CENOZOIC PLANT MACROFOSSIL SITES OF TASMANIA

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(with one text-figure and one appendix)

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Tasmania has an outstanding Cenozoic plant fossil record, including several sites of international significance. This paper provides a compendium of macrofossil sites and associated literature. Macrofossils (leaves, fruit, flowers, wood) are known from 59 sites, ranging from Early Eocene to Late Pleistocene in age. Most are Palaeogene to early Neogene, or Pleistocene, with only one Late Neogene deposit. Most late Palaeogene and early Neogene fossiliferous beds are directly overlain by or interbedded between basalt or other volcanic rocks. Others have indirect association with past volcanic activities. Furthermore, most sites are on or near the floors of major valley systems, whether associated with basalt or not. This association with a limited range of environments may cause some biases in the sampling of past regional floras. The ages of these sites may be significant for our understanding of the ages of volcanism in Tasmania, and also suggest areas for further investigation.

Key Words: Palaeogene, Neogene, Pleistocene, geoconservation, Tertiary, palaeoecology.

INTRODUCTION

Most of the literature on the Tasmanian Cenozoic plant fossil record has focused on particular groups of plants, often in the context of other Australian fossils. For example, several papers (most recently Hill & Brodribb 1999) have reviewed the very rich conifer record. *Nothofagus* has also received considerable attention (e.g. Hill 1991a, Hill & Scriven 1997, Jordan & Hill 1999). Tasmanian fossils of Epacridaceae (Jordan & Hill 1996), Proteaceae (Jordan *et al.* 1998) and Cunoniaceae (Barnes *et al.* 2000) have also been reviewed. Only a few reviews have considered whole floras of specific sites. Carpenter *et al.* (1994) and Hill (1995b) presented the most recent specific overviews of Tasmanian plant macrofossil floras, with close attention to several sites of particular significance.

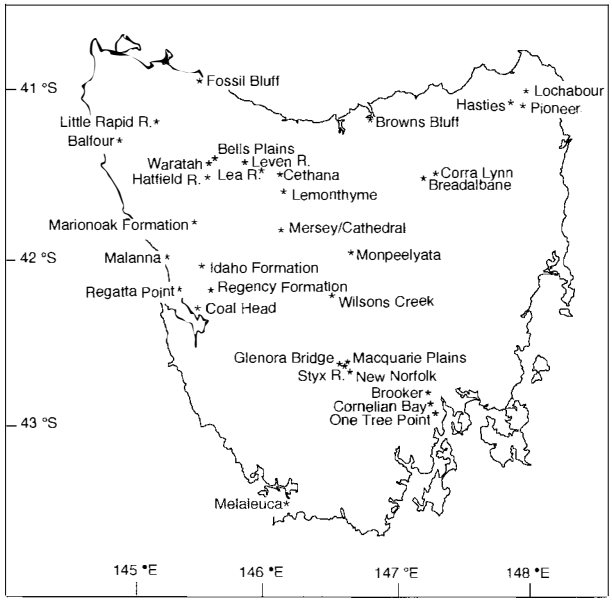

FIG. 1. Locations of selected Tasmanian Cenozoic fossil sites.

This paper reviews the relevant literature and provides a compendium of Tasmanian Cenozoic plant fossil sites. It also considers the relationship of their formation to volcanic activity, and the significance of this for interpreting fossil data. Some of this information was previously presented in Jordan & Hill (1998) but this work is not widely available. Furthermore, the present work includes significant data from drill cores, recent discoveries and analyses.

METHODS

This report combines data from literature and field observations. All sites, except those that have been destroyed, have been visited by the authors in the last five years.

RESULTS

The 59 Cenozoic plant fossil sites in Tasmania that could be precisely located (fig. 1, appendix) can be classified into a few major geographic or temporal categories, as follows.

The Oligo–Miocene Sites of Northwestern Tasmania

Northwestern Tasmania contains many diverse, well-preserved and thoroughly studied Early Oligocene to Miocene assemblages.

