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), Banksiae (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 &

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 palaeobotany 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 wilkinsonii* Ett. from Vegetable Creek (syn. *Podocarpus wilkinsonii* (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 zoeylocarya, a previously undescribed monotypic genus of Proteaceae assigned to the monogenic subfamily Eidothoideae (Douglas & Hyland 1995). Penteune clarkei F. Muell., common in Victorian deep lead deposits, 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 Spondylolobrosthus 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 achievement 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 *Pentene 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 *Podocarpxylon* by Krausel (1949). Florin (1963) referred to Victorian macrofossils in his major monograph on fossil conifers.

**1970–1999**


Significant advances in biostratigraphic analyses of the Otway and Gippsland basins were completed over this period (eg. Harris 1971; Stover & Partridge 1973; McGowran 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.

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**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 Proteacridites 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.
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<td></td>
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<td>3. Werribee Gorge: Parwan and Bacchus Marsh/Maddingley</td>
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<td>Leaf impressions, including Eucalyptus kiteson, rainforest taxa</td>
<td>Hanks (1934); Paterson (1934); Gill (1949); Douglas (1983); Abele et al. (1988)</td>
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<tr>
<td>A. Parwan*/Parwan Creek</td>
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<td>B. Bacchus Marsh*/Maddingley</td>
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<td>Late Paleocene/Early Eocene</td>
<td>Cinnamomum-type mummified leaves; Nothofagus leaves and cupules; Eucalyptus fruits</td>
<td>Christophel &amp; Greenwood (1989); Greenwood (1994); Greenwood &amp; Christophel (1994); Partridge (1998); Cookson (1954); Abele et al. (1988)</td>
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<td>C. Wensleydale</td>
<td>Eocene</td>
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<tr>
<td>D. Anglesea*</td>
<td>Late Middle Eocene</td>
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<tr>
<td>E. Lookout Hill</td>
<td>Early–Middle Miocene</td>
<td>Seeds, stems; impressions of broad-leaved taxa and Banksieae-like leaves</td>
<td>Gill (1952); Abele et al. (1988)</td>
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<td>Wood of <em>Lauraceae</em> (<em>Cryptocarya</em> ypsi<em>landicum</em>)</td>
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<td>E. Narracan*</td>
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<td>Paterson (1935); Thomas &amp; Baragwanath (1951)</td>
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<td>3. Macroadoras of the brown coals</td>
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<td>A. Tralagon</td>
<td>Late Miocene</td>
<td>Overlying LaTrobe Unconformity</td>
<td>Leaf impressions and compressions</td>
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<td>Late Oligocene–Early Miocene</td>
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<td>Leaf compressions, impressions (including <em>Eucalyptus</em>); fruits; seeds</td>
<td>Chapman (1925); Duigan (1965); Blackburn &amp; Sluiter (1994)</td>
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<tr>
<td>D. Morwell* clay</td>
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<td></td>
<td></td>
<td></td>
<td><em>Oleites</em> leaves</td>
<td>Cookson (1947)</td>
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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 Weribee 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 represent 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 (Banksieaeformis) 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 Nothofagidae 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, stamine 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 Natophyll 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 (Trow) Greenwood and P. lanceolata Greenwood (all Podocarpaceae). Angiosperms include leaves of rainforest trees such as Austrodirosyphos eocenica Basinger & Christophel (Ebenaceae; flowers and leaves), Myrtyciphyllyum douglasi Christophel & Lys (Myrtaceae), two Banksieae-phyllum spp. (Banksiaceae, Proteaceae), Musgraveinanus alcoensis Christophel (Musgraveinae, Proteaceae; flowers), Megahertzia1 sp. (Oritieae, Proteaceae), Brachychiton sp. (Sterculiaeae), Gymnostoma sp., at least 5 Laurophyllum spp. (Lauraceae), Elaeocarpaceae cf. Sloanea, leaves of the monocot Petermanniopsis anglesiensis Conran et al. (Petermanniaceae), and a palm attributed to Linospadix (Areaceae). 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.

1This fossil taxon was originally attributed to the undescribed 'Orites sp. nov.' from Noah Creek in northeastern 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 (e.g. Cinnamomum polymorphaeoides 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 mummmified 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 Eucta and Dacrycarpus), and fruits of Elaeocarpaceae from Bacchus Marsh. Unpublished research on possibly Pleocene-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), Sapindaceae (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 Phylityles), Rubiaceae (as Coprosmaephyllum), Pulitena (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 ± 0.1 m.y. (Rich et al. 1991). Cookson (1954) reported Acacia phylloides 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 Wannon 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 Wannon Falls at Redruth (now Wannon) 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 Budgeree, 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 ± 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 (possibly as Weinmannia, but more probably Geissos) as Chapman referred to a close similarity to W. biagiana syn. Geissos biagiana), Lauraceae (as Cinnamomum and Cryptocarya), Moraceae (as Ficonium), Proteaceae (as Lomatia and Persoonia), Myrtaceae (including both Eucalyptus and Tristanites or Tristaina s.l.), Monimiaceae (as Hedycarya and Mollinedia), Loganiaceae (as Strychnos), cf. Casuarina (Casuarinaceae), and Dacrycarpus (Podocarpaceae, as Podocarpus praeuspriessformis Btt.) 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. 1991; 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.

2Weinmannia and other genera now placed in the Cunoniaceae were originally placed in the Saxifragiaceae 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, Myrtacyphyllum 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 latrobensis (Podocarpaceae); I, stem fragment of Gymnostoma sp.
Macrofossils described from these coals include taxa typical of modern temperate (e.g., Nothofagus) to subtropical–tropical rainforest (e.g., Agathis, Diospyros and Gymnostoma), in addition to sclerophyllous taxa (e.g., Casuarina and Banksiinae). Interseam parting clays commonly contain leaf remains. An unpublished report on the interseam unit of the late Eocene 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 ± 0.3 m.y. (McKenzie et al. 1984), providing a Late Oligocene–Early Miocene age for the Thorpdale fossils.

Thorpdale fruits represent Spondylostrobus, 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, Phyllocadus 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 Theniopteris 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 Gymnocrata (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 Lasraea (Filicales; which Gill & McWhae (1959) described as Cyclosorus dargoensis). The material described as Ginkgo is more likely to be a fern. 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 ± 0.6 m.y. to 33.1 ± 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 misidentification 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 reetermined as Cyclosorus dargoensis by Gill & McWhae (1959). A leaf impression from Bundara River in the National Museum of Victoria collection labelled as Ginkgo murrayii (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 dentata (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 Banksia-aeiphyllum 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 charcoalified 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. Guymor, 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 40m 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) fluvisial 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 (*Spirobolus* sp.), acarid mite (*Acronothrus* sp.), spider (*Artadina* sp.), beetle (representing the families *Pselaphidae*, *Tenebrionidae* and *Seymareaidae*), and ant bodies (*Ponera* and *Iridomyrum* 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 Pliocene floras. This imbalance may be partly paucity of knowledge regarding Paleocene and Eocene and Miocene floras, noting the comparative floral record (Christophel & Greenwood 1989; of the Australian Paleogene and Neogene macro-

emphasis on the mid-Paleogene to mid-Neogene Agathis thrive in cultivation in many parts of climatic change. Extensive and largely unexplored for debate regarding future environmental and Neogene. This record could also provide a basis to climatic changes during the Paleogene and ecosystem and phylogenetic evolution in response to 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 Mallacoota (likely Pleistocene) and E. amygdalina from Redrush/

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 Psilotophytes, 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, palaeontological 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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