

# VICTORIAN PALEOGENE AND NEOGENE MACROFLORAS: A CONSPECTUS

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Victoria has a rich record of Paleogene and Neogene vegetation represented in a diverse range of macrofloras ranging in age from Paleocene to Pliocene. These macrofloras are present in deposits ranging from the laterally extensive and thick brown coal and associated interseam clays of the LaTrobe Valley, to small clay lenses with leaf impressions or scattered plant fragments preserved under the basalts of the Dargo and Bogong High Plains. Most floras are composed of leaf compressions (or mummifications) or leaf impressions. There are also significant accumulations of seeds, fruits or silicified wood fragments in placer deposits known as 'deep leads'. Rare sites include tree stumps in growth position, in some instances representing 'fossil forests'. Amber containing fossil insects and leaves is known from a single site. The Victorian Paleogene and Neogene macrofloras provide an extensive yet largely unexploited database for palaeoenvironmental, biostratigraphic and palaeoclimatic analysis.

AUSTRALIA'S Paleogene and Neogene macrofloras are a primary record of the evolution of vegetation and climate; they reflect a Gondwanan conifer- and angiosperm-dominated floristic heritage established after the dominant pteridosperm and ginkgophyte floral elements of the mid-Cretaceous were replaced by angiosperms. Duigan (1951) listed 129 macrofloras in a catalogue of the Australian Tertiary floras known at that time, of which 55 were found in Victoria. Douglas (1990) noted that in addition to the floras listed by Duigan, another 30 Victorian Cenozoic (Paleogene and Neogene) macrofloras had been discovered since the 1950s, and that the actual number of floras may exceed 100. Some of these floras were listed by Hill (1988a) and Greenwood (1994). Publication of two successful non-specialist books on palaeobotany (White 1986, 1994) and a specialist edited volume (Hill 1994) indicates great interest in Australian palaeobotany, and in the floras of the Cenozoic in particular, but also indicates the greater variety of previously largely unknown or unreported macrofloras. This paper is an attempt to redress the lack of review and summation of information regarding the Cenozoic macrofossil record of Victoria.

Victoria figured early and prominently in Australian Cenozoic macrofossil palaeobotany, with Mueller (1874, 1883), McCoy (1876, 1878), and Ettingshausen (1883, 1886, 1888, 1891) describing Victorian plant fossils. This work was maintained with descriptions of macrofloras under 'auriferous drifts' or deep leads (Deane 1923; Chapman 1926a)

and those associated with coal deposits (Deane 1902b, 1902d, 1925; Paterson 1935; Cookson 1947; Cookson & Duigan 1950; Patton 1958; Duigan 1965). Researchers identified several important geographical areas with numerous fossil floras, including the Victorian High Plains (eg. Murray et al. 1878) and many close to Melbourne (Deane 1902c, 1904; Patton 1919, 1928; Paterson 1934; Gill 1949; Gill & Baker 1950). Research described not only leaf floras (eg. Deane 1902a), but also fruits (Chapman 1914; Pike 1952) and wood (Chapman 1918). Individual elements of these macrofloras were identified as significant early on, including *Eucalyptus* (Chapman 1926b), *Casuarina* (Patton 1936), *Acacia* (Cookson 1954), Banksieae (Cookson & Duigan 1950), cycads (Cookson 1953), *Dacrydium* (Cookson & Pike 1953b) and other podocarps (Cookson & Pike 1953a, 1954). Reviews of this large body of research were produced by Deane (1900); Chapman (1921); Howchin (1928); Duigan (1951) and Gill (1952). A number of Cenozoic localities have subsequently achieved prominence (eg. Christophel et al. 1987; Christophel 1989, 1993, 1994; Greenwood 1987, 1994; Pole et al. 1993). Some localities such as Berwick were extensively studied due to the presence of significant taxonomic entities such as the 'earliest' *Eucalyptus* macrofossils (Deane 1902b; Chapman 1926a, 1926b; Pole et al. 1993), or by virtue of their scale, as evidenced by continuing interest in the macrofloras of the LaTrobe Valley coals and associated sediments (Chapman 1925a, 1925b; Deane 1925; Cookson &

Duigan 1950; Cookson & Pike 1953a, 1953b, 1954; Pike 1952; Patton 1958; Duigan 1966; Blackburn 1981a, 1981b, 1985; Greenwood 1981; Blackburn & Sluiter 1994).

This paper is a compilation of information on most known Paleogene and Neogene macrofloras in Victoria. Earlier catalogues of Paleogene and Neogene macrofossil localities produced by Duigan (1951) and Hill (1988a) provided details of validly published taxonomic entities. Previous syntheses of Australian Cenozoic macrofloras have provided 'overviews' (eg. Chapman 1921; Gill 1952, 1975; Barlow 1981; Christophel 1981, 1989, 1993; Christophel & Greenwood 1989; Hill 1990a, 1992b) but generally included little specific information on the sites, and omitted some macrofloras. The value of collating and assessing site information for individual 'floras' is shown by a stratigraphic evaluation of the Vegetable Creek and Elsmore macrofloras, which indicated a series of sites spanning the Late Eocene to Early Miocene, each with a characteristic 'flora' (Pickett et al. 1990).

Information on the Paleogene and Neogene macrofloras of Victoria has been derived from museum records, personal communications, field reconnaissance, published literature and from detailed maps and reports produced by the Geological Survey of Victoria over more than 100 years. These Geological Survey publications provide a wide range of information, ranging from the Casterton 1:63 360 sheet describing the Eocene Duntroon Formation and noting the presence of carbonised plant remains, the Colac 1:50 000 sheet that first noted the Lake Colac macroflora (see below), and the Report of Progress (Murray et al. 1878) that provided specific locality information and the first descriptions of the Paleogene macroflora at Bundara River (see below). Where possible, we have provided information on stratigraphic arrangement of macrofloras, including information on spore-pollen zones and stratigraphic nomenclature. It is hoped this compilation will encourage study of Paleogene and Neogene macrofloras not in isolation, but as individual samples of a continuum of past vegetation. As previously stated by Douglas (1990), the variety and temporal and geographic spread of Victorian macrofloras affords opportunities for broad regional syntheses.

#### A HISTORY OF VICTORIAN PALEOGENE AND NEOGENE MACROFOSSIL PALAEOBOTANY

Research on Victorian Cenozoic macrofossil palaeo-

botany is here divided into four periods: late 19th Century, 1900 to 1940, 1940 to 1970 and 1970 to 1999. The most recent period has included a shift in emphasis to pre-Cenozoic Victorian floras, and to macrofloras outside Victoria (see Douglas 1969, 1973, 1990; Gould 1975, 1981). Significant advances were made in descriptive and stratigraphic palynology by Victorian palaeobotanists such as Cookson from the 1920s to the 1970s. These advances combined with research relating to commercial oil exploration in the Gippsland Basin contributed to the palynostratigraphic framework currently used for most of the Cenozoic macrofloral record (eg. Stover & Partridge 1973; MacPhail et al. 1994; Partridge, in prep.).

#### Late 19th Century

Earliest descriptions of the Cenozoic flora of Australia, for example those of Mueller (1874, 1883), Ettingshausen (1883, 1886, 1888, 1891), McCoy (1876, 1878), Johnston (1885, 1887) and Schimper & Schenk (1890) must be viewed with an understanding of the limitations of their times. These researchers assigned many Australian Cenozoic plant fossils to Northern Hemisphere taxa such as *Quercus*, *Laurus* and *Fagus*, or implied relationship to such genera, such as *Pseudopinus wilkinsoni* Ett. from Vegetable Creek (syn. *Podocarpus wilkinsoni* (Ett.) Selling 1950). Although more recent researchers (eg. Deane 1900; Selling 1950; Christophel 1981, 1993) were to decry this practice, it was probably the consequence of a more thorough knowledge of European rather than Australian plant morphology, systematics and ecology at that time. An extension of early palaeobotanical research was the perception of an Australian Paleogene '*Cinnamomum* flora', typified by large-leaved Lauraceae with acrodromous venation (eg. *Cinnamomum polymorphoides* McCoy) and other leaves of the 'brush type', a reference to similarity with vegetation now termed subtropical to tropical rainforest.

Of greater controversy at the time was Ettingshausen's 'Cosmopolitan Theory' (Ettingshausen 1888), which proposed that all continents had originally supported essentially the same community of taxa, and that evolution and extinction had subsequently led to differentiation of the distinctive floras of Australia and other parts of the world. This theory was criticised by palaeontologists at the time (eg. Deane 1900; Andrews 1916); however it was largely ignored by researchers in areas other than palaeontology (Hill 1994).

Principal Victorian macrofloras discovered and described in this early period were mostly associated with gold diggings and included Daylesford, Eldorado, Foster, Haddon, Maddingley, Tanjil, Thorpdale, Werribee Creek and the High Plains. The bias towards descriptions of fossil seeds in the taxonomic research of Mueller reflects the macrofloras associated with deep lead deposits. This research is still considered to have some systematic value (eg. Rozefelds & Christophel 1996a, 1996b). A fossil seed of *Xylocaryon lockii* F. Muell. from Haddon near Ballarat figured by Mueller (1883) was recently recognised as equivalent to extant *Eidothea zoxylocarya*, a previously undescribed monotypic genus of Proteaceae assigned to the monogeneric subfamily Eidotheoideae (Douglas & Hyland 1995). *Penteune clarkei* F. Muell., common in Victorian deep leads, was subsequently matched with endocarps of extant *Elaeocarpus* (Selling 1950; Rozefelds & Christophel 1996b). Other common seed or fruit types described by Mueller from the deep lead floras, such as *Spondylostrobus* F. Muell., remain enigmatic although some affinity with Cupressaceae was suggested by him at the time.

#### 1900–1940

Significant palaeobotanical studies in this period were produced by Deane (1900, 1902a, 1902b, 1902c, 1902d, 1904, 1923, 1925), who described important leaf floras at Berwick, Sentinel Rock and Mornington, and a deep lead flora at Foster in South Gippsland. The most important work (Deane 1900) was a brief account of Australian Cenozoic floras, including an extensive critique of Ettingshausen's (1883) 'Cosmopolitan Theory' of plant evolution and a discussion of problems relating to the use of leaf venation as a diagnostic tool in macrofossil taxonomy. Deane (1900) recognised that many identifications of Australian Cenozoic macrofossils as Northern Hemisphere genera, such as *Quercus* (Fagaceae; Ettingshausen 1883), were based on apparently limited comparisons of leaf morphology, and were more likely to represent extant Australian genera. Significantly, Deane (1900) argued that leaf venation and general leaf architecture were so variable within genera as to be almost useless as a diagnostic tool, and thus many identifications based on leaf features, such as *Cinnamomum* (Lauraceae), were suspect.

Other researchers active in this period included Chapman (1914, 1918, 1921, 1925a, 1925b, 1926a, 1926b), Patton (1919, 1928, 1936), and Paterson (1934, 1935). Anecdotal records from several sites were also published (eg. Keble 1925; Thomas 1932; Ewart 1933), some of which indicated the existence

of Cenozoic floras in the Eastern Highlands and East Gippsland (Chapman 1918; Kenny 1937). The open-cut coal mine at Morwell provided the first plant fossil material (primarily seeds and wood) from the extensive thick brown coals of the LaTrobe Group sediments in the LaTrobe Valley (Deane 1923; Chapman 1925a, 1925b; Nobes 1922). Material from several sites near Melbourne was also described (Armitage 1910; Chapman 1914; Patton 1919; Paterson 1934), reflecting increased roadworks and the construction of the new Melbourne sewerage system. Deane (1902a) and other workers also published accounts of Cenozoic floras from outside Victoria at this time. Research by European workers continued on from Mueller's work, and included description or reclassification of seeds from deep lead floras (Kubart 1922; Kirchheimer 1935). Reviews of Australian Cenozoic floras were included in papers by American (Andrews 1916) and Australian (Chapman 1921; Howchin 1928) researchers. Both Maiden (1922) and Chapman (1926b) reviewed the Paleogene and Neogene macrofossil record of *Eucalyptus*, based largely on Victorian material.

#### 1940–1970

This period saw very active palaeobotanical research into Victorian Cenozoic macrofloras, largely through the efforts and influence of Isabel Cookson and her associates, based mainly in the School of Botany at The University of Melbourne. Cookson researched macrofloras and microfloras (pollen, spores and plankton) ranging from Silurian to Pleistocene, and a thorough account of her achievements is beyond the scope of this paper (see Baker 1973 for a complete bibliography). The hallmark of Cookson's research was an appreciation of the importance of establishing taxonomic relationships based on detailed comparison of anatomical diagnostic features of both fossil and extant taxa (eg. Cookson & Duigan 1950).

Few additional Cenozoic macrofloras were described in this period, although major advances were made in understanding the systematics of many macrofloras, particularly those of the LaTrobe Valley coal measures, by Cookson (1947, 1953), Cookson & Duigan (1950, 1951), Pike (1952), Cookson & Pike (1953a, 1953b, 1954), Clifford & Cookson (1953) and particularly by Duigan (1965). Gill and co-workers documented Cenozoic macrofloras near Melbourne, such as Lilydale (Gill 1942) and within the Melbourne metropolitan area, such as Pascoe Vale and Maribyrnong (Gill 1949; Gill & Baker 1950). They also provided the solitary report of a Cenozoic fungus from the LaTrobe

Valley coals (Willis & Gill 1965). Gill (1952, 1961, 1965, 1975) proposed hypotheses regarding the evolution of the Australian flora and climate through the Cenozoic. The sole Australian record of amber containing plant or animal remains was also described during this time (Hills 1956). Selling (1950) described *Araucaria balcombensis* Selling from the Mornington macroflora, and also referred *Penteune clarkei* F. Muell. from the deep lead floras to extant *Elaeocarpus*, and other fossil seeds to extant tropical Australian taxa. Fossil woods described from Victorian localities by Nobes (1922) were transferred to *Podocarpoxyton* by Krausel (1949). Florin (1963) referred to Victorian macrofossils in his major monograph on fossil conifers.

#### 1970–1999

Research on Victorian Cenozoic palaeobotany during this period has been dominated by workers based outside Victoria, with a focus on a small number of floras, particularly the Anglesea Eocene flora (Christophel 1993). This period is dominated by research completed or initiated at The University of Adelaide by Christophel (Christophel 1980, 1981, 1984, 1986, 1989, 1993, 1994) and his associates, for example in Christophel & Basinger (1982), Basinger & Christophel (1985), Blackburn (1985), Christophel & Lys (1986), Christophel et al. (1987), Greenwood (1987, 1991, 1994), Christophel & Greenwood (1988, 1989), Rozefelds (1988), Barrett & Christophel (1990), Scriven & Christophel (1990), O'Dowd et al. (1991), Rozefelds et al. (1992) and Rozefelds & Christophel (1996a, 1996b). Significant long-running research into Victorian Cenozoic macrofloras was also conducted initially in Adelaide but mainly at The University of Tasmania by Hill (1978, 1980, 1988a, 1989, 1990a, 1990b, 1994) and his associates, for example in Hill & Christophel (1989), Hill & Carpenter (1991), Hill & Pole (1992), Pole et al. (1993) and Scriven & Hill (1995). In addition to these two main research groups there have been reports by other individuals (eg. Douglas 1977, 1983; Leisman 1986).

Significant advances in biostratigraphic analyses of the Otway and Gippsland basins were completed over this period (eg. Harris 1971; Stover & Partridge 1973; McGowan 1991; MacPhail et al. 1994). These improved the potential for placing Victorian Cenozoic macrofloras into stratigraphic context, particularly when combined with concomitant radiometric analyses of volcanic rocks (Wellman 1974, 1983).

## PALEOGENE AND NEOGENE SEDIMENTARY BASINS OF VICTORIA

There are three main Paleogene and Neogene onshore sedimentary basins in Victoria (Fig. 1), which are primarily of marine origin but also include significant terrestrial sequences. The Otway Basin covers much of southwestern Victoria including the Otway Ranges and coast, and extends offshore. The Murray Basin encompasses most of northwestern Victoria. The Gippsland Basin covers much of southeastern Victoria and includes the laterally extensive and thick coal-bearing sequences of the LaTrobe Valley (Douglas 1993). Biostratigraphic dating of macrofloras is primarily based on palynostratigraphic schemes derived from the Gippsland Basin (Stover & Partridge 1974) and Otway Basin (Harris 1971, 1985) as summarised by MacPhail et al. (1994). Age controls on palynostratigraphic zones are based on correlations with assemblages of cosmopolitan marine nannofossils and microfossils. Radiometric dating of interleaved volcanic sediments and detailed sequence stratigraphy of onshore exposures of the LaTrobe Group sediments of the Gippsland Basin is providing greater refinements in the chronostratigraphic placement of some floras (Holdgate et al. 1995). Stratigraphic positions of floras outside the main basins, such as those from the Eastern Highlands, are problematic: key stratigraphic marker pollen types may be lacking or may show different patterns of first and last appearance than seen in the type sections (MacPhail et al. 1994; Partridge, in prep.).