Little Rapid River

Road-building for forestry in the 1980s exposed the Little Rapid River fossil locality. The fossiliferous beds have been dated palynostratigraphically as Early Oligocene (Macphail *et al.* 1994). Weathered and presumably undatable basalt overlies the beds, which seem to directly overlie Precambrian rocks. The fossils from this rich and well-studied site have been discussed elsewhere (Hill 1987a, b, 1989, 1990a, b, c, d, 1991a, 1992a, b, 1994a, b, c, 1995a, b, 1997, 2001a, Hill

& Bigwood 1987, Wells 1987, Hill & Carpenter 1989, 1991a, b, Wells & Hill 1989, Read *et al.* 1990, Hill & Pole 1992, Hill *et al.* 1993a, c, Carpenter *et al.* 1994, Macphail *et al.* 1994, Hill & Dettmann 1996, Hill & Scriven 1997, Jordan & Hill 1995, 1999, Jordan *et al.* 1996, Scriven & Hill 1997, Barnes & Hill 1999, Swenson *et al.* 2000). The site is particularly noted for the exceptional diversity of conifers (Hill & Brodribb 1999), and *Nothofagus* (Hill 1987a, 1991a).

Lea River

This well-studied site contains fossils of leaves and reproductive structures (Hill 1990c, Hill 1992a, 2001a, Hill *et al.* 1993a, Carpenter *et al.* 1994, Whang & Hill 1995, Hill & Whang 1997, Jordan *et al.* 1998, Hill & Scriven 1997, Resource Planning and Development Commission 1998, Barnes & Jordan 2000). The fossil-bearing sediment has been dated palynostratigraphically as Early Oligocene (Carpenter *et al.* 1994). It is exposed in two places: a natural river cutting and a nearby gravel pit. At both sites, the sediment appears to lie between basalt flows, although sediment exposed in the river cutting might overlie Ordovician sandstone (see Pemberton & McKibben 1996). Tertiary basalt surrounds the gravel pit exposure, and clearly underlies it. Basalt also occurs opposite the river-cutting beds (Pemberton & McKibben 1996), which are overlain by a soil that may have been derived from *in situ* basalt (John Pemberton pers. comm.).

Cethana

The fossil-bearing siltstone at this reasonably well-studied site has been dated palynostratigraphically as Early Oligocene (Macphail *et al.* 1994). It overlies Late Cambrian–Ordovician sandstone (McClenaghan *et al.* 2001), and is exposed on the side of a steep valley. Tertiary basalt occurs about 2 km to the northeast and 2.5 km to the southeast, but there is no evidence that the deposition of the siltstone was associated with volcanic activity. However, the siltstone is displaced by small scale faults. The siltstone contains compression and impression fossils of an unusually diverse range of leaves, flowers and fruits (Hill 1983a, b, 1984a, 1988a, 1990c, d, 1991a, c, 1992a, b, 1994a, b, c, 1998, 2001a, Carpenter 1988, 1991a, b, 1994, Carpenter & Hill 1988, Hill & Christophel 1988, Hill *et al.* 1988, 1993b, 1995a, b, in press, Hill & Carpenter 1989, 1991a, b, Read *et al.* 1990, Carpenter & Buchanan 1993, Carpenter *et al.* 1994, Carpenter & Jordan 1997, Hill & Scriven 1997, Barnes & Hill 1999). Macrofossils of 56 species have been formally recorded, but many other distinctive forms have not been described because of inadequate preservation (Carpenter 1991b).

Amateur collectors (including school groups) have over-collected this site, and little or no significant material appears to remain *in situ*. Relatively large collections are stored at the University of Tasmania.

Lemonthyme Creek and other drill-core sites

Fine sandstone and siltstone beds occur beneath basalt in Hydro-Electric Commission hole 5825 near Lemonthyme Creek. The beds have been dated palynostratigraphically as Early Oligocene. This site is of considerable interest because the underlying beds have been interpreted as glacial, representing the earliest known Southern Hemisphere Cenozoic glaciation outside Antarctica (Macphail *et al.* 1993). The pollen flora was summarised by Macphail *et al.* (1993), but the siltstone also contains moderately diverse, well-preserved plant macrofossils. Of these, only four species of Proteaceae (Jordan *et al.* 1998), and one of *Callicoma*, from the Cunoniaceae (Barnes & Hill 1999), have been formally documented.

Fossiliferous sediment from a drill-core at Bells Plains has been dated as Oligocene (Hill 1983b), and underlies basalt. This site is of limited interest because of the limited amount of material, with only *Nothofagus tasmanica* (Hill 1983b) and *Athrotaxis rhomboidea* (Hill & Brodribb 1999) formally documented. Other drill cores have been inspected unsuccessfully for fossils. However, sediment overlain by basalt is reasonably common in such cores, and fossiliferous material may have been overlooked. On the other hand, many cores drilled by the Hydro-Electric Commission are now effectively lost, and other core is poorly archived.

Leven River

The Leven River fossiliferous sandstone is exposed on a sharp bend of the river. It is overlain, and possibly underlain, by basalt, and has been dated palynostratigraphically as Early Oligocene (Carpenter & Jordan 1997). It contains fossils of conifer and angiosperms, of which two species have been documented — *Orites excelsoides* (Carpenter & Jordan 1997, Jordan *et al.* 1998, Hill 1998) and *Eucryphia* (Barnes & Jordan 2000), consistent with *E. aberensis* (R. W. Barnes pers. comm.). The preservation is reasonable, but poorer than at sites such as Little Rapid River. The site has potential for further study, although extraction of satisfactory specimens is difficult.

Waratah

Siltstone and occasionally lignite outcrop at the base of Waratah Falls (Seymour 1989). The siltstone is overlain by basalt of the extensive Guildford Plateau. According to Harris (1968, 1973) the palynoflora suggests a Late Oligocene to Early Miocene age. However, most other samples from the Guildford Plateau are of Oligocene age (S.M. Forsyth, pers. comm.). These beds may also be the source of Johnston's (1885a, b, c, 1887) Mt Bischoff fossil flora, from which he described species of *Eucalyptus*, *Quercus*, *Ulmus* and others. However, these identifications are unreliable, because they were based on very limited information: Johnston did not use cuticle analysis or make detailed comparisons with extant species. Johnston's original specimens have been lost, and poor line drawings are all that remain of these fossils. The identification of *Eucalyptus* is particularly unfortunate, since it has been subsequently used to suggest a great age for this genus (e.g. Maiden 1922). Similar problems apply to several of Johnston's other Tertiary fossil sites (e.g. Macquarie Harbour and One Tree Point).

Hatfield River and other sediments associated with basalt

Fossiliferous mudstone beds were exposed by road-building on the basalt plateau above the Hatfield River. The mudstone is overlain by basalt, and may have basalt underneath it. It is dated as Early Oligocene (M. K. Macphail, pers. comm.) by palynostratigraphy, and contains well-preserved leaves, fruit and conifer twigs. However, the fossils are quite sparse within the matrix.

Fossil Bluff near Wynyard, northwestern Tasmania, is well-known for its rich shallow-marine fossil fauna (Macphail 1996), as well as a marsupial skeleton. The strata are aged as Early Miocene based on foraminifera, palynostratigraphy and marine faunas (Quilty 1972,

Macphail 1996). Johnston (1888a) reported leaf fossils from this site, although this lens has not been relocated. A moderately diverse spore and pollen assemblage occurs in a lens of terrestrial mudstone near the base of the marine section, although the former may have been transported later from its original site of deposition.

Well-preserved conifer wood (*Athrotaxis* or another Cupressaceae; K. Voltchanskii pers. comm.) was found under basalt in a quarry south of Somerset along the East Cam River road (*Advocate* 13 March 1967). Similar wood was excavated beneath the basalt in the Mersey River, Devonport, in 1999. No sedimentary beds remains exposed at either site and their ages are not known, but may be Oligo-Miocene, based on the peak periods of volcanism in the region (e.g. Sutherland & Wellman 1986). Fossil wood can also be found in strata exposed on the Cradle Mountain Link Road.

Balfour

Gravel exposed in a road cutting in far northwestern Tasmania contains mummified logs, and one lens of compressed organic material, including leaves and reproductive structures. These beds are Oligocene–Early Miocene in age, based on palynostratigraphy (Hill 2001b). They have no known association with volcanic activity. Six species have been recorded from this site. Cupules of five *Nothofagus* species have been recorded, including one new species of the tropical subgenus *Brassospora* (Hill 2001b). The other record is of a fertile leaf fragment of *Lophosoria quadripinnata*, a fern now found only in South and Central America (Hill *et al.* 2001). The lens also contains an undescribed, diverse suite of conifers, including Araucariaceae, Cupressaceae and Podocarpaceae.

The Derwent Graben

Wilsons Creek

Siltstone and fine sandstone at Wilsons Creek in the upper Derwent Valley (Prider 1948) have been dated palynostratigraphically as Latest Eocene–Early Oligocene (Barnes & Jordan 2000). They are overlain by aquagene basalt flows, and also appear to be underlain by basalt. As yet the fossils are poorly studied, but comprise a diverse and abundant assemblage of compressed leaves, conifer stems and reproductive organs. To date, the only published record is of *Eucryphia mucronata*, known only from this site (Barnes & Jordan 2000).

Bushy Park area

Four fossil sites (Macquarie Plains, New Norfolk, Styx River and Glenora Bridge) are associated with volcanic activity that diverted the Derwent River near Bushy Park. Road work at Macquarie Plains exposed a fossil forest of opalised logs more or less in growth position (Hooker 1842, Banks 1955, 1991). It was possibly discovered by Robert Brown in 1804 (Banks 1955, 1991), and was visited by Joseph Dalton Hooker (Hooker 1842) and possibly Charles Darwin (Banks 1991). The logs were up to 1 m diameter and 3 m long, and contained beautifully preserved petrified wood of several species — *Cupressoxylon hookeri* (Arber 1904), *Nothofagus*, *Araucaria*, *Phyllocladus* and *Banksia* (as identified by Mary Calder in a pers. comm. to Max Banks 1964) and other Proteaceae (including *Orites* or *Knightia* according to H. D. Ingle in a pers. comm. to Max Banks 1966). The logs were preserved in tuff associated with the volcanism that produced the local basalt flows. Unfortunately this site has been more or less completely collected and, apart from specimens remaining in the Tasmanian Museum and elsewhere, is now mainly of historical interest.

The New Norfolk site is exposed under volcanic rocks on the Lyell Highway 11 km west of New Norfolk. It has been dated palynostratigraphically as Oligo-Miocene (Hill 1983b). This site is the type locality of *Nothofagus tasmanica* (Hill 1983b). It also contains other undocumented fossils, although the preservation is mostly poor.

The Styx River cuts into organic-rich sandstone beds underneath a road bridge at Glenora, at the southern edge of the basalt ridge that diverted the Derwent River. The sediments are very likely to be of Palaeogene age, based on known dates for local basalt flows and on the presence of conifers and broad-leaved angiosperms in the fossil flora. The sediment may be the lignite near the junction of the Styx and Derwent rivers described by Johnston (1888a).

About 1 km to the east, under the same basalt ridge, lignite dated palynostratigraphically as Early Eocene (Carpenter *et al.* 1994) was excavated on the northern bank of the Styx River (now diverted) at Bushy Park. It contained a well-preserved, conifer-rich flora (Carpenter *et al.* 1994), but only one angiosperm species. No species have been formally described from this interesting site, but specimens at the University of Adelaide are being examined. When visited recently, no *in situ* material was found.

Hobart suburbs

Westward dipping beds exposed in a road cutting on the Brooker Highway near the Box Hill Road overpass contain impressions and some compression fossils of leaves and conifer twigs. The material is believed to be Early Eocene, based on palynostratigraphy (Stephen Forsyth, pers. comm.). Although basalt flows occur nearby these flows are flat lying, and therefore probably younger than the beds. Very little material has been collected, and most is of impression only. The exposure has been graded over and undisturbed material is now buried. Two species of Proteaceae described from the material (Jordan *et al.* 1998) are not known from anywhere else.

The impression fossils in the siltstone under Pipe Clay Bluff on the Derwent River in Hobart have been known for over 120 years (Johnston 1881, Ettingshausen 1888). Their age is almost certainly Palaeogene because of the macroflora, which is dominated by large-leaved angiosperms. However, the preservation (impressions with moderately good preservation of venation details) means that few of the fossils can be identified with any great accuracy.

Two suburban sites containing plant fossils preserved in travertine were exposed by nineteenth-century quarrying. The Geilston Bay site was dated as Late Oligocene, based on an isotopic date of overlying basalt (Tedford & Kemp 1998). The Burnett Street site may be of similar age. Both sites were foci of nineteenth-century palaeobotany in Tasmania (Strzelecki 1845, Darwin 1860, Allport 1866, Johnston 1879b, 1881, 1887, 1888a, Ettingshausen 1888, Banks 1971), although many of the identifications are unreliable (see the notes on the Waratah site). It is not known whether any fossiliferous material remained when the quarries were abandoned, and urban development has made the sites inaccessible. A school playing field covers the Geilston Bay site, and a park covers Burnett Street.

Museum collections from these sites include some of the oldest marsupial fossils in southern Australia (Tedford *et al.* 1975, Tedford & Kemp 1998), and an early record of *Araucaria* (Selling 1950).

Several other sites of Palaeogene age occur in the Derwent Graben, including Johnston's (1888a) sites at One Tree Point, Lindisfarne and Sandy Bay and another site near sea level at Taroona. Although One Tree Point is the type locality for several species (Ettingshausen 1883), the preservation at each of these sites is poor. The beds at One Tree Point are so intensely weathered that no fossils can be collected and the Taroona sediment is also very weathered. No fossil material seems to be accessible at Lindisfarne. Johnston (1888a) recorded fossil leaves from Sandy Bay, in and near the grounds of what is now the University of Tasmania, and others were excavated during building works in the early 1990s. The preservation of this recently located material has not been of sufficient quality to demand further study. A fossil log identified as *Eucalyptus* by H. D. Ingle was found under the Elwick Roundabout (Gill 1962). Its age is unknown.

Northeastern Tasmania

The large area of fluvial gravel near the northeast coast contains several fossil sites exposed by tin mining (Hill 1989). Gravel beds exposed in the abandoned Hasties and Locharbour mines have been dated as Middle–Late Eocene, based on palynostratigraphy (Bigwood 1984, Bigwood & Hill 1985, Bigwood *et al.* 1988, Hill & Christophel 1988). The Hasties beds contains mummified logs, and lenses of finer sediments contain a moderately diverse assemblage of mummified leaves and conifer foliage (Hill & Bigwood 1987, Hill 1990b, c, d, Read *et al.* 1990, Hill & Carpenter 1991a, 1994c, Carpenter *et al.* 1994). The fossil flora, which was summarised by Pole (1992), includes 12 species of conifers and seven of angiosperms. The Locharbour gravels and mudstone lenses (referred to as Loch Aber in the palaeobotanical literature) contain mummified logs, leaves, conifer foliage and reproductive structures. Although this site is moderately well-studied, the good preservation of delicate reproductive structures warrants further investigation. Of the six conifer and two angiosperm species recorded, two are not known from any other site (Hill & Christophel 1988, Hill 1991c, Taylor 1994, Taylor & Hill 1996, Hill & Scriven 1999, Barnes & Jordan 2000).

Mudstone lenses exposed by the Pioneer tin mine contained abundant mummified leaves and reproductive structures. These sediments were dated palynostratigraphically as Late Oligocene/Early Miocene (Hill & Macphail 1983). Volcanic activity may have contributed to the formation of the river system. Balfour (described above) and Pioneer are the only well-preserved lowland floras of this age in Tasmania (Hill 1983b, Scriven & Hill 1997, Hill & Scriven 1997, Jordan & Hill 1999). The site was flooded after mining operations (and hence pumping) ceased, and no more material can be easily obtained.

Other fossils have been recorded immediately below a basalt cap at Pipers River (Marshall *et al.* 1969), and in the Briseis underground mine at Derby (Scott 1937). No more material could be found at the former site, and the latter has been flooded. The Briseis Mine material included well-preserved wood, leaves and fruit. The presence of overlying basalt suggest that both sites are Palaeogene or earliest Neogene.

Launceston Basin

Johnston (1888a) documented many sites in the Launceston Basin that contained plant macrofossils. One such site was Muddy Creek, on the Tamar River. However, the only fossiliferous sediment that has been found recently in the area was at Brown's Bluff at the mouth of Muddy Creek. Fossiliferous sandstones and mudstones form a cliff about 10 m high and extend for at least 100 m along the foreshore of the Tamar. They are of Palaeogene, possibly Palaeocene or Early Eocene age, based on correlation with other sediments in the Launceston Basin. Most specimens are only impressions, but organically preserved fossils can be found in places. These include conifer foliage, angiosperm leaves, Casuarinaceae cones and twigs, and Araucariaceae cone scales. The site warrants further study.

Petrified wood is embedded in breccia cliffs on the northern bank of the North Esk River, south of Corra Lynn. The volcanic activity in the area was probably Palaeogene, and hence the wood would be the same age. Johnston (1874) identified *Banksia* (probably better interpreted as an unidentified member of Proteaceae) and noted that several other taxa were present. Wood fragments remain *in situ*.

Lignite exposed by railway cuttings near Breadalbane, south of Launceston, is probably that mentioned by Johnston (1873, 1874, 1888). The lignite is overlain by sandstone and basalt, and is Palaeogene, based on correlation with other sediments in the Launceston Basin, and on local basalt dates (e.g. an Early Oligocence date on basalt at nearby Cocked Hat Hill; Lin Sutherland, pers. comm.). The fossil flora includes conifer twigs and some angiosperms, but the preservation is poor.

Fossil wood, leaves, twigs and fruit were found in gold diggings in gravel at Brandy Creek, Beaconsfield, in the late nineteenth century (Johnston 1879a, 1880, 1887, 1918, von Mueller 1883, Ettingshausen 1888). *Elaeocarpus* fruits occur in the sediments (Kirchheimer 1935, Rozefelds and Christophel 2000). No material is collectable from this site, which has been highly modified by past mining, although the Queen Victoria Museum (Launceston) and Mineral Resources of Tasmania have some specimens. The location recorded in the appendix is a gold prospect that is the most likely site of the collections.

Johnston (1888) and Milligan (1849) mentioned other sites near Launceston, including Windmill Hill. None could be relocated. Poorly preserved ferruginised leaves occur at Youngtown. Fossil leaves have been recorded from a number of other sites in the area (e.g. Stephensons Bend and Windmill Hill).

Regatta Point and Other Macquarie Harbour Sites

Sediment rocks containing mummified leaves and reproductive structures are exposed in several places around Macquarie Harbour on the west coast of Tasmania (Maiden 1922, Cookson & Eisenack 1967, Baillie & Corbett 1985, Bigwood & Hill 1985, Hill & Bigwood 1987, Tyler & Hill

1988, Hill 1990a, Carpenter *et al.* 1994, Hill & Pole 1994, Hill *et al.* 1993a,b, 1996, 1999). The best studied is about 500 m south of Regatta Point. This has been dated palynostratigraphically as Early Eocene. Much younