaceae and Araucariaceae were more common in inland regions, whereas *Nothofagus* was the most abundant pollen type in coastal regions (Martin, 1990).

When the fossil and present day distribution of the taxa are compared (Table 1), it shows that former widespread distributions have contracted to northern and eastern coastal Australia. Northeast Queensland is particularly rich in these relict distributions. This restriction of distributions has resulted from the development of the arid interior of Australia. The northern and east coast strip, extending south to Tasmania, are the only regions which are wet enough to support these ancient rainforest taxa.

This review is primarily concerned with the Tertiary, but the Pleistocene glacial-interglacial cycles must have had a profound effect on the distribution of rainforest. We are at present in an inter-glacial period, when it is warmer and wetter than glacial times. During the last glacial period, temperatures were some 9° lower and the summer temperatures would have been like present day winter temperatures for the south eastern highlands (Galloway, 1965). It was also drier and more windy. The sand dunes of the arid and semi-arid regions, which are mainly vegetated and stable today, were mobile in the glacial periods (Bowler, 1976). Models of the vegetation of northern Australia during the last glacial period, constructed from the climatic parameters controlling vegetation, show that there were no mappable areas of rainforest on the Australian mainland (Nix & Kalma, 1972). Thus there has probably been substantial change in the rainforest since the Tertiary. Indeed, some Tertiary taxa, now no longer growing on the Australian mainland, existed into the Pleistocene. For example, *Dacrydium, Dacrycarpus, Phyllocladus* and the *brassii* type of *Nothofagus* were found in northeast Queensland prior to the last glacial period (Kershaw, 1985; Note: these taxa are not considered tropical, they are examples of changing distributions.)

A tropical element in the Australian flora has long been recognised and is variously known as "Malaysian", "Melanesian" or "Indo-Melanesian" (see the discussion by Burbidge, 1960). It had been thought that this element migrated into Australia in relatively recent times. The fossil record, however, shows that many of these taxa have been in Australia for a very long time. Some of these taxa were present in south eastern Australia when it was adjacent to Antarctica. On the basis of plate tectonics, an influx of "tropical" taxa may be expected when Australia came into contact with the Indonesian region in the mid-Late Miocene. This proposition is examined by Truswell *et al.* (1987) and no marked influx is found. An exchange of taxa, more or less throughout the Tertiary, even though these two regions were once widely separated, is evident from the fossil record (Truswell *et al.*, 1987). Though proximity may be conducive to migration between the two regions, it should be remembered that the Australian environment is very different to that of New Guinea and Indonesia. Australia has a large, arid interior, the development of which started in mid-Late Miocene time. The soils of Australia are mostly very old and infertile (Bowen, 1981; Martin, 1982). These two factors are in sharp contrast to most of New Guinea and Indonesia where volcanism, fertile soils and high rainfall create a very different environment for plant growth. In a comparison of rainforests in north eastern Australia with those of New Guinea, Webb and Tracey (1972) found that similar habitats shared similar rainforest taxa, but that the habitats in New Guinea were, for the most part, different to those in Australia. When adjacent rainforest and sclerophyll eucalypt communities in northeastern Australia are compared, the difference are far greater than comparisons of similar habitats in Australia and New Guinea.

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