Duigan (1951) listed 55 Paleogene and Neogene macrofloras from Victoria. A summary of floristic and stratigraphic information on the majority of these floras is presented below, together with an overview of floras reported since that initial catalogue. Macrofloras are primarily grouped according to stratigraphic stage within sedimentary basins (Fig. 2). Macrofloras of the Eastern Highlands and those of the deep leads are also discussed under separate headings. Very little macrofossil material has been reported from the Murray Basin and so this material is discussed with the floras of the Eastern Highlands.

### MACROFLORAS OF THE OTWAY BASIN

#### *South-western Victoria*

A number of significant Paleogene and Neogene macrofloras have been reported from sites in the Otway Basin, in the Otway Ranges and coast, and

from near Hamilton and Casterton in western Victoria (Chapman 1921; Paterson 1935; Douglas 1983, 1990; Abele et al. 1988). The Eocene macroflora at Anglesea is the most significant of these in terms of the amount of published detail (discussed below). Early reports on the Victorian Cenozoic discussed the following floras from the Otway Basin: Lookout Hill near Aireys Inlet

(Eocene); Sentinel Rock and Pitfield (Miocene); Redruth Ironstone near Casterton (Miocene or Pliocene); Wannon Falls (Pliocene); and Grange Burn or Hamilton (Pliocene or Early Pleistocene). Crespin (1954) and Kenley (1971) reported leaves of cf. *Cinnamomum* and cf. *Banksia* from bore samples of the Dartmoor Formation (considered a junior synonym of Dilwyn Formation; Abele et al.

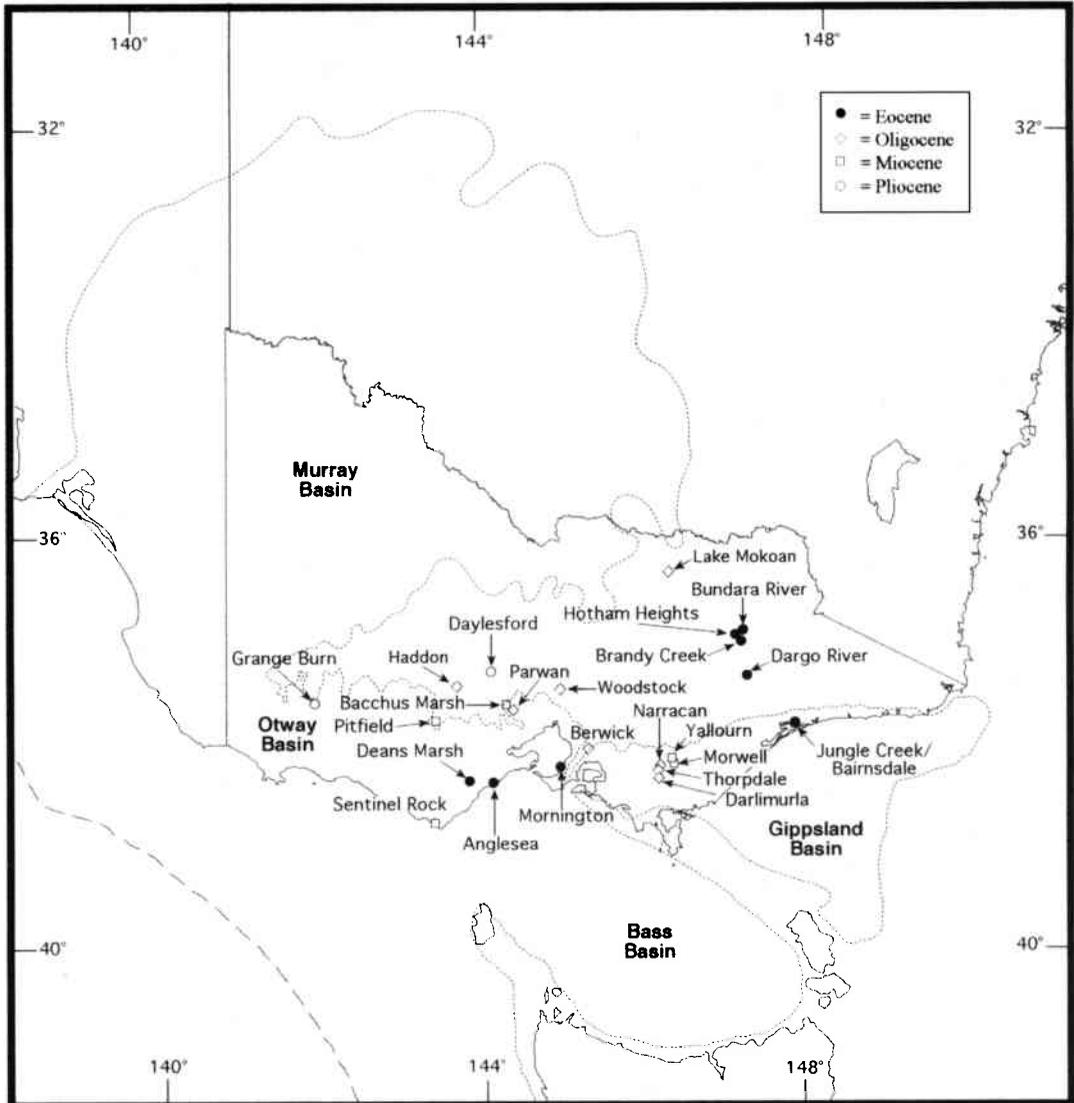
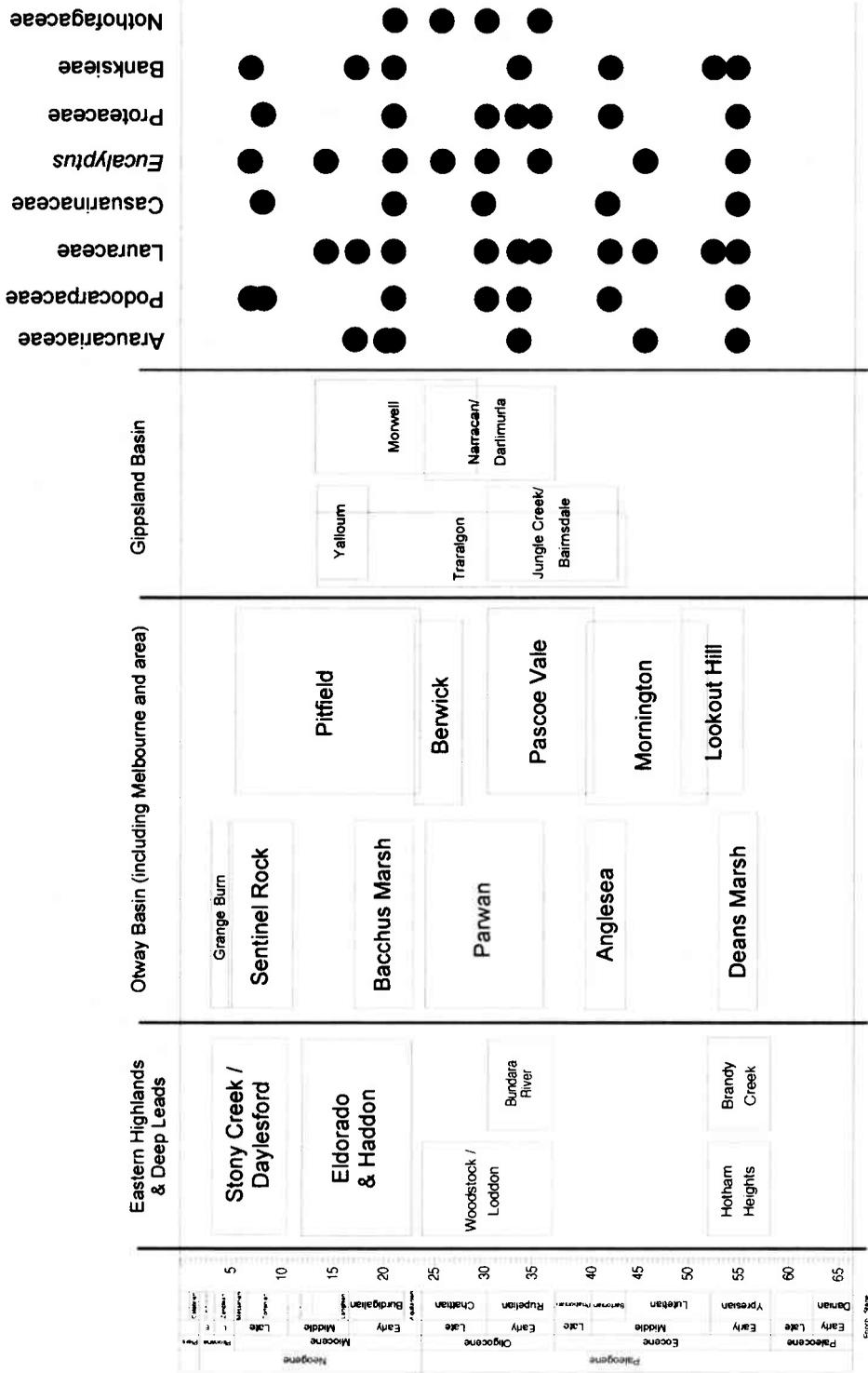


Fig. 1. Principal Paleogene and Neogene macrofloras in Victoria. Fine dashed lines indicate approximate limits of Paleogene and Neogene sediments in the major sedimentary basins; wider dashed line indicates inferred limit of continental crust. (Basin details after Abele et al. 1988.)



1988) near Nelson. Carbonised plant remains in Dilwyn Formation sediments in outcrop in the Glenelg and Stokes River valleys north of Dartmoor indicate a Late Paleocene to Early Eocene flora, as the sediments contain a microflora correlated with the *Cupanieidites orthoteichus* Zone of the Otway Basin (Harris 1985; Abele et al. 1988). Rare plant fragments have also been reported from the Late Miocene to Early Pliocene Dorodong Sand at Red Cap Creek (Abele et al. 1988), and leaf impressions of possible Proteaceae, *Eucalyptus* and 'tea trees' (?*Leptospermum*) are known from volcanic tuff at Lake Colac that has been radiometrically (K/Ar) dated at 2 million years (J. G. Douglas, unpub. data).

#### Melbourne and metropolitan area

A substantial number of known Victorian Cenozoic macrofloras occur within 100 km of Melbourne (Fig. 1; Table 1). These macrofloras were commonly collected from fluvial or fluvio-lacustrine facies below Newer Volcanics or Older Volcanics, depending on location and site stratigraphy. Macrofloras considered important to one generation of palaeobotanists occasionally appear to have been either overlooked by subsequent generations, or displaced from their former position of importance by later discoveries. For example, whereas some recent papers on Australian Cenozoic macrofloras (Christophel 1981, 1989, 1993; Christophel & Greenwood 1989; Greenwood 1994; Pole et al. 1993; Hill 1994) mention only the Berwick and Bacchus Marsh (Maddingley) macrofloras, Douglas (1967, 1983) and earlier researchers (eg. Chapman 1921; Gill 1950) cite additional floras.

Several other localities close to Melbourne (eg. Flemington) are now beneath suburbia and are uncollectable. Material representative of most of such floras is housed in the National Museum of Victoria. Providing ages for these floras is problematic, as host sediments were often in subcrop, and the stratigraphic units (eg. Werribee Formation and equivalent units) were time-transgressive across the Melbourne area (Abele et al. 1988). Sediments associated with basalt flows to the east of Melbourne are generally older (Late Eocene to Oligocene) than sediments so associated to the west (Early Miocene to Pliocene). In many cases, no further analysis of the

stratigraphic position of these floras has been undertaken since their original description.

#### Pascoe Vale

The macroflora locality at Pascoe Vale has been described in varying degrees of detail by numerous authors including Hanks (1934), Paterson (1934), Gill (1949), Douglas (1967, 1983) and Abele et al. (1988). This flora is worthy of detailed systematic study as both high quality impressions and mummified leaves have previously been collected. Indeed, Paterson (1934) recorded leaf impressions of three taxa of *Nothofagus* in addition to *Eucalyptus kitsoni*, Proteaceae, Lauraceae and other dicot leaf taxa of the 'brush type', in addition to mummified leaf fossils possibly representing *Nothofagus* and *Eucalyptus*. Gill (1949) considered the Pascoe Vale flora to be of Paleogene age (underlying Older Volcanics) and likely contemporaneous with the Late Oligocene Berwick flora. However, Abele et al. (1988) suggested the Pascoe Vale macroflora occurred in the Werribee Formation, indicating a Late Eocene to Early Oligocene age (Fig. 2).

#### Berwick

The Berwick flora was originally described by Deane (1902), and was recollected and redescribed by Pole et al. (1993). This macroflora crops out in a series of sub basaltic fluvio-lacustrine lenses (Deane 1902; Pole et al. 1992). The palynoflora associated with these sediments is correlated with the Middle *Proteacidites tuberculatus* Zone of the Gippsland Basin (Stover & Partridge 1974), indicating a Late Oligocene to Early Miocene age (Fig. 2). Macrofossils are preserved as impressions in a pale grey matrix with organic preservation of leaf cuticle, or as impressions with no organic preservation.

Deane (1902) recorded several taxa of *Eucalyptus* as leaves from Berwick; however Pole et al. (1993) described only one taxon, using both leaf venation and cuticular information, and amended the diagnosis of *Eucalyptus kitsoni* Deane. Pole et al. (1993) interpreted the Berwick flora as reflecting a transitional phase in Victoria, suggesting the mixture of temperate rainforest forms (eg. *Nothofagus*) and sclerophyllous plants (eg. *Eucalyptus*) reflected initial drying of the regional climate and the early development of tall open eucalypt forests.

Fig. 2. Stratigraphic arrangement of Victorian Paleogene and Neogene macrofloras with constraining spore-pollen zones for south-eastern Australia (Gippsland and Otway basins). Palynostratigraphic scheme adapted from MacPhail et al. (1994).

Basin/locality	Age	Stratigraphy/ pollen zone	Taxa	References
<b>OTWAY BASIN</b>				
1. <i>South-western Victoria</i>				
A. Red Cap Creek/ Dorodong Sand	Late Miocene- Early Pliocene Pliocene	Dorodong Sand	Plant fragments (rare)	Abele et al. (1988)
B. 'Redruth' (=Wannon Falls)			Leaf impressions including <i>Eucalyptus</i> and <i>Banksia</i>	Chapman (1910, 1921)
C. Sentinel Rock*	Middle Miocene- Pliocene	Sentinel Rock Clay	Leaves of <i>Casuarina</i> , <i>Acacia</i> , Proteaceae Myrsinaceae, Rubiaceae, Fabaceae, <i>Phyllocladus</i> ; fruits	Deane (1902d); Paterson (1935); Cookson (1954); Douglas (1983); Abele et al. (1988)
D. Wannon Falls	Late Miocene-Early Pliocene	Wannon River Beds	Leaf impressions	Chapman (1911); Abele et al. (1988)
E. Nintingbool		Deep lead	Fruits and seeds	Mueller (1875); Selling (1950); Duigan (1951)
F. Pitfield*	Neogene		Diverse rainforest flora; mainly leaves including: <i>Cinnamomum</i> , <i>Sterculia</i> , <i>Eucalyptus</i> , Mollinedia, Sapindaceae, Winteraceae, Araliaceae	Deane (1902); Paterson (1935)
G. Grange Burn*	Pliocene		<i>Phyllocladus</i> wood; dicot and conifer leaves; <i>Acacia</i> phyllodes	Douglas (1983); Abele et al. (1988); Rich et al. (1991)
H. Hamilton	Late Pliocene		<i>Phyllocladus</i> wood	Gibbons & Gill (1964)
I. Lillieur	Pliocene-Pleistocene		Algae fossils	Krause (1887)
J. Ouyen (Murray Basin)			Algae and fungi fossils	Chapman (1913)
2. <i>Melbourne and Metropolitan Area</i>				
A. Lookout Hill/Aireys Inlet	Early-Middle Eocene	'Boonah Sandstone'/ Eastern View Formation; Lower <i>Nothofagidites</i> <i>asperus</i>	Leaf impressions	Gill (1952); Abele et al. (1988); Douglas (1983)
B. Flinders	Late Middle Eocene	Flinders Basalt	Stems and dicot leaves	Deane (1923); Douglas (1983); Abele et al. (1988)
C. Flemington	Late Eocene-Early Oligocene	Yaloak/Werribee Formation	Leaf impressions	Paterson (1934); Abele et al. (1988)
D. Pascoe Vale	Late Eocene-Early Oligocene	Werribee Formation/Older Volcanics	Dicot leaves including <i>Eucalyptus</i> , <i>Nothofagus</i> and leaves of 'brush-type'	Paterson (1934); Gill (1949); Douglas (1983); Abele et al. (1988)
E. Berwick*	Late Oligocene-Early Miocene	Middle <i>Proteacidites</i> <i>tuberculatus</i>	Conifer leaf impressions; <i>Eucalyptus</i> <i>kitsoni</i> leaves and capsules; <i>Nothofagus</i> leaves	Deane (1902); Pole et al. (1993)

F. Bulla	Neogene		? <i>Eucalyptus</i> leaves	Patton (1919); Douglas (1983)
G. Keilor	Neogene		Leaf impressions, including <i>Eucalyptus</i>	Patton (1919); Douglas (1983)
H. Clifton Hill			<i>Casuarina</i> wood	Armitage (1910); Gill & Baker (1950)
I. Altona			Conifer ( <i>Mesembrioxylon</i> sp.) wood	Chapman (1921)
J. 'Balcombe Bay' (=Morrington)			<i>Araucaria balcombensis</i>	Selling (1950)
K. Mornington*			<i>Eucalyptus praecoriacea</i> leaves	Deane (1902b); Chapman (1921)
L. Gisborne			Legume fruits and flowers	Thomas (1932)
M. Lilydale			<i>Beilschmiedia</i> wood; <i>Nothofagus</i> leaves	Gill (1942)
3. <i>Werribee Gorge: Parwan and Bacchus Marsh/Maddingley</i>				
A. Parwan*Parwan Creek	Late Paleocene to Early Miocene	Werribee Formation/'Yaloak Formation'	Leaf impressions, including <i>Eucalyptus kisoni</i> , rainforest taxa	Hanks (1934); Paterson (1934); Gill (1949); Douglas (1983); Abele et al. (1988)
B. Bacchus Marsh*/Maddingley	Early Miocene	Upper <i>Proteacidites tuberculatus</i>	<i>Cinnamomum polymorphoides</i> impressions; leaves of <i>Nothofagus</i> , Myrtaceae, <i>Araucaria</i> , <i>Dacrycarpus</i> ; <i>Casuarina</i> and <i>Acacia</i> foliage; <i>Elaeocarpus</i> fruits; <i>Eucalyptus</i> fruits, flowers and leaves	Cookson & Duigan (1951); Christophel (1985); Abele et al. (1988); Greenwood (1994); Blazey (1994)
4. <i>Deans Marsh, Anglesea and surrounding area</i>				
A. 'Benwerrin' (=Deans Marsh)	Late Paleocene/Early Eocene	Eastern View Formation; <i>Lygistepollenites balmei</i>	Fossil leaves	Abele et al. (1988); Douglas (1983)
B. Deans Marsh*	Early Eocene	Eastern View Formation; <i>Proteacidites asperopolus</i>	<i>Cinnamomum</i> -type mummified leaves; <i>Nothofagus</i> leaves and cupules; <i>Eucalyptus</i> fruits	Christophel & Greenwood (1989); Greenwood (1994); Greenwood & Christophel (1994); Partridge (1998)
C. Wensleydale	Eocene	Eastern View Formation	Leaf impressions	Cookson (1954); Abele et al. (1988)
D. Anglesea*	Late Middle Eocene	Eastern View Formation; Lower/Middle <i>Nothofagidites asperus</i>	Leaf impressions and compressions, including taxa of: <i>Lygodium</i> , <i>Bowenia</i> , <i>Pterostoma</i> , <i>Dacrycarpus</i> , <i>Falcatifolium</i> , <i>Podocarpus</i> , <i>Prunniptys</i> , <i>Austrodiospyros</i> , <i>Myrtaciphyllum</i> , <i>Banksiacaphyllum</i> , <i>Musgraveianthus</i> , <i>Megahertzia</i> , <i>Brachychiton</i> , <i>Gymnostoma</i> , <i>Laurophyllum</i> , <i>Sloanea</i> , <i>Petermanniopsis</i> , <i>Limnospadix</i> , Loranthaceae, Sapindaceae and Rutaceae	Christophel (1981, 1984, 1988); Christophel & Lys (1986); Christophel & Greenwood (1988, 1989); Greenwood (1993)
E. Lookout Hill	Early-Middle Miocene	Boonah Sandstone	Seeds, stems; impressions of broad-leaved taxa and Banksieae-like leaves	Gill (1952); Abele et al. (1988)

(Legend to Table 1 and table continued overleaf)

Basin/locality	Age	Stratigraphy/ pollen zone	Taxa	References
GIPPSLAND BASIN				
1. <i>Darlimurla, Narracan and other South Gippsland floras</i>				
A. Hazelwood			Leaf impressions	Cookson (1947); Duigan (1951)
B. Tanjil River			Fruits and seeds	Selling (1950); Duigan (1951)
C. Bruthen	Eocene		<i>Eucalyptus</i> wood	Chapman (1918)
D. Jungle Creek*/Bairnsdale	Late Eocene–Early Oligocene		Wood of Lauraceae ( <i>Cryptocaryoxylon gippslandicum</i> )	Chapman (1918); Leisman (1986)
E. Narracan*	Late Early Oligocene–Early Miocene	Childers Formation, LaTrobe Group	Leaf impressions including: Lauraceae, Sterculiaceae, <i>Nothofagus</i> , Cunoniaceae, Moraceae, Proteaceae, Myrtaceae (including <i>Eucalyptus</i> ), Monimiaceae, Loganiaceae, Casuarinaceae, <i>Podocarpus</i> , <i>Dacrycarpus</i>	Howchin (1923); Chapman (1926); Paterson (1935); Douglas (1983)
F. Darlimurla*	Late Oligocene		Leaf impressions including: Lauraceae, Sterculiaceae, <i>Eucalyptus</i> , <i>Nothofagus</i>	Paterson (1935); Thomas & Baragwanath (1951)
2. <i>Thorpdale</i>				
A. Thorpdale*	Paleogene		<i>Spondylostrombus smythii</i> fruits and seeds	Duigan (1951); A. J. Vadala (unpub. data)
3. <i>Macrofloras of the brown coals</i>				
A. Traralgon	Late Middle Eocene		Leaf impressions and compressions	Thomas & Baragwanath (1950); Gloe et al. (1988)
B. Gelliondale	Early Oligocene–Late Miocene	Overlying LaTrobe Unconformity	Coal seam	Chapman (1925); Duigan (1965); Blackburn & Sluiter (1994)
C. Morwell* coal	Late Oligocene–Early Miocene	Middle/Upper <i>Proteacidites tuberculatus</i> (Morwell 1A and 1B seams)	Leaf compressions, impressions (including <i>Eucalyptus</i> ); fruits; seeds	Duigan (1965); Blackburn & Sluiter (1994)
D. Morwell* clay	Late Oligocene–late Early Miocene	Middle <i>Proteacidites tuberculatus</i>	Leaf compressions and impressions	Duigan (1965); Blackburn & Sluiter (1994)
E. Yallourn* clay	late Early Miocene–early Middle Miocene	Upper <i>Proteacidites tuberculatus</i> – <i>Tripoporollenites bellus</i> (Yallourn Clays)	Dispersed cuticle; leaves of <i>Pterostoma</i> , <i>Gymnostoma</i> , <i>Diospyros</i> , <i>Ceratopetalum</i> , Lauraceae, Myrtaceae, <i>Podocarpus</i> , <i>Prumnopiys</i> , <i>Dacrycarpus</i> , <i>Phyllocladus</i> , <i>Agathis</i> , <i>Araucaria</i> ; <i>Wilkinsonia</i> seeds	Greenwood (1981, 1993); Rozefelds & Christophel (1995)
F. Yallourn* coal	early–mid Middle Miocene	<i>Tripoporollenites bellus</i> (Yallourn Seam)	Dispersed cuticle; leaves; seeds of <i>Elaeocarpus cerebriiformis</i>	Duigan (1965); Blackburn (1985); Blackburn & Sluiter (1994); Christophel (1994b); Rozefelds & Christophel (1996)
G. Hazelwood			<i>Oleinites</i> leaves	Cookson (1947)

4. <i>Deep lead floras</i>			
A. Woodstock*/Loddon	Oligocene	Dicot leaves and fruits	Douglas (1983); Partridge & Wilkinson (1982)
B. Foster	? Oligocene	Seeds; <i>Elaeocarpus clarkei</i> fruits	Mueller (1874); Deane (1925); Rozefelds & Christophel (1996)
C. Eldorado/Chiltern	Early/Middle Miocene	<i>Bankia</i> infrutescences; <i>Elaeocarpus clarkei</i> and <i>E. angularis</i> fruits	Selling (1950); Pike (1953); Abele et al. (1988); Rozefelds & Christophel (1996)
D. Haddon*	Early–Middle Miocene	<i>Eucalyptus</i> leaves; <i>Elaeocarpus clarkei</i> , <i>Xylocaryon lockii</i> fruits; legume fruits.	Mueller (1874, 1883); McCoy (1874); Selling (1950); Rozefelds & Christophel (1996)
E. Nintingbool		<i>Xylocaryon lockii</i> , <i>Spondylostrobus smythii</i> fruits; legume and other fruits	Mueller (1875); Selling (1950)

Table 1. Victorian Paleogene and Neogene macrofossil localities, with age (where known), stratigraphy/pollen zone (where known) and details of taxonomic composition as recorded in the associated reference(s). Locality information is derived mainly from Duigan (1951), with additional data from Douglas (1983) and from sources examined for the current survey. Where a locality has been described by two or more authors using different names (eg. Benwerrin and Deans Marsh), both are listed separately. Those localities shown on Fig. 1 are indicated by an asterisk (\*).

Several poorly documented macrofloras are known from localities close to Melbourne. The Flemington macroflora is largely undocumented but is recorded from the Yaloak Formation, a probable equivalent of the Werribee Formation (Douglas 1967, 1983; Abele et al. 1988). The Maribyrnong and Clifton Hill macrofloras are known from records of impressions of *Casuarina* twigs in basalt (Armitage 1910; Gill & Baker 1950), and are unlikely to be important. Additional largely undocumented macrofloras from St Kilda and Cranbourne are represented by collections held at Museum Victoria. The Cranbourne macroflora is likely coeval with the Berwick flora (below). Plant remains have also been reported from the Late Miocene to Early Pliocene (Cheltenhamian) Black Rock Sandstone, which crops out from Beaumaris to Black Rock in metropolitan Melbourne.

Little has been published on the Miocene Mornington–Balcombe Bay macroflora since the original description by Deane (1902), and the specimens in Museum Victoria are largely unusable due to previous heavy use of varnish as a preservative. The Flinders locality is associated with the Flinders Basalt (Middle Eocene; Abele et al. 1988), and consists of plant stems and leaf impressions (Douglas 1982). Deane's (1902) description of *Eucalyptus praecoriacea* from Mornington provoked some debate over its systematic position (Christophel 1981; Hill 1994). Maiden (1922; see Chapman 1926) accepted the fossil as *Eucalyptus*, but Hill (1994) noted that Patton (1919) considered the original identification doubtful. Indeed, Hill (1980) considered the specimen likely to be a pinnule of a zamioid cycad. Foliage of *Araucaria balcombensis* Selling (1950) has also been described from Balcombe Bay, probably from the same sediments as the Mornington flora.

#### *Deans Marsh, Anglesea and surrounding area*

The Deans Marsh macroflora was collected from overburden at the abandoned Wensleydale brown coal open-cut mine south of Winchelsea in sediments towards the base of the Eastern View Formation, above its contact with the Demons Bluff Formation. The collection used in the analyses of Christophel & Greenwood (1989), Christophel (1993), Greenwood (1994) and Greenwood & Wing (1995) represents a single large block of sediment from which 128 whole or near whole mummified leaves were extracted. These leaves probably represents the only collection of the macroflora as the site is now flooded. The Deans Marsh

macroflora is of Early Eocene age based on palynological correlations (Abele et al. 1988; Christophel & Greenwood 1989; Fig. 2) although Rowett & Sparrow (1994) indicated an early Middle Eocene age was possible. An unstudied Eocene macroflora at Benwerrin in the Otway Ranges has been noted to contain conifer shoots (Douglas 1983; J. G. Douglas, unpub. data).

The Lookout Hill macroflora is known from sites on a ridge overlooking Aireys Inlet, in sediments of the Boonah Sandstone of Early to Middle Eocene age (Gill 1952; Abele et al. 1988). Gill (1952) reported seeds, stems and impressions of broad leaves and *Banksia*-type (*Banksiaeformis*) leaves. Poorly preserved leaf impressions in coarse sandstone can still be collected from a roadside quarry near the locality (J. G. Douglas & D. R. Greenwood, unpub. data).

Douglas (1977) first noted the Anglesea macroflora. Abundant, taxonomically diverse and well preserved plant macrofossils have been described in a number of publications (Hill 1978, 1980; Christophel 1980, 1981; Greenwood 1987; Hill & Christophel 1988; Rowett & Christophel 1988; Rozefelds 1988; Rozefelds et al. 1991; Conran et al. 1994). Macrofossils have been collected from the Eastern View Formation in a series of fluvio-lacustrine lenses in overburden from the Anglesea open-cut brown coal mine (Christophel et al. 1987). The associated microflora indicates a mid-late Middle Eocene Age (Lower *Nothofagidites asperus* Zone of Stover & Partridge 1974; Fig. 2). Macrofossils are preserved as impressions in a pale grey matrix with minor organic (cuticle) preservation, as impressions with no organic preservation, and as mummifications comprising laterally extensive horizons of leaf mats preserved in a mudstone matrix.

Mummified material from Anglesea is unimpressive in hand specimen; however maceration using a hydrogen peroxide bath typically releases large numbers of organically intact leaf, fruit and flower fossils with good cellular detail (eg. Christophel & Lys 1986). Flowers, staminate conifer cones containing pollen and fern sporangia with spores have previously been recovered (Basinger & Christophel 1985; Christophel 1984; Greenwood 1987; Rozefelds et al. 1992). Barrett & Christophel (1990) reported that lateral and vertical variations in the composition of macrofloras was significant between and within discrete

'lenses', but that macrofossils belonging to the major identified taxa were encountered throughout the locality following extensive sampling (see also Christophel et al. 1987; Rowett & Christophel 1989). Palaeoecological interpretation of the Anglesea macroflora indicates a diverse, laterally heterogeneous rainforest of similar floristic and foliar physiognomic character to extant upland tropical rainforests (Simple Notophyll Vine Forest *sensu* Webb 1959) of northeastern Queensland in the Daintree River area. Christophel (1993, 1994) suggested analogy with rainforest at Noah Creek, where many rare taxa (eg. *Megahertzia* and *Gymnostoma*) with close matches to Anglesea fossil taxa can be found in close proximity.

Christophel (1994) suggested over 100 taxa were present in the Anglesea macroflora. Although a complete taxonomic list is not yet available, the following taxa have been recorded: the fern *Lygodium*; foliage of the cycads *Bowenia eocenica* Hill and *Pterostoma zamioides* Hill (Zamiaceae), and the conifers *Dacrycarpus eocenica* Greenwood, *Falcatifolium australis* Greenwood, *Podocarpus platyphyllum* Greenwood, *Prumnopitys tasmanica* (Townrow) Greenwood and *P. lanceolata* Greenwood (all Podocarpaceae). Angiosperms include leaves of rainforest trees such as *Austrodiospyros eocenica* Basinger & Christophel (Ebenaceae; flowers and leaves), *Myrtaciphyllum douglasii* Christophel & Lys (Myrtaceae), two *Banksiaephyllum* spp. (Banksiae, Proteaceae), *Musgraveinanthus alcoensis* Christophel (Musgraveinae, Proteaceae; flowers), *Megahertzia*<sup>1</sup> sp. (Ortiteae, Proteaceae), *Brachychiton* sp. (Sterculiaceae), *Gymnostoma* sp., at least 5 *Laurophyllum* spp. (Lauraceae), Elaeocarpaceae cf. *Sloanea*, leaves of the monocot *Petermanniopsis anglesaensis* Conran et al. (Petermanniaceae), and a palm attributed to *Linospadix* (Arecaceae). Escalloniaceae (cf. *Quintinia*), Loranthaceae, Sapindaceae and Rutaceae have also been recorded as present (Christophel 1981, 1989, 1993, 1994; Basinger & Christophel 1985; Christophel & Basinger 1982; Christophel & Greenwood 1988, 1989; Christophel et al. 1987; Rozefelds et al. 1992; Conran et al. 1994). O'Dowd et al. (1991) noted the presence of oribatid mites in domatia of Elaeocarpaceae (cf. *Sloanea*) leaves from Anglesea, indicating the persistence since the Middle Eocene of this association. Rozefelds (1988) also recorded insect leaf mines in Anglesea leaf lamina.

<sup>1</sup>This fossil taxon was originally attributed to the undescribed '*Orites* sp. nov.' from Noah Creek in northeast Queensland. (Christophel 1994: 266), which has subsequently been described as *Megahertzia amplexicaulis* A. S. George & B. Hyland (George & Hyland 1995). The morphology of the leaf fossil is indistinguishable from the extant material.

*Bacchus Marsh/Maddingley and Werribee Gorge*

McCoy (1876) described leaf fossils in ironstone from Werribee Creek, and Douglas (1983) listed a macroflora at Parwan Creek (Late Paleocene to Early Miocene according to Abele et al. 1988), a tributary of the Werribee River. Both Werribee Creek and Parwan Creek macrofloras are in Werribee Gorge (in the vicinity of Bacchus Marsh); they are preserved in ferruginised sandstone (ironstone), and are likely the same sediments. The majority of collections attributed to Bacchus Marsh/Maddingley appear to be from the same stratigraphic unit as the Werribee Creek and Parwan Creek floras (Werribee Formation) and in the same locale. More recent collections have come from the remaining overburden of the Maddingley Open Cut No. 2 brown coal mine. Large tree trunks have been recovered from the Bacchus Marsh coalfield (Gloe et al. 1988). The Maddingley Coal seam is probably Early Miocene in age (Fig. 2), based on correlation of the associated microflora with the Upper *Proteacidites tuberculatus* Zone of the Gippsland Basin (Stover & Partridge 1974).

Early reports of Paleogene and Neogene plant fossils from Bacchus Marsh refer to the site as Maddingley (or Maddingly), and noted leaf impressions in ironstone (McCoy 1876; Chapman 1921), including Lauraceae (eg. *Cinnamomum polymorphoides* McCoy). Fossil plant material in ironstone was also reported from Parwan. A more recent report (Christophel 1985) is based on collections from a very different lithology, with mummified leaves and fruit compression fossils in unconsolidated mudstones.

Christophel (1985) and Greenwood (1994) reported leaves and cupules of *Nothofagus* subgenus *Lophozonia* (Fig. 3A) with leaves of Myrtaceae (non-*Eucalyptus*), conifer shoots (*Araucaria* Section *Eutacta* and *Dacrycarpus*), and fruits of Elaeocarpaceae from Bacchus Marsh. Unpublished research on possibly Pliocene-Pleistocene material from fire-holes at the top of the Bacchus Marsh coal has detected abundant charcoalfied fruits, flowers and rarely foliage of *Eucalyptus* with *Casuarina* and *Acacia* foliage (Blazey 1994).

*Pitfield and Sentinel Rock*

Miocene macrofloras at Pitfield (38 km south-west of Ballarat) and Sentinel Rock (2 km west of the mouth of the Aire River) were first described by Deane (1902) and subsequently by Paterson (1935), who listed the following taxa for Pitfield: Lauraceae (as *Cinnamomum*), Sterculiaceae (as *Sterculia*), *Eucalyptus*, Monimiaceae (as *Mollinedia*), Sapind-

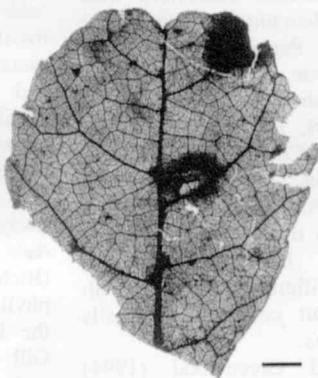
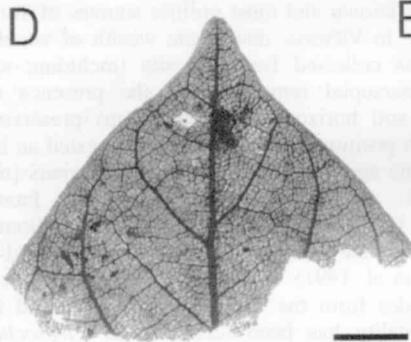
aceae (as *Nephelites* and *Carpolithes*), *Eucryphia*, *Drimys* (Winteraceae), *Pittosporum* and Araliaceae (as *Panacites*). The Sentinel Rock macroflora consists of leaf compressions in grey mudstone. Taxa include possible *Casuarina*, Myrsinaceae (as *Myrsine*), Proteaceae (as *Persoonia* and *Phyllites*), Rubiaceae (as *Coprosmaephyllum*), *Pultenaea* (Fabaceae) and *Phyllocladus* (Deane 1902; Paterson 1935). Cookson (1954) reported pollen and phyllodes of *Acacia* from the locality. Sentinel Rock deserves recollection and analysis, however the outcrop is part of an intertidal rock platform and is often partly obscured by fallen aeolianite from adjacent coastal cliffs (Douglas 1983). An associated macrofossil locality 500 m east of the mouth of the Aire River (J. G. Douglas, unpub. data) may expand this list of taxa considerably.

*Grange Burn and Hamilton*

Gill (1952) described Grange Burn as one of the 'oldest known and most prolific sources of Tertiary fossils' in Victoria, due to the wealth of vertebrate remains collected from the site (including whale and marsupial remains), and the presence of a fossil soil horizon with tree stumps preserved in growth position. Douglas (1993) suggested an Early Pliocene age (approximately 5 million years [m.y.]; Fig. 2), and the associated mammalian fauna is Early Pliocene, based on a corrected radiometric date for the overlying basalt of  $4.46 \pm 0.1$  m.y. (Rich et al. 1991). Cookson (1954) reported *Acacia* phyllodes from the locality and some wood from the locality has been identified as *Phyllocladus*. Gill (1952) noted leaf fossils in a grey to black carbonaceous clay below basalt at Wannan Falls, upstream from Grange Burn, and Douglas (1983) reported large fragments of conifer wood and leaves from that locality. Chapman (1910, 1921, 1926b) reported fossil leaves of *Banksia* and leaves 'provisionally' assigned to *Eucalyptus amygdalina* Labill. by Maiden (1922) from ironstone collected below Wannan Falls at Redruth (now Wannan) near Casterton, although the exact source of the latter material is unknown (Spencer-Jones 1971).

*Otway Basin bore cores*

Plant remains have been recorded from bore cores intersecting Paleogene and Neogene sediments in many parts of the Otway Basin, but records are almost entirely confined to reports commissioned by or written by private companies. Douglas (1960) recorded fungal hyphae from 1423 m depth in Portland Bore 2 and an abundance of cuticular fragments from 1416 m depth in Portland Bore 3.



### MACROFLORAS OF THE GIPPSLAND BASIN

Brown coal and interseam macrofloras of the LaTrobe Valley, and particularly those from the Yallourn and Morwell open-cut coal mines, have been the most extensively researched of Victorian Cenozoic macrofloras. Leaf impressions were reported from Darlimurla coal mine and at Narracan, in addition to a seed flora from Foster (Deane 1923; Chapman 1926; Paterson 1935; Thomas & Baragwanath 1951; Abele et al. 1988). Duigan (1951) listed Paleogene and Neogene macrofloras at Budgerie, Hazelwood, Korumburra and Tanjil River. Chapman (1918, 1921, 1926b) reported Miocene–Pliocene silicified wood of *Eucalyptus melliodora* from Bruthen near Bairnsdale and of *E. piperita* Sm. from Mallacoota Inlet. Leisman (1986) described silicified lauraceous wood (*Cryptocaryoxylon gippslandicum*) from Jungle Creek approximately 75 km north-east of Bairnsdale, proposing an Eocene age for these fossils based on nearby basalts.

#### *Darlimurla, Narracan and other South Gippsland floras*

The thin coal seam at Darlimurla was described by Thomas & Baragwanath (1951) as containing strata of dark, carbonaceous clays bearing leaf impressions and estimated as post-Older Volcanics in age (Fig. 2). Paterson (1935) recorded Sterculiaceae (as *Sterculia*), *Nothofagus*, Lauraceae (as *Cryptocarya*), and Myrtaceae (*Eucalyptus*) from these clays. The nearby locality at Narracan is overlain by Late Oligocene basalts dated at  $26 \pm 0.5$  m.y. (McKenzie et al. 1984) and is particularly diverse. Chapman (1926) and Paterson (1935) described Sterculiaceae (as both *Sterculia* and *Brachychiton*), *Nothofagus*, Cunoniaceae<sup>2</sup> (possibly as *Weinmannia*, but more probably *Geissois* as Chapman referred to a close similarity to *W. biagiana* syn. *Geissois biagiana*), Lauraceae (as *Cinnamomum* and *Cryptocarya*), Moraceae (as *Ficonium*), Proteaceae (as *Lomatia* and *Persoonia*),

Myrtaceae (including both *Eucalyptus* and *Tristanites* or *Tristania* s.l.), Monimiaceae (as *Hedycarya* and *Mollinedia*), Loganiaceae (as *Strychnos*), cf. *Casuarina* (Casuarinaceae), and *Dacrycarpus* (Podocarpaceae, as *Podocarpus praecupressiformis* Ett.) from Narracan. More recent undescribed collections from Narracan include lauraceous leaf impressions and other dicot taxa (A. J. Vadala & J. G. Douglas, unpub. data). These more recent collections are from cemented sandstone of the Childers Formation (LaTrobe Group) and likely represent the same sediments as material described by Paterson (1935). Thomas & Baragwanath (1951) quoted Wright (1894) as suggesting the leaf-bearing clays at Narracan were typical of sediments usually associated with brown coals in the area.

#### *Macrofloras of the brown coals*

Highly fossiliferous sediments of the LaTrobe Group are intersected in the open-cut brown coal mines at Yallourn, Morwell and Traralgon in the LaTrobe Valley. Interseam sediments associated with the brown coal seams contain well-preserved fossil leaves, fruits and seeds, wood, and *in situ* tree stumps (Chapman 1922, 1925a, 1925b; Cookson 1947, 1953; Cookson & Duigan 1950, 1951; Cookson & Pike 1953a, 1953b, 1954; Pike 1952; Patton 1958; Duigan 1965). Several specimens of amber from the Morwell open-cut are curated in the NMV. Recent publications provide substantial detail on the coal floras (eg. Blackburn 1981b, 1985; Blackburn & Sluiter 1994; Kershaw et al. 1994; Balme et al. 1995; Barton et al. 1995). Sediments range in age from late Middle Eocene (Traralgon seam, accessible in the Loy Yang open-cut), to Oligocene and Early to Middle Miocene (exposed in the Loy Yang, Morwell and Yallourn open-cut mines). Individual coal seams may attain thicknesses greater than 100 m. Holdgate et al. (1995) indicated the time of accumulation for each coal seam was likely to have been in the range 0.5 to 2 m.y., with substantial time gaps within each seam.

<sup>2</sup>*Weinmannia* and other genera now placed in the Cunoniaceae were originally placed in the Saxifragiidae or Saxifragaceae.

Fig. 3. Leaf fossils from Victorian Neogene macrofloras. A, *Nothofagus tasmanica* (Nothofagaceae) leaf impression from Bacchus Marsh (Maddingley). B–I, Leaf and stem fossils from the Yallourn Clays (LaTrobe Valley); scale bars = 5 mm: B, *Nothofagus tasmanica* cuticle; C, *Myrtaciphyllum* sp. (Myrtaceae); D, apical fragment of leaf of indeterminate affinity, showing drip tip; E, cf. *Sloanea* (Elaeocarpaceae); F, *Laurophyllum* sp. (cf. *Beilschmiedia*; Lauraceae); G, H, foliage types of *Dacrycarpus latrobenis* (Podocarpaceae); I, stem fragment of *Gymnostoma* sp.

Macrofossils described from these coals include taxa typical of modern temperate (eg. *Nothofagus*) to subtropical-tropical rainforest (eg. *Agathis*, *Diospyros* and *Gymnostoma*), in addition to sclerophyllous taxa (eg. *Casuarina* and *Banksiinae*). Interseam parting clays commonly contain leaf remains. An unpublished report on the interseam unit of the late Early Miocene Yallourn Clay (Greenwood 1981) lists the following taxa: *Pterostoma* (Zamiaceae), *Podocarpus* or *Prumnopitys*, *Dacrycarpus latrobensis*, *Phyllocladus*, *Agathis*, *Araucaria*, *Gymnostoma*, *Diospyros* (Ebenaceae), *Ceratopetalum* (Cunoniaceae), and taxa of Lauraceae and Myrtaceae. Rozefelds & Christophel (1995) described seeds of *Wilkinsonia* (Hicksbeachiinae, Proteaceae) from the Yallourn Formation. These *Wilkinsonia* seeds are most closely similar to extant monotypic *Athertonia*, endemic to rainforests of northeastern Queensland.

The palaeobotanical and palaeoecological potential of the LaTrobe Valley coals are yet to be fully realised. The complete coal and interseam sequence spans the late Middle Eocene to late Middle Miocene (Holdgate et al. 1995; Fig. 2), an interval of substantial climatic change and vegetative evolution. Macrofloras of the Yallourn and Morwell seams are the most studied (Blackburn & Sluiter 1994). A near-complete sequence is available in the Loy Yang open-cut mine, near Traralgon: Traralgon seam (Late Eocene), Morwell 2c aquifer, Morwell 2c seam (Early to Late Oligocene), Morwell 2b aquifer, Morwell 2b seam (Late Oligocene), clays (?), Morwell 2a seam (Late Oligocene–Early Miocene), two parting clays (late Early Miocene), and the Yallourn seam (Middle Miocene). Current mining operations do not intersect the lowest seams. Interseam clays are better exposed in the Yallourn and Morwell open-cuts, as these sediments are much thinner in the Traralgon area (Abele et al. 1988) and individual clays may be absent on exposed benches at any particular time in the Loy Yang open-cut mine. A probable Pliocene macroflora containing *Eucalyptus* fruits has been collected from the top of the overburden, overlying the Haunted Hills Gravel, near the Morwell pumping station.

#### *Thorpdale*

Low-grade coals in Thorpdale contain abundant carbonised fruits and seeds. The seeds are not found in attachment with the fruits, and may be isolated by gentle disaggregation of the coal by hand. The coals are overlain by basalts, probably belonging to the LaTrobe Valley Group (Douglas 1984), which have often produced anomalous K/Ar dates

(Bowen 1975; McKenzie et al. 1984). However, the radiometric age range for the Thorpdale Volcanics is 19–24 m.y. (Wellman & McDougall 1974), and Thorpdale Volcanics at nearby Jeffrey's Quarry have been K/Ar dated at  $22.4 \pm 0.3$  m.y. (McKenzie et al. 1984), providing a Late Oligocene–Early Miocene age for the Thorpdale fossils.

Thorpdale fruits represent *Spondylostrobos*, and are comparable to *S. smythii* F. Muell. described from 'auriferous drifts' at Nintingbool and Haddon, near Ballarat in central-western Victoria (Mueller 1874). Fruits recovered from Thorpdale are approximately the same size and shape and overall state of preservation as those described by Mueller (1874) from Haddon and are likely to be conspecific with them (A. J. Vadala, unpub. data). Much of the material referred to by Mueller (1874, 1883) has not been found in the collections of the National Museum of Victoria, and many of the generic affinities are not strongly based.

#### *Gippsland Basin offshore*

Macrofloral remains have been recovered from bore cores taken in the offshore Gippsland oil and gas fields. These fossils have been described in company reports, but are otherwise undocumented. The Esso Barracouta 2 bore core from the Gippsland Shelf contains abundant fragmentary leaf impressions and several resin blobs in a highly-compacted siltstone matrix (J. G. Douglas, unpub. data).

### MACROFLORAS OF THE EASTERN HIGHLANDS

Paleogene leaf-beds and fossil woods have been reported from the Eastern Highlands (Victorian High Plains), particularly from sediments beneath volcanics near Mt Hotham, the Bogong High Plains and the Dargo High Plains in the Alpine National Park (Hunter 1909; Singleton 1935, 1941; Paterson 1935; Douglas 1983). Plant remains were deposited extensively within gravels, conglomerates, clays, sands and occasionally lignites over the pre-Older Volcanics topography of the Victorian High Plains (Eastern Highlands). The fossil-bearing sediments were subsequently overlain by basalts during the Oligocene; these basalts filled palaeovalleys incised into the eastern section of the Central Uplands. Paleogene macrofossil-bearing sediments are currently only exposed in the banks of creeks and rivers that have subsequently eroded through the basalt cap-rocks (Jenkin 1988). Beavis

(1962) reported *Agathis*, *Araucaria*, *Phyllocladus* and fern foliage (*Dryopteris dargoensis* and *Taeniopteris tenuissime striata*) from fossiliferous clays near Mt Jim at a locality called 'The Lake' on the Bogong High Plains. Fossils referred to the Mesozoic pteridosperm *Taeniopteris tenuissime striata* from the Bogong and Dargo High Plains were listed by both Duigan (1951) and Douglas (1983) as misidentifications of dicots.

The systematic composition of Paleogene macrofloras from the High Plains remains under-researched. However, the floras featured prominently in early reports as sites (deep leads) worthy of prospecting for alluvial gold (see references to Brandy Creek and the Cobungra River, Bogong High Plains and the Bundara River in Murray et al. (1878). Paterson (1935) suggested the Dargo macroflora was of Late Oligocene age, whilst Douglas (1983) indicated an Eocene age. Wellman (1974) suggested an age range of Late Eocene to Late Oligocene for basalts in the Eastern Highlands.

#### *Dargo/Brandy Creek*

The Dargo macroflora is exposed by the diggings of the abandoned Brandy Creek gold mine, approximately 5 km west of Hotham Heights near Dinner Plain. Fossils occur in two beds at this locality (Douglas 1983). Upper beds contain leaf mummifications in compressed carbonaceous mudstones laminated alternately with siltstones and fine sandstones, immediately overlain by basalt. These basalts are likely to be Early–Mid Oligocene Older Volcanics (Bolger & King 1976; Bolger 1984). Recent palynological analysis of the Dargo (Brandy Creek mine) sediments indicates an Early Eocene age for the macrofloras beneath the basalts (Scriven & Hill 1995; Fig. 2). The other fossil-bearing beds at the Brandy Creek mine site are lower in the section and consist of heavily compacted, iron-stained fine siltstones with impression fossils (A. J. Vadala & D. R. Greenwood, unpub. data). Specimens from Brandy Creek mine held by the National Museum of Victoria are from the lower beds. Infructescences of *Gymnostoma* (Casuarinaceae) have also been reported from this locality, which was described as 'Mt Hotham' by Christophel (1980) and Scriven & Hill (1995).

Paterson (1935) listed the following taxa from Dargo/Brandy Creek mine: *Laurus*, *Eucalyptus*, *Ginkgo*, *Ficus* and *Lastraea* (Filicales; which Gill & McWhae (1959) described as *Cyclosorus dargoensis*). The material described as *Ginkgo* is more likely to be a fern (J. G. Douglas, unpub. data). Although Douglas (1993) stated no post-

Cretaceous records of *Ginkgo* exist for Australia, Carpenter et al. (1994) have since reported *Ginkgo* from the Middle–Late Eocene Richmond macroflora in Tasmania.

A leaf flora in the collections of the National Museum of Victoria and labelled as being from Omeo may correspond to the Cobungra River locality (Duigan 1951). Similarities between the matrix and the component taxa of these 'Omeo' fossils and the Brandy Creek macroflora strongly suggest that the material from Omeo is in fact from Brandy Creek (a tributary of the Cobungra River).

#### *Bundara River*

The presence of fossils at Bundara River has been comparatively well documented (Table 1) owing to extensive collections over a number of years, described in the National Museum of Victoria collection as 'Head of the Bundarah River, Bogong High Plains,' which was indicated in a map accompanying specimen NMV P166994 and the associated reference (Murray et al. 1878).

The locality re-examined as part of this survey is approximately 0.9 km and 116° SE of Mt Jim on the banks of the Bundara River (36°56.08'S, 147°14.08'E, 1647 m a.s.l.). Another nearby locality, at the branch of the Cope West Aqueduct off the High Plains Creek (36°54.96'S, 147°93.17'E, 1594 m a.s.l.), was not collected but contained many, poorly preserved, leaf remains.

Leaf beds at Bundara River crop out in narrow bands of non-marine sediments otherwise covered by or intercalated with the same Early–mid Oligocene Older Volcanics that cover most of the Bogong High Plains (Bolger & King 1976; Bolger 1984). These Older Volcanics have been K/Ar dated at  $36.3 \pm 0.6$  m.y. to  $33.1 \pm 0.8$  m.y. near Mt Hotham (Wellman 1974). Finely laminated, hard siltstones with carbonaceous streaks contain dark leaf impressions and directly overlie pyroclastics and red-brown clays that are exposed for approximately 10 m above the bed of Bundara River. These sediments are overlain by darker, softer and finely laminated claystones/siltstones containing dark leaf impressions and compressions. Above this layer and overlain by more sediment is an approximately 600 mm wide band of dark brown-black coals with soft organic remains.

Fossil-bearing sediments at Bundara River were first described by Murray et al. (1878) as 'yellowish-brown laminar clay' on the southwest margin of overlying basalts at the head of the Bundara River. These authors described *Taeniopteris tenuissime striata* and *Laestrea dargoensis* as elements

of the flora. Fossils recorded previously from Bundara River include *Dryopteris dargoensis*, *Taeniopteris tenuissime striata* (likely to be a mis-identification of a dicot: see above), *Phyllocladus* sp., *Agathis* sp. and *Araucaria* sp. (Bolger 1984). Duigan (1951) considered *L. dargoensis* 'incertae sedis', however this taxon was redetermined as *Cyclosorus dargoensis* by Gill & McWhae (1959). A leaf impression from Bundara River in the National Museum of Victoria collection labelled as *Ginkgo murrayi* (Table 1) is more likely to be a dicot. The two extant Victorian taxa of *Cyclosorus* (*C. parasiticus* and *C. pennigerus*) have since been revised (Entwisle 1994) into *Christella denata* (whose distribution in Victoria is isolated to moist shaded sites around Buchan) and *Pneumatopteris pennigera* (confined to the lower tracts of the Glenelg River, and to stream banks near Port Campbell), respectively. *C. dargoensis* has similar frond morphology to some extant Victorian taxa of *Lastreopsis*, especially *L. hispida*, which currently occurs in the Otway Ranges and the southern part of the Eastern Highlands (Entwisle 1994).

#### Hotham Heights and other High Plains localities

The Hotham Heights locality is 1 km ESE from Mt Hotham resort along the Great Alpine Road (36°59.65'S, 147°09.32'E, 1733 m a.s.l.). Basement marine sedimentary rocks in the area have been assigned to the upper Middle–Upper Ordovician (Bolger & King 1976; Bolger 1984). Basalts near Mt Hotham are Upper Eocene to mid Oligocene Older Volcanics (Wellman 1974; Bolger & King 1976).

Outcrop comprises heavily weathered, steeply-inclined Palaeozoic strata unconformably overlain by fluvio-lacustrine Paleogene sand/siltstones capped by basalts, and Kenny (1937) reported plant remains in sediments below these Older Volcanics. The Mt Hotham macroflora was described as Paleocene by Christophel (1980, 1989), although Scriven & Hill (1995) were critical of this estimate. The palynoflora of the sediments correlates with the uppermost part of the Upper *Malvacipollis diversus* Zone from the Gippsland Basin, indicating a lower Early Eocene age (Partridge 1998; Fig. 2). Recent sampling of basalts associated with the macrofloras should provide a radiometric chronologic framework for them (M. Banks, D. Greenwood, A. Vadala & J. Webb, work in progress).

The Paleogene sediments contain abundant leaf impressions and mummified leaves. This material has significant potential for further collecting and analysis. Lauraceae, Proteaceae (including *Banksi-*

*aeophyllum* and rainforest taxa) and Elaeocarpaceae are abundant (Greenwood et al. 1999), and leaves of *Spiraeopsis* (Cunoniaceae) have been identified (R. Barnes, pers. comm.). Fern and conifer foliage are also present, including *Agathis*, *Dacrycarpus* and *Libocedrus* (Greenwood et al. 1999; R. S. Hill, pers. comm.). Collections are stored at Victoria University of Technology, The University of Melbourne and The University of Tasmania. Hotham Heights is the highest elevation Paleogene macroflora in Australia (1723 m a.s.l.), but is likely to have been at a substantially lower elevation during the Eocene (Ollier 1986).

Other Paleogene macrofloras occur outside the regions discussed above. For example, Douglas (1983) listed an ironstone leaf flora from Lake Mokoan near Glenrowan. Recent collections of leaf impressions from Glenrowan are likely from the same site as the Lake Mokoan flora listed by Douglas, and include lauraceous leaves and silicified wood. The Glenrowan macroflora is probably of Paleogene age, occurring below Older Volcanics. Fruits and stems have been reported from the Murray Basin Pliocene Calivil Sands (Calivil Formation; Macumber 1972) that crop out between Horsham and Echuca (Abele et al. 1988).

#### Deep lead floras

'Deep leads' are buried Cenozoic placer deposits formed along rivers that drained inland from the main divide (Hunter 1909; Whiting & Bowen in Abele et al. 1988). These deposits were intensively mined for gold during the mid to late 19th Century, and less intensively up to the 1950s. Several deep leads yielded charcoaled seeds and fruits. Similar deposits containing Paleogene- and Neogene-age fruit and seed floras were reported from southern New South Wales (Mueller 1873, 1874; Kirchheimer 1935; Rozefelds & Christophel 1996b). The most prominent Victorian deep lead floras were Eldorado, Foster and Haddon, although collections have been described from many other sites. Douglas (1976) illustrated and briefly described a mummified leaf from a depth of 70 m recovered from a bore core taken from Woodstock, west of Bendigo. Grey silts at this depth may be associated with the Haddon deep lead (see also Partridge & Wilkinson 1982). Mueller (1873) originally described seeds and fruits from Eldorado, Foster and Haddon, although later researchers (eg. Kirchheimer 1935; Selling 1950; Pike 1952; Rozefelds & Christophel 1996b) have provided most of the detailed systematic analyses of the taxa. *Banksia* cones and *Elaeocarpus clarkei* (F. Muell.) Selling endocarps were described from

Eldorado (Pike 1952; Rozefelds & Christophel 1996b). *Elaeocarpus clarkei* most closely matches *E. bancroftii* F. Muell. & F. M. Bailey and *E. linsmithii* G. P. Guymmer, both today restricted to rainforests of northeastern Queensland. Apart from Victorian localities, *Elaeocarpus* fossils are also known from deep leads at Orange, Bathurst and Gulgong in New South Wales (Rozefelds & Christophel 1996b).

Most Victorian deep leads are considered to be Neogene in age (Mueller 1874; Walcott 1920; Macumber 1978), although an Oligocene age has been indicated for deep leads in the Loddon and Murray valleys (Martin 1977; Partridge & Wilkinson 1982; Archer 1984; Fig. 2). Rozefelds & Christophel (1996b) summarised arguments over the age of the Victorian deep lead floras. Deep leads at Orange in New South Wales can be constrained to a minimum mid-Miocene (possibly Early Miocene) age based on a radiometric date of 10.9–12.7 Ma for the overlying basalts (Wellman & McDougall 1974). Rozefelds & Christophel (1996b) argued that the presence of several fruit taxa common to both the Orange and Haddon deep lead macrofloras (Mueller 1874) indicated these floras were broadly contemporaneous, and that Foster and Eldorado may also be of Middle to Early Miocene age.

Abundant and diverse seed and fruit floras at Haddon, Foster and Thorpdale (see below) warrant further systematic analysis. However, the existing collections are in need of careful curatorial attention as much material has been lost through oxidation of pyritic minerals in the fruits.

#### *Daylesford and area*

Poorly known macrofloras have been reported from Daylesford and area. McCoy (1876) described leaves of *Eucalyptus pluti* from deep leads at Daylesford. Another (Middle Pliocene) macrofossil locality has been reported at Stony Creek or Stony Creek basin (Orr 1927; Patton 1928; Ewart 1933), and fossil leaves of *E. obliqua* L'Herit from Malmsbury (Chapman 1926b). Leaf morphology of the specimens from Daylesford corresponds to 'typical' non-bloodwood eucalypts, and McCoy (1876) suggested that these specimens represent extant *E. globulus*. Patton (1928) indicated more than one taxon of *Eucalyptus* was present at the Stony Creek basin site and noted the close resemblance of leaves from that locality to extant *E. amygdalina* (syn. *E. regnans*) and *E. viminalis*. Maiden (1922) and Hill (1994) accepted the generic identification of *E. pluti* by McCoy (1876).

Acceptance of the determination of the Daylesford fossils as *Eucalyptus* partly depends on the Pliocene (or rarely Miocene) age given the host sediments. The fossil-leaf bearing sediments reported by Patton (1928) and McCoy (1876) are likely to correspond respectively to the reported 40 m of possibly Pliocene ligneous and diatomaceous clay and sandy clay in the Stony Creek basin. Fossil wood in these sediments was assigned to *Phyllocladus* (Podocarpaceae; Patton 1928). *Acacia* phyllodes and pollen have also been reported from Stony Creek basin sediments (Ewart 1933; Cookson 1954). Sediments of similar age to those in the Stony Creek basin underlie basalt at Daylesford (Abele et al. 1988), which has been radiometrically dated as Late Miocene to Pliocene (Wellman 1974).

Several other plant macrofossil localities have been reported from near Daylesford–Ballarat and Bendigo (Duigan 1951; Pike 1954; Douglas 1983), including: Ballan (Paleogene, ferns and dicot leaves), Spargo Creek (Paleogene, dicot leaves), Lal Lal (possibly Oligocene, leaves in lignite), Creswick Creek, Toolleen (Pike 1954; Wilkinson 1971) and Smeaton (Hills 1956). Wilkinson (1971) cited an unpublished report by Pike (1954) that leaves of Lauraceae and *Acacia* had been collected from Upper Paleogene and Neogene (possibly Pliocene) fluvial sediments at Toolleen, east of Bendigo. The Pliocene to Pleistocene Smeaton locality (also referred to as 'Allendale': Hills 1956), included a large fragment of fossilised tree resin (amber). The amber apparently included a green leaf of *Agathis* and that of an unnamed dicotyledon. In addition, millipede (*Spiroboles* sp.), acarid mite (*Acronothrus* sp.), spider (*Ariadna* sp.), beetle (representing the families Pselaphidae, Tenebrionidae and Scyphaenidae), and ant bodies (*Ponera* and *Iridomyrmex* spp.) were identified (Hickman 1957; Oke 1957; Womersley 1957). Poinar & Poinar (1995) indicated there were no records of Australian amber containing animal remains, implying the Allendale specimen may be the sole record for Australia. A recent search failed to locate this material in the collections of the National Museum of Victoria, although several specimens of amber are listed in their catalogue.

#### DISCUSSION

A narrowing of focus has occurred in the study of Paleogene and Neogene macrofloras in Victoria since the early surveys of the 19th Century. Researchers have necessarily focused on large and taxonomically diverse localities such as Anglesea

and the LaTrobe Valley coals. This has led to emphasis on the mid-Paleogene to mid-Neogene (Eocene to Early Miocene). Some recent reviews of the Australian Paleogene and Neogene macrofloral record (Christophel & Greenwood 1989; Truswell 1993; Carpenter et al. 1994; Christophel 1994; Greenwood 1994) have emphasised these Eocene and Miocene floras, noting the comparative paucity of knowledge regarding Paleocene and Pliocene floras. This imbalance may be partly due to local geology (there are no surface sediments of some ages). There are numerous largely unstudied Victorian macrofloras, including a significant number of Oligocene and Pliocene localities that are available for further analysis. Early reports and anecdotal accounts suggest some of these floras (eg. Narracan, Grange Burn and Stony Creek basin) and others of Eocene (eg. Hotham Heights), Miocene (eg. Haddon, Sentinel Rock) and Paleocene age contain material of important plant community types or of key Australian taxa (Table 1; Fig. 2).

This macrofossil record affords a geological long-term view of environmental change, including ecosystem and phylogenetic evolution in response to climatic changes during the Paleogene and Neogene. This record could also provide a basis for debate regarding future environmental and climatic change. Extensive and largely unexplored Victorian Paleogene and Neogene macrofloras potentially offer insights into the evolutionary history of key Australian plant genera and regarding the role of climate change in shaping the taxa and communities that characterise the modern flora of Australia. *Acacia*, *Agathis*, *Araucaria*, *Banksia*, *Casuarina*, *Eucalyptus* and *Phyllocladus* are known from a number of Victorian macrofloras, only some of which have been systematically described. Extant *Agathis*, *Araucaria* and *Phyllocladus* are absent from Victoria, but may have formed a significant part of Victorian forests until the Pleistocene. Several species of *Araucaria* and *Agathis* thrive in cultivation in many parts of Victoria, suggesting that extant climates in Victoria could support natural populations of these taxa.

*Eucalyptus* is a dominant element in the modern flora of Australia. However, Lange (1980) failed to find conclusive evidence for *Eucalyptus* in a survey of leaf cuticles from Australian Paleogene macrofloras. Hill (1994) noted the Paleogene and Neogene record of *Eucalyptus* is more extensive than commonly recognised, and much of the fossil record of *Eucalyptus* is from Victorian localities (Table 1). Indeed, Duigan (1951) listed 31 records of named Paleogene and Neogene taxa of *Eucalyptus* and three unnamed taxa from 19

localities throughout Australia, of which 14 taxa were from 10 Victorian localities, spanning the Eocene to Pliocene. However, Hill (1994) also noted the relative paucity of taxonomically reliable fossil records of *Eucalyptus*, citing records of wood from New South Wales (Bishop & Bamba 1985), leaves (*E. kitsoni*) from Berwick in Victoria (Deane 1902; Pole et al. 1993), fruit and two distinct leaf forms (*E. bugaldiensis*) from the Warrumbungle Ranges in New South Wales (Holmes et al. 1982), and records of fruit from central Australia (Lange 1978; Ambrose et al. 1979; Greenwood et al. 1990; Greenwood 1991) in addition to leaves (*E. pluti*) from Daylesford. Chapman (1926b) cited only two Pliocene records of *Eucalyptus* leaves, namely *E. pluti* McCoy from Daylesford and *E. milligani* Johnston from Macquarie Harbour in Tasmania. However, Chapman (1926b) also listed several fossil leaves of 'provisional' *Eucalyptus* recorded by Maiden (1922): *E. obliqua* from Malmsbury (likely Pleistocene) and *E. amygdalina* from Redruth/Wannon (Miocene or Pliocene). Chapman (1926b) additionally listed Miocene-Pliocene silicified wood of *E. melliodora* from Bruthen and of *E. piperita* Sm. from Mallacoota Inlet. White (1994) illustrated fruits and leaves of *Eucalyptus* from Pliocene mudstone from Inverell in New South Wales. Leaves of *Eucalyptus* have also been reliably reported from several Victorian Pliocene sites including Grange Burn, Wannon Falls and Keilor/Bulla (Fig. 2; Patton 1919; Douglas 1983). Examination of literature and the collections of the National Museum of Victoria suggests that Bundara River, Narracan, Dargo, Pascoe Vale, Flemington and Darlimurla should also be re-examined for the presence of *Eucalyptus*.

Abundant seed floras at Haddon and the LaTrobe Valley offer potential for comparisons of seed size and morphological variation within taxa with nearest living relatives in north Queensland rainforests. Such analyses offer insight into the evolution of lineages as much as on evolution of reproductive strategies (eg. Wing & Tiffney 1987).

Several Victorian Paleogene macrofloras are now at high elevation, including Bundara River, Dargo, Hotham Heights, Bogong and Brandy Creek mine. Contemporaneous floras are also preserved at low elevations. Such pairs of high and low elevation coeval floras potentially offer insight into the timing and rate of uplift of the Victorian Alpine zone. There are three models of the evolution of the high country (Ollier 1986). The first model proposes a late Mesozoic uplift followed by Paleogene and Neogene erosion to the present landforms. The second model proposes a middle

Paleogene and Neogene uplift with initial rapid erosion; and the third proposes several phases of uplift including some degree of middle to late Paleogene and Neogene vertical movement. Several studies on the rate and timing of uplift of mountains or elevated plateaux in North America have used estimates of mean annual temperature from coeval pairs of macrofloras at low and high elevation to estimate palaeoelevation of high elevation floras, and thus in part the elevation of the upland at a point in time. There appears to be scope for a similar analysis in the Victorian high country.

We can only speculate on the Paleogene and Neogene history of many plant groups, especially within the cryptogams, which are poorly represented in fossil records for the Cenozoic. Cryptogams figure prominently in many Victorian Early Cretaceous localities, and seem to have survived and in some cases even diversified during the Paleogene and Neogene, though in environments not represented in either coal measures or sub-basaltic regimes. Consequently, current knowledge of Early Cretaceous bryophytes, for example, is more extensive than that of Paleogene and Neogene bryophytes. Some groups such as the non-calcareous algae are poorly represented throughout the Phanerozoic, whilst others such as the fungi have not been thoroughly researched. Similarly, the Pterophyta have an extensive Early Cretaceous record, with more than thirty taxa described and at least a dozen more awaiting examination and description. Although extant taxa of this group, along with the Lycophytes, Sphenophytes and Psilophytes, dominate many ecological niches in Victoria, their Paleogene and Neogene record is scant.

The Paleogene probably saw the expansion and diversification of the angiosperms first manifest in the Cretaceous, when conifer forests were the dominant elements of the flora. Silicified logs as large as a metre in diameter indicate that dicotyledonous flowering plants were prominent components of the flora of Victoria as early as the mid-Paleogene (Leisman 1986). However, diversification and expansion of the monocots is still largely a matter of mystery.

Examples given in this review illustrate the value of contemporary summaries of stratigraphic, palaeobotanical and bibliographic information for macrofloras. With greater stratigraphic precision, re-examination of the 'revealed' Victorian fossil record of *Eucalyptus* and possibly *Acacia*, *Agathis*, *Araucaria*, *Casuarina* and *Banksia*, may provide insights into the phylogeny and history of these important Australian genera, and the development of the modern flora of Victoria.

## SUMMARY

Despite 150 years of palaeobotanical research, the widespread and temporally comprehensive Paleogene and Neogene plant macrofloras of Victoria are a largely untapped resource. Analysis of these macrofloras is urgently required, but should be directed to answer critical questions of interest to a wider scientific and lay audience, or such research will face another period of decline. The macrofloras from the localities and drill cores discussed above, and future new discoveries, furnish an enormous amount of information on the vegetation of the past. This in turn fuels speculation on palaeoenvironment and palaeoclimate, which in turn is a key to providing a forecast for the future management and preservation of our very finite resources.

Key questions include, but are not limited to:

- the character and nature of vegetative responses to climate changes during the Cenozoic;
- the evolutionary history of genera significant in the modern flora of Australia, such as *Acacia*, *Agathis*, *Araucaria*, *Banksia*, *Casuarina* s.l. and *Eucalyptus* s.l.;
- the nature and character of early Australian rainforest communities, which were the antecedents of extant tropical rainforests of north Queensland; and
- the rate and timing of the uplift of the Victorian high country.

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## REFERENCES

- ABELLE, C., GLOE, C. S., HOCKING, G., HOLDGATE, G., KENLEY, P. R., LAWRENCE, C. R., RIPPER, D., THRELFALL, W. F. & BOLGER, P. F., 1988. Tertiary. In *Geology of Victoria*, J. G. Douglas & J. A. Ferguson, eds, Geological Society of Australia (Victorian Division), Melbourne, 251–350.
- ANDREWS, E. C., 1916. The geological history of the Australian flowering plants. *American Journal of Science* 42: 171–232.
- ARCHER, V., 1984. Palynological dating of samples from the Murray Basin deep leads, Victoria. *Geological Survey of Victoria Report* 1983: 107.
- ARMITAGE, W. R., 1910. Notes on the occurrence of plant remains in olivine basalt, Clifton Hill Quarry. *Victorian Naturalist* 21(12): 21–30.
- BALME, B. E., KERSHAW, A. P. & WEBB, J. A., 1995. Floras of Australian coal measures, with notes on their associated Mesozoic faunas. In *Geology of Australian Coal Basins*, C. R. Ward, H. J. Harrington, C. W. Mallett & J. W. Beeston, eds, *Geological Society of Australia Coal Geology Group Special Publication* 1: 41–62.
- BARLOW, B. A., 1981. The Australian flora: its origin and evolution. *Flora of Australia* Vol. 1, AGPS, Canberra, 25–76.
- BARRETT, D. J. & CHRISTOPHEL, D. C., 1990. The spatial and temporal components of two Australian Tertiary plant megafossil deposits. In *Proceedings, 3rd IOP Conference*, Melbourne 1988, J. G. Douglas & D. C. Christophel, eds, 43–49.
- BARTON, C. M., BOLGER, P. F., HOLDGATE, G. R., THOMPSON, B. R. & WEBSTER, R. L., 1995. Gippsland Basin. In *Geology of Australian Coal Basins*, C. R. Ward, H. J. Harrington, C. W. Mallett & J. W. Beeston, eds, *Geological Society of Australia Coal Geology Group Special Publication* 1: 541–559.
- BASINGER, J. F. & CHRISTOPHEL, D. C., 1985. Fossil flowers and leaves of the Ebenaceae from the Eocene of southern Australia. *Canadian Journal of Botany* 63: 1825–1843.
- BEAVIS, F. C., 1962. Geology of the Kiewa Area. *Proceedings of the Royal Society of Victoria* 75: 349–410.
- BLACKBURN, D. T., 1981a. Floristic control on lithotype banding within the Yallourn coal seam in the Yallourn open cut, Victoria: Evidence from megafossil assemblages. *SECV Palaeobotany Project, Major Report No. 2*, State Electricity Commission of Victoria, Melbourne.
- BLACKBURN, D. T., 1981b. *Plant Fossils of the Latrobe Valley: a Field Guide*. *International Botanical Congress Field Trip* 37, IBC, Melbourne.
- BLACKBURN, D. T., 1985. Palaeobotany of the Yallourn and Morwell coal seams. *SECV Palaeobotanical Project, Report No. 3*, State Electricity Commission of Victoria, Melbourne.
- BOLGER, P. F., 1984. Explanatory notes on the Tallangatta 1:250 000 geological map. *Geological Survey of Victoria Report* 73, Geological Survey of Victoria, Melbourne.
- BOLGER, P. F. & KING, R. L., 1976. *Tallangatta 1:250 000 Geological map, Sheet SJ 55-3*, 1st Edn, Mines Department, Melbourne.
- BOWEN, K. G., 1975. Potassium–Argon dates—determinations carried out by the Geological Survey of Victoria. *Geological Survey of Victoria Report* 1975/3, Geological Survey of Victoria, Melbourne.
- CARPENTER, R. J., HILL, R. S. & JORDAN, G. J., 1994. Cainozoic vegetation in Tasmania: macrofossil evidence. In *History of the Australian Vegetation: Cretaceous to Recent*, R. S. Hill, ed., Cambridge University Press, Cambridge, 276–298.
- CHAPMAN, F., 1913. Description of New and Rare Fossils obtained by deep boring in the Mallee. Pt 1. Plantae; and Rhizopoda to Brachiopoda. *Proceedings of the Royal Society of Victoria* 26: 165–191.
- CHAPMAN, F., 1914. On an impression of the fruit of *Casuarina* or sheoak in the newer basalt of Victoria. *Victorian Naturalist* 31: 89–91.
- CHAPMAN, F., 1918. On the age of the Bairnsdale gravels; with a note on the included fossil wood. *Proceedings of the Royal Society of Victoria* 31: 166–174.
- CHAPMAN, F., 1921. A sketch of the geological history of Australian plants: the Cainozoic flora. *Victorian Naturalist* 37: 127–133.
- CHAPMAN, F., 1925a. Notes on the Brown Coal from Morwell, South Gippsland. *Records of the Geological Survey of Victoria* 4: 485–487.
- CHAPMAN, F., 1925b. On some seed-like bodies from the Morwell Brown Coal. *Records of the Geological Survey of Victoria* 4: 487–489.
- CHAPMAN, F., 1926a. New or little-known fossils in the National Museum. Part XXIX. On some Paleogene and Neogene plant remains from Narracan, South Gippsland. *Proceedings of the Royal Society of Victoria (new series)* 38: 183–191.
- CHAPMAN, F., 1926b. The fossil *Eucalyptus* record. *Victorian Naturalist* 42: 229–231.
- CHRISTOPHEL, D. C., 1980. Occurrence of *Casuarina* megafossils in the Paleogene and Neogene of south-eastern Australia. *Australian Journal of Botany* 28: 249–259.
- CHRISTOPHEL, D. C., 1984. Early Paleogene and Neogene Proteaceae: The first floral evidence for the *Musgraveinae*. *Australian Journal of Botany* 32: 177–186.
- CHRISTOPHEL, D. C., 1986. First record of well preserved megafossils of *Nothofagus* from mainland Australia. *Proceedings of the Royal Society of Victoria* 97(4): 175–178.
- CHRISTOPHEL, D. C., 1989. Evolution of the Australian flora through the Tertiary. *Plant Systematics and Evolution* 162: 63–78.
- CHRISTOPHEL, D. C., 1993. Prehistory of the flora of Victoria. In *Flora of Victoria*. Vol. 1. *Introduction*, D. B. Foreman & N. G. Walsh, eds, Inkata Press, Melbourne, 3–23.
- CHRISTOPHEL, D. C., 1994. The early Tertiary macrofloras of continental Australia. In *History of the Australian Vegetation: Cretaceous to Recent*, R. S. Hill, ed., Cambridge University Press, Cambridge, 262–275.

- CHRISTOPHEL, D. C. & BASINGER, J. F., 1982. Earliest floral evidence for the Ebenaceae in Australia. *Nature* 296: 439-441.
- CHRISTOPHEL, D. C. & GREENWOOD, D. R., 1988. A comparison of Australian tropical rainforest and Tertiary fossil leaf-beds. In *The Ecology of Australia's Wet Tropics*, R. Kitching, ed., *Proceedings of the Ecological Society of Australia*, 15. Surrey Beatty & Sons, Chipping Norton, NSW, 139-148.
- CHRISTOPHEL, D. C. & GREENWOOD, D. R., 1989. Changes in climate and vegetation in Australia during the Tertiary. *Review of Palaeobotany and Palynology* 58: 95-109.
- CHRISTOPHEL, D. C., HARRIS, W. K. & SYBER, A. K., 1987. The Eocene flora of the Anglesea locality, Victoria. *Alcheringa* 11: 303-323.
- CHRISTOPHEL, D. C. & LYS, S. D., 1986. Mummified leaves of two new species of Myrtaceae from the Eocene of Victoria, Australia. *Australian Journal of Botany* 34: 649-662.
- CHURCHILL, D. M., 1969. The fossil occurrence of *Lygodium* in Australia. *Neues Jb. Geol. Palaont. Mh.* 5: 257-265.
- CHURCHILL, D. M., 1973. The ecological significance of tropical mangroves in the early Tertiary floras of southern Australia. *Geological Society of Australia Special Publication* 4: 79-85.
- CHURCHILL, D. M. & DODSON, J. R., 1980. The occurrence of *Phyllocladus asplenifolius* (Labill.) Hook. f. in Victoria, prior to 1100 B.P. *Muelleria* 4: 277-284.
- CLIFFORD, H. T. & COOKSON, I. C., 1953. *Muscites yallournensis*, a fossil moss capsule from Yallourn, Victoria. *The Bryologist* 56: 53-55.
- CONRAN, J. G., CHRISTOPHEL, D. C. & SCRIVEN, L. J., 1994. *Petermanniopsis anglesiensis*: An Australian fossil net-veined monocotyledon from Eocene Victoria. *International Journal of Plant Science* 155: 816-827.
- COOKSON, I. C., 1947. On fossil leaves (Oleaceae) and a new type of fossil pollen grain from Australian brown coal deposits. *Proceedings of the Linnean Society of New South Wales* 72: 183-197.
- COOKSON, I. C., 1953. On *Macrozamia hopeites*—an early Tertiary cycad from Australia. *Phytomorphology* 3(3): 306-312.
- COOKSON, I. C., 1954. The Cainozoic occurrence of *Acacia* in Australia. *Australian Journal of Botany* 2(1): 52-59.
- COOKSON, I. C. & DUGAN, S. L., 1950. Fossil Banksieae from Yallourn, Victoria, with notes on the morphology and anatomy of living species. *Australian Journal of Scientific Research (Series B; Biological Sciences)* 3(2): 133-165.
- COOKSON, I. C. & PIKE, K. M., 1953a. The Paleogene and Neogene occurrence and distribution of *Podocarpus* (section *Dacrycarpus*) in Australia and Tasmania. *Australian Journal of Botany* 1: 71-82.
- COOKSON, I. C. & PIKE, K. M., 1953b. A contribution to the Tertiary occurrence of the genus *Dacrydium* in the Australian region. *Australian Journal of Botany* 1: 474-484.
- COOKSON, I. C. & PIKE, K. M., 1954. The fossil occurrence of *Phyllocladus* and two other podocarpaceous types in Australia. *Australian Journal of Botany* 2: 60-67.
- CRESPIN, I., 1954. The Nelson bore, south-western Victoria. *Report of the Bureau Mineral Resources, Geology and Geophysics, Australia*, No. 11.
- DEANE, H., 1900. Observations on the Tertiary flora of Australia, with special reference to Ettingshausen's theory of the Tertiary cosmopolitan flora. *Proceedings of the Linnean Society of New South Wales* 25: 463-475.
- DEANE, H., 1902a. Notes on fossil leaves from the Tertiary deposits of Wingello and Bungonia. *Records of the Geological Survey of New South Wales* 7: 59-65.
- DEANE, H., 1902b. Notes on the fossil flora of Pitfield and Mornington. *Records of the Geological Survey of Victoria* 1: 15-20.
- DEANE, H., 1902c. Notes on the fossil flora of Berwick. *Records of the Geological Survey of Victoria* 1: 21-32.
- DEANE, H., 1902d. Preliminary report on the fossil flora of Pitfield, Mornington, Sentinel Rock (Otway coast), Berwick, and Wonwron. *Records of the Geological Survey of Victoria* 1: 13-14.
- DEANE, H., 1904. Further notes on the Cainozoic flora of Sentinel Rock, Otway Coast. *Records of the Geological Survey of Victoria* 1: 212-216.
- DEANE, H., 1923. Tertiary fossil fruits from deep lead, Foster, south Gippsland. *Records of the Geological Survey of Victoria* 4: 489-492.
- DEANE, H., 1925. Fossil leaves from the open cut, State Brown Coal Mine, Morwell. *Records of the Geological Survey of Victoria* 4: 492-498.
- DOUGLAS, A. W. & HYLAND, B. P. M., 1995. Subfamily 3: Eidotheoideae. In *Flora of Australia, Vol. 16: Elaeagnaceae, Proteaceae I*, A. E. Orchard, ed., CSIRO Australia, Melbourne, 127-129.
- DOUGLAS, J. G., 1960. Preliminary identification of microplankton and microflora. Appendix 2 in Bores 2 & 3, Portland, Victoria—subsurface geology and engineering data. *Mining & Geological Journal of Victoria* 6: 4-9.
- DOUGLAS, J. G., 1967. Fossil plants of the Melbourne area. *Bulletin of the Geological Survey of Victoria* 59, 84-86.
- DOUGLAS, J. G., 1976. Tertiary leaf fossils, parish of Woodstock. *Geological Survey of Victoria, Report 1976/62*, Geological Survey of Victoria, Melbourne.
- DOUGLAS, J. G., 1977. A new fossil plant assemblage from the Eastern View Coal measures. *Geological Survey of Victoria, Report 1977/31*, Geological Survey of Victoria, Melbourne.
- DOUGLAS, J. G., 1978. Victoria's oldest flowers. *Victorian Naturalist* 95: 137-140.
- DOUGLAS, J. G., 1983. *What Fossil Plant is That? A guide to the ancient floras of Victoria*, Field Naturalists Club of Victoria, Melbourne.
- DOUGLAS, J. G., 1984. Explanatory notes on the Warragul 1:250 000 Geological Map. *Geological Survey of Victoria Report 57*, Geological Survey of Victoria, Melbourne.

- DOUGLAS, J. G., 1990. Palaeobotany in Australia. In *Proceedings, 3rd IOP Conference, Melbourne 1988*. J. G. Douglas & D. C. Christophel, eds, A-Z Printers, Melbourne, 3-5.
- DOUGLAS, J. G., 1993. Geology and geomorphology of Victoria. In *Flora of Victoria. Vol. 1. Introduction*, D. B. Foreman & N. G. Walsh, eds, Inkata Press, Melbourne.
- DUIGAN, S. L., 1951. A catalogue of the Australian Tertiary flora. *Proceedings of the Royal Society of Victoria* 63: 41-56.
- DUIGAN, S. L., 1965. The nature and relationships of the Tertiary brown coal flora of the Yallourn area in Victoria, Australia. *The Palaeobotanist* 14: 191-201.
- ENTWISLE, T. J., 1994. Ferns and allied plants (Psilophyta, Lycopodiophyta, Polypodiophyta). In *Flora of Victoria, Vol. 2: Ferns and Allied Plants, Conifers and Monocotyledons*, N. G. Walsh & T. J. Entwisle, eds, Inkata Press, Melbourne.
- ETTINGSHAUSEN, C. VON, 1883. Beiträge zur Kenntniss der Tertiärflora Australiens. Pt 1. *Denkschriften der Österreichischen Akademie der Wissenschaften, Mathematisch-Naturwissenschaftliche Klasse* 47: 101-148.
- ETTINGSHAUSEN, C. VON, 1886. Beiträge zur Kenntniss der Tertiärflora Australiens. Pt 2. *Denkschriften der Österreichischen Akademie der Wissenschaften, Mathematisch-Naturwissenschaftliche Klasse* 53: 81-142.
- ETTINGSHAUSEN, C. VON, 1888. Contributions to the Tertiary flora of Australia. *Memoirs of the Geological Survey of New South Wales* 2: 1-189.
- EWART, A. J., 1933. Fossil Blackwood? *Victorian Naturalist* 33: 76.
- FLORIN, R., 1963. The distribution of conifer and taxad genera in time and space. *Acti Horti Bergiani* 20: 121-312.
- FRAKES, L. A., FRANCIS, J. E. & SYKTUS, J. I., 1992. *Climate modes of the Phanerozoic. The history of the Earth's climate over the past 600 million years*, Cambridge University Press, Cambridge.
- GENTILLI, J., 1971. Climates of Australia and New Zealand. *World Survey of Climatology* Vol. 13, Elsevier, Amsterdam.
- GEORGE, A. S. & HYLAND, B., 1995. *Megahertzia*. In *Flora of Australia Vol. 16: Eleagnaceae, Proteaceae I*, A. E. Orchard, ed., CSIRO Australia, Melbourne, 354-355.
- GIBBONS, F. R., & GILL, E. D., 1964. Terrains and soils of the basalt plains of far western Victoria. *Proceedings of the Royal Society of Victoria* 77: 387-395.
- GILL, E. D., 1942. The bearing of the Tertiary sub-basaltic deposits on the palaeogeography of the Lilydale district. *Proceedings of the Royal Society of Victoria* 54: 245-255.
- GILL, E. D., 1949. Early Tertiary plant beds near Pascoe Vale, Melbourne, Victoria. *Victorian Naturalist* 66: 69-73.
- GILL, E. D., 1952. Range in time of the Australian Tertiary flora. *The Australian Journal of Science* 15: 47-49.
- GILL, E. D., 1961. The climates of Gondwanaland in Kainozoic times. In *Descriptive Palaeoclimatology*, A. Nairn, ed., Interscience, New York, 332-353.
- GILL, E. D., 1965. Palaeontology of Victoria. *Victorian Year Book* 79: 1-8.
- GILL, E. D., 1975. Evolution of Australia's unique flora and fauna in relation to the plate tectonics theory. *Proceedings of the Royal Society of Victoria* 87: 215-234.
- GILL, E. D. & BAKER, A. A., 1950. Fossil plants in basalt at Maribymong, Victoria. *Victorian Naturalist* 67: 123-129.
- GILL, E. D. & MCWHAEE, K. M., 1959. Tertiary fossil ferns from Victoria, Australia. *Memoirs of the National Museum of Victoria* 24: 45-50.
- GLOE, C. S., BARTON, C. M., HOLDGATE, G. R., BOLGER, P. F., KING, R. L. & GEORGE, A. M., 1998. Economic Geology: Brown Coal. In *Geology of Victoria*, J. G. Douglas & J. A. Ferguson, eds, Geological Society of Australia Incorporated, Victorian Division, Melbourne, 453-590.
- GOULD, R. E., 1975. The succession of Australian pre-Tertiary megafossil floras. *Botanical Review* 41: 453-483.
- GOULD, R. E., 1981. Palaeobotany is blooming: 1970-1979, a review. *Alcheringa* 5: 49-70.
- GREENWOOD, D. R., 1981. *The Miocene Fossil Flora of the Yallourn Clays and its Relationship to the Associated Morwell and Yallourn Coal Floras*, Unpubl. Bsc(Hons) Thesis, Botany Department, The University of Adelaide.
- GREENWOOD, D. R., 1987. Early Tertiary Podocarpaceae: megafossils from the Eocene Anglesea locality, Victoria, Australia. *Australian Journal of Botany* 35: 111-134.
- GREENWOOD, D. R., 1991. The taphonomy of plant macrofossils. In *Fossilisation: the processes of taphonomy*, S. K. Donovan, ed., Belhaven Press, London, 145-169.
- GREENWOOD, D. R., 1994. Palaeobotanical Evidence for Tertiary Climates. In *History of the Australian Vegetation: Cretaceous to Recent*, R. S. Hill, ed., Cambridge University Press, Cambridge, 44-59.
- GREENWOOD, D. R., CALLEN, R. A. & ALLEY, N. F., 1990. *The correlation and depositional environment of Paleogene and Neogene strata based on macrofloras in the Southern Lake Eyre Basin, Report Book No. 90/15*, South Australian Department of Mines & Energy, Adelaide.
- GREENWOOD, D. R., VADALA, A. J. & BANKS, M. A., 1999. Climates and changes in forest floristics during the Paleocene and Eocene in southeastern Australia. In *Early Paleogene Warm Climates and Biosphere Dynamics*, Abstract Vol. ISSN 1400-383X. F. P. Andreasson, B. Schmitz & E. I. Thompson, eds, Göteborg University, Sweden.
- HANKS, W., 1934. The Tertiary sands and Older Basalt of Coburg, Pascoe Vale, and Campbellfield, Victoria. *Proceedings of the Royal Society of Victoria (new series)* 46: 144-150.

- HARRIS, W. K., 1971. Tertiary stratigraphic palynology. In *The Otway Basin of Southeastern Australia*. Special Bulletin, Geological Surveys of South Australia and Victoria. H. Wopfner & J. G. Douglas, J. G. eds, Government Printer, Adelaide, 67–87.
- HARRIS, W. K., 1985. Middle to Late Eocene depositional cycles and dinoflagellate zones in southern Australia. *Special Publication, South Australian Department of Mines and Energy* 5: 133–144.
- HICKMAN, V. V., 1957. A fossil spider from Tertiary retinite at Allendale, Victoria. *Proceedings of the Royal Society of Victoria* 69: 25–28.
- HILL, R. S., 1978. Two new species of *Bowenia* Hook. ex. Hook. f. from the Eocene of Eastern Australia. *Australian Journal of Botany* 26: 837–846.
- HILL, R. S., 1980. Three new Eocene cycads from Eastern Australia. *Australian Journal of Botany* 28: 105–122.
- HILL, R. S., 1988a. Australian Tertiary angiosperm and gymnosperm remains—an updated catalogue. *Alcheringa* 12: 207–219.
- HILL, R. S., 1988b. A Re-investigation of *Nothofagus muelleri* (Ett.) Paterson and *Cinnamomum nuytsii* Ett. from the Late Eocene of Vegetable Creek. *Alcheringa* 12: 221–231.
- HILL, R. S., 1989. New species of *Phyllocladus* (Podocarpaceae) macrofossils from southeastern Australia. *Alcheringa* 13: 193–208.
- HILL, R. S., 1990a. Evolution of the modern high latitude Southern Hemisphere flora; evidence from the Australian macrofossil record. In *Proceedings of the 3rd IOP Conference, 1988*, J. G. Douglas & D. C. Christophel, eds, A–Z Printers, Melbourne, 31–42.
- HILL, R. S., 1990b. *Araucaria* (Araucariaceae) species from Australian Tertiary sediments—a micro-morphological study. *Australian Systematic Botany* 3: 203–220.
- HILL, R. S., 1992a. *Nothofagus*: evolution from a Southern perspective. *Trends in Ecology and Evolution* 7: 190–194.
- HILL, R. S., 1992b. Australian vegetation during the Tertiary: macrofossil evidence. *The Beagle, Records of the Northern Territory Museum of Arts and Sciences* 9: 1–10.
- HILL, R. S., 1994. The history of selected Australian taxa. In *History of the Australian Vegetation: Cretaceous to Recent*, R. S. Hill, ed., Cambridge University Press, Cambridge, 390–420.
- HILL, R. S. & CARPENTER, R. J., 1991. Evolution of *Acmopyle* and *Dacrycarpus* (Podocarpaceae) foliage as inferred from macrofossils in south-eastern Australia. *Australian Systematic Botany* 4: 449–479.
- HILL, R. S. & CHRISTOPHEL, D. C., 1988. Tertiary leaves of the tribe Banksieae (Proteaceae) from south-eastern Australia. *Botanical Journal of the Linnean Society* 97: 205–227.
- HILL, R. S. & POLE, M., 1992. Leaf and shoot morphology of extant *Afroparpus*, *Nageia* and *Retrophillum* (Podocarpaceae) species, and species with similar leaf arrangement, from Paleogene and Neogene sediments in Australasia. *Australian Systematic Botany* 5: 337–358.
- HILLS, E. S., 1956. Fossiliferous Tertiary resin from Allendale, Victoria. *Proceedings of the Royal Society of Victoria* 69: 15–20.
- HOLDGATE, G. R., KERSHAW, A. P. & SLUITER, I. R. K., 1995. Sequence stratigraphic analysis and the origins of Tertiary brown coal lithotypes, LaTrobe Valley, Gippsland Basin, Australia. *International Journal of Coal Geology* 28: 249–275.
- HOLMES, W. B. K., HOLMES, F. M. & MARTIN, H. A., 1982. Fossil *Eucalyptus* remains from the Middle Miocene Chalk Mountain Formation, Warrumbungle Mountains, New South Wales. *Proceedings of the Linnaean Society of New South Wales* 106: 299–310.
- HOWCHIN, W., 1928. *The Building of Australia and the Succession of Life: with special reference to South Australia. Pt II. Mesozoic and Cainozoic*. Handbooks of the Flora and Fauna of South Australia, Government Printer, Adelaide, 205–448.
- HUNTER, S. B., 1909. The deep leads of Victoria. *Memoirs of the Geological Survey of Victoria* 7.
- JENKIN, J. J., 1988. Geomorphology. In *Geology of Victoria*, J. G. Douglas & J. A. Ferguson, eds, Victorian Division, Geological Society of Australia, Melbourne, 403–426.
- JOHNSTON, R. M., 1885. Descriptions of new species of fossil leaves from the Tertiary deposits of Mount Bischoff belonging to the genera *Eucalyptus*, *Laurus*, *Quercus*, *Cycadites*, etc. *Papers and Proceedings of the Royal Society of Tasmania* 1885: 322–325.
- JOHNSTON, R. M., 1887. Observations with respect to the nature and classification of the Tertiary rocks of Australasia. *Papers and Proceedings of the Royal Society of Tasmania* 1887: 135–207.
- KEBLE, R. A., 1925. Lignite at Beenak. *Records of the Geological Survey of Victoria* 4: 436–437.
- KEMP, E. M., 1978. Tertiary climatic evolution and vegetation history in the southeast Indian Ocean region. *Palaeogeography, Palaeoclimatology, Palaeoecology* 24: 169–208.
- KEMP, E. M., 1981. Tertiary palaeogeography and the evolution of Australian climate. In *Ecological Biogeography of Australia*, A. Keast, ed., Junk, The Hague, 31–50.
- KENLEY, P. R., 1971. Cainozoic geology of the eastern part of the Gambier Embayment, southwestern Victoria. In *The Otway Basin of Southeastern Australia*, H. Wopfner & J. G. Douglas, eds, Government Printer, Adelaide, 89–154.
- KENNY, J. P. L., 1937. Damsite, Mitta Mitta River below Gibbo Junction. *Records of the Geological Survey of Victoria* 4: 461–465.
- KIRCHHEIMER, F., 1935. Paläobotanische Mitteilungen II. Das Vorkommen von *Elaeocarpus* L. in den begrabenen goldseifen Australiens. *Sonder Abdruck Zentralblatt f. min. Abt. B* 5: 178–183.
- KRAUSE, F. M., 1887. The Tripolite Deposits of Lilicur. *Transactions and Proceedings of the Royal Society of Victoria* 23: 250–255.

- KRAUSEL, R., 1949. Die Fossilen Koniferen-Holzer (Unter Ausschluss von *Araucarioxylon* Kraus.) II. Teil. Kritische Untersuchungen zur Diagnostik Lebender und Fossiler Koniferen-Holzer. *Palaeontographica Abt. B. Bd.* 89: 83–203.
- KUBART, B., 1922. Was ist *Spondylostrombus smythii* F.v.M.? *Sitz-Ber. Akad. Wiss. Wein. (Math-nat. Cl.) Abt. 1 Bd.* 131: 9–10.
- LANGE, R. T., 1978. Carpological evidence for fossil *Eucalyptus* and other Leptospermeae (subfamily Leptospermoideae of Myrtaceae) from a Tertiary deposit in the South Australian arid zone. *Australian Journal of Botany* 26: 221–233.
- LANGE, R. T., 1980. Evidence for lid-cells and host-specific microfungi in the search for Tertiary *Eucalyptus*. *Review of Palaeobotany and Palynology* 29: 29–33.
- LANGE, R. T., 1982. Australian Tertiary vegetation, evidence and interpretation. In *A History of Australasian Vegetation*, J. M. G. Smith, ed., McGraw Hill Book Co, Sydney, 44–89.
- LEISMAN, G. A., 1986. *Cryptocaryoxylon gippslandicum* gen. et sp. nov., from the Tertiary of eastern Victoria. *Alcheringa* 10: 225–34.
- LULY, J., SLUITER, I. R. & KERSHAW, A. P., 1980. Pollen studies of Tertiary brown coals: Preliminary analyses of lithotypes within the LaTrobe Valley, Victoria. *Monash Publications in Geography No. 3*, Department of Geography and Environmental Science, Monash University, Melbourne.
- MAIDEN, J. H., 1922. A Critical Revision of the Genus *Eucalyptus* 4: 165–218.
- MACPHAIL, M. K., ALLEY, N. F., TRUSWELL, E. M. & SLUITER, I. R. K., 1994. Early Tertiary vegetation: evidence from spores and pollen. In *History of the Australian Vegetation: Cretaceous to Recent*, R. S. Hill, ed., Cambridge University Press, Cambridge, 189–261.
- MACUMBER, P. G., 1978. Evolution of the Murray River during the Tertiary period—evidence from northern Victoria. *Proceedings of the Royal Society of Victoria* 90: 43–52.
- MARTIN, H. A., 1977. the Tertiary stratigraphic palynology of the Murray Basin in New South Wales 1. The Hay–Balranald–Wakool districts. *Proceedings of the Royal Society of New South Wales* 110: 41–47.
- MCCOY, F., 1876. Prodrum of Palaeontology of Victoria. Decade IV, *Geological Survey of Victoria, Special Publication* 1876/xx, Geological Survey of Victoria, Melbourne, 29–32.
- MCCOY, F., 1878. Schedule of reports on fossil specimens. *Progress Report of the Geological Survey of Victoria* 5: 174–176.
- MCGOWRAN, B., 1991. Maastrichtian and early Cainozoic, southern Australia: planktonic and foraminiferal biostratigraphy. In *The Cainozoic in Australia: A re-appraisal of the evidence*, M. A. J. Williams, P. Dedecker & A. P. Kershaw, eds, *Geological Society of Australia Special Publication No. 18*, Geological Society of Australia, Sydney, 79–98.
- MCGOWRAN, B., MOSS, G. & BEECKROFT, A., 1992. Late Eocene and Early Oligocene in southern Australia: local neritic signals of global oceanic changes. In *Eocene–Oligocene Climatic and Biotic Evolution*, D. R. Prothero & W. A. Berggren, eds, Princeton University Press, 178–201.
- MCKENZIE, D. A., NOTT, R. J. & BOLGER, P. F., 1984. Radiometric Age Determinations. *Geological Survey of Victoria Report 1984/75*, Department of Minerals and Energy, Melbourne.
- MUELLER, F. VON, 1874. *Observations on New Vegetable Fossils of the Auriferous Drifts*. Decade I, Geological Survey of Victoria, Melbourne.
- MUELLER, F. VON, 1883. *Observations on New Vegetable fossils of the Auriferous Drifts*. Decade II, Geological Survey of Victoria, Melbourne.
- MURRAY, R. A. F., KRAUSE, F. M., TAYLOR, N., HOWITT, A. W., NICHOLAS, W., MCCOY, F. & NEWBERRY, J. C., 1878. Reports on the Geology, Mineralogy, and Physical Structure of Various Parts of the Colony. *Geological Survey of Victoria Report of Progress 1878*, Geological Survey of Victoria, Melbourne.
- NOBES, E. D., 1922. A preliminary note on the fossil woods from some Australian brown coal deposits. *Transactions of the Royal Society of South Australia* 46: 528–536.
- O'DOWD, D. J., BREW, C. R., CHRISTOPHEL, D. C. & NORTON, R. A., 1991. Mite–plant associations from the Eocene of southern Australia. *Science* 252: 99–101.
- OKE, C. G., 1957. Fossil Insecta from Cainozoic resin at Allendale, Victoria. *Proceedings of the Royal Society of Victoria* 69: 29–32.
- OLLIER, C. D., 1986. The origin of alpine landforms in Australasia. In *Flora and Fauna of Alpine Australia: Ages and Origins*, B. A. Barlow, ed., CSIRO Australia, Melbourne, 3–26.
- ORR, D., 1927. The Stony Creek Basin and the Corinella Dyke. *Proceedings of the Royal Society of Victoria (new series)* 40: 23–33.
- PARTRIDGE, A. D., 1998. *Palynological analysis of macroplant fossil locality, Hotham Heights, Victoria*. *Biostrata Report 1998/12*, Biostrata, Melbourne.
- PARTRIDGE, A. D. & WILKINSON, H. E., 1982. Palynological examination of samples from the Woodstock 10008 Bore, Loddon deep lead. *Geological Survey of Victoria Report 1982/11*, Geological Survey of Victoria, Melbourne.
- PATERSON, H. T., 1934. Notes on some Tertiary leaves from Pascoe Vale. *Proceedings of the Royal Society of Victoria (new series)* 46: 264–273.
- PATERSON, H. T., 1935. Notes on plant remains from Narracan and Darlimurla, South Gippsland. *Proceedings of the Royal Society of Victoria (new series)* 48: 67–74.
- PATTON, R. T., 1919. Notes on eucalypt leaves occurring in the Tertiary beds at Bulla. *Proceedings of the Royal Society of Victoria (new series)* 31: 362–363.
- PATTON, R. T., 1928. Fossil plants of the Stony Creek basin. *Proceedings of the Royal Society of Victoria (new series)* 40: 88–90.

- PATTON, R. T., 1936. A fossil *Casuarina*. *Proceedings of the Royal Society of Victoria* 49: 36-39.
- PATTON, R. T., 1958. Fossil wood from Victorian brown coal. *Proceedings of the Royal Society of Victoria* 70: 129-143.
- PICKETT, J. W., SMITH, N., BISHOP, P. M., HILL, R. S., MACPHAIL, M. K. & HOLMES, W. B. K., 1990. A stratigraphic evaluation of Ettingshausen's New England Tertiary plant localities. *Australian Journal of Earth Science* 37: 293-303.
- PIKE, K. M., 1952. Fossil fruiting cones of *Casuarina* and *Banksia* from Tertiary deposits in Victoria. *Proceedings of the Royal Society of Victoria* 65: 1-8.
- PIKE, K. M., 1954. Plant remains, Parish of Crosbie. *Mines Department Unpublished Report* 1954/58.
- POLE, M., 1992a. Early Eocene coastal vegetation, Regatta Point, Tasmania. *Resumes/Abstracts. Organisation Internationale de Paleobotanique, IV<sup>ème</sup> Conférence*, Paris, 1992, p. 124. OFB Informations 16 B, 190 pp.
- POLE, M., 1992b. Eocene vegetation from Hasties, north-eastern Tasmania. *Australian Systematic Botany* 5: 431-475.
- POLE, M. S., HILL, R. S., GREEN, N. & MACPHAIL, M. K., 1993. The Miocene Berwick Quarry—rain-forest in a drying environment. *Australian Systematic Botany* 6: 399-427.
- RICH, T. H., ARCHER, M., HAND, S. J., GODTHEL, H., MUIRHEAD, J., PLEDGE, N., LUNDELUS, E. L. JNR, FLANNERY, T. F., RICH, L. S. V., WOODBURNE, M. O., CASE, J. A., WHITELAW, M. J., TEDFORD, R. H., KEMP, A., TURNBULL, W. D. & RICH, P. V., 1991. Appendix 1. Australian Mesozoic and Tertiary Terrestrial Mammal Localities. In *Vertebrate Palaeontology of Australasia*, P. V. Rich, J. M. Monaghan, R. F. Baird & T. H. Rich, eds, Pioneer Design Studio & Monash University Publications Committee, Melbourne, 1005-1070.
- ROWETT, A. I. & CHRISTOPHEL, D. C., 1990. The dispersed cuticle profile of the Eocene Anglesea clay lenses. In *Proceedings, 3rd IOP Conference*, J. G. Douglas & D. C. Christophel, eds, A-Z Printers, Melbourne, 115-121.
- ROZEFELDS, A., 1988. Insect leaf mines from the Eocene Anglesea locality, Victoria, Australia. *Alcheringa* 12: 1-6.
- ROZEFELDS, A., 1995. Miocene *Wilkinsonia* fruits (Hicksbechiinae, Proteaceae) from the base of the Yallourn Formation, LaTrobe Valley, Victoria. *Papers and Proceedings of the Royal Society of Tasmania* 129: 59-62.
- ROZEFELDS, A. C. & CHRISTOPHEL, D. C., 1996a. *Elaeocarpus* (Elaeocarpaceae) endocarps from the Early to Middle Miocene Yallourn Formation of eastern Australia. *Muelleria* 9: 229-237.
- ROZEFELDS, A. C. & CHRISTOPHEL, D. C., 1996b. *Elaeocarpus* (Elaeocarpaceae) endocarps from the Oligo-Miocene of eastern Australia. *Papers and Proceedings of the Royal Society of Tasmania* 130: 41-48.
- ROZEFELDS, A. C., CHRISTOPHEL, D. C. & ALLEY, N. F., 1992. Tertiary occurrence of the fern *Lygodium* (Schizaeaceae) in Australia and New Zealand. *Memoirs of the Queensland Museum* 32: 203-222.
- SCRIVEN, L. J. & CHRISTOPHEL, D. C., 1990. A numerical taxonomic study of extant and fossil *Gymnostoma*. In *Proceedings, 3rd IOP Conference*, J. G. Douglas & D. C. Christophel, eds, A-Z Printers, Melbourne, 137-147.
- SCRIVEN, L. J. & HILL, R. S., 1995. Macrofossil Casuarinaceae: their identification and the oldest macrofossil record, *Gymnostoma antiquum* sp. nov., from the Late Paleocene of New South Wales, Australia. *Australian Systematic Botany* 8: 1035-1053.
- SELLING, O. H., 1950. Some Tertiary plants from Australia. *Svensk Botanisk Tidskrift* 44: 551-561.
- SINGLETON, F. A., 1935. Cainozoic. In *Outline of the Physiography and Geology of Victoria: Handbook*, Australian and New Zealand Association for the Advancement of Science, 128-135.
- SINGLETON, O. P., 1941. The Tertiary geology of Australia. *Proceedings of the Royal Society of Victoria* 53: 1-125.
- SPENCER-JONES, D., 1971. Marginal Tertiary deposits of the Tyrendarra Embayment—Grassdale and Hamilton District. In *The Otway Basin of Southeastern Australia. Special Bulletin, Geological Surveys of South Australia and Victoria*, H. Wopfner & J. G. Douglas, eds, Government Printer, Adelaide, 241-249.
- STOVER, L. E. & PARTRIDGE, A. D., 1973. Tertiary and late Cretaceous spores and pollen from the Gippsland Basin, southeastern Australia. *Proceedings of the Royal Society of Victoria* 85: 237-286.
- TAYLOR, D. H., WHITEHEAD, M. L., OLSHINA, A. & LEONARD, J. G., 1995. Ballarat 1:100 000 map geological report. *Geological Survey of Victoria Report 105*, Geological Survey of Victoria, Melbourne.
- THOMAS, D. E., 1932. The Kerrie Series and Associated Rocks. *Proceedings of the Royal Society of Victoria* 44: 257-285.
- THOMAS, D. E. & BARAGWANATH, W., 1950. Geology of the brown coals of Victoria, Pt 2. *Mining and Geological Journal of Victoria* 4: 36-52.
- THOMAS, D. E. & BARAGWANATH, W., 1951. Geology of the brown coals of Victoria, Pt 4. *Mining and Geological Journal of Victoria* 4: 36-50.
- TRUSWELL, E. M., 1990. Australian rainforests: the 100 million year record. In *Australian Tropical Rainforests*, L. J. Webb & J. Kikkawa, eds, CSIRO Australia, Melbourne, 7-22.
- WALCOTT, R. H., 1920. Evidence of the age of some Australian gold drifts, with special reference to those containing mammalian remains. *Records of the Geological Survey of New South Wales* 9: 66-97.
- WEBB, L. J., 1959. A physiognomic classification of Australian rainforests. *Journal of Ecology* 47: 551-570.

- WELLMAN, P., 1974. Potassium-argon ages on the Cainozoic volcanic rocks of eastern Victoria. *Journal of the Geological Society of Australia* 21: 359-376.
- WELLMAN, P., 1983. Hotspot volcanism in Australia and New Zealand: Cainozoic and mid-Mesozoic. *Tectonophysics* 96: 225-243.
- WELLMAN, P. & MCDUGALL, I., 1974. Potassium-argon ages on Cainozoic volcanic rocks of New South Wales. *Journal of the Geological Society of Australia* 21: 247-272.
- WILKINSON, H. E., 1971. Geology of the Bendigo area. *Geological Survey of Victoria Report 1977/3*, Mines Department, Melbourne.
- WHITE, M. E., 1986. *The Greening of Gondwana*. Reed Books, Adelaide.
- WHITE, M. E., 1994. *After the Greening. The Browning of Australia*. Kangaroo Press.
- WILLIS, J. H. & GILL, E. D., 1965. Fossil fungus (*Hypoxylon*) from Tertiary brown coal, Yallourn, Victoria, Australia. *Proceedings of the Royal Society of Victoria* 78, 115-117.
- WING, S. L., 1987. Eocene and Oligocene floras and vegetation of the Rocky Mountains. *Annals of the Missouri Botanical Gardens* 74: 748-784.
- WING, S. L. & TIFFNEY, B. H., 1987. Interactions of angiosperms and herbivorous tetrapods through time. In *The origins of angiosperms and their biological consequences*, E. M. Friis, W. G. Chaloner & P. R. Crane, eds, Cambridge University Press, Cambridge, 203-224.
- WOMERSLEY, H., 1957. A fossil mite (*Acronothrus ramus* n. sp.) from Cainozoic resin at Allendale, Victoria. *Proceedings of the Royal Society of Victoria* 69: 21-24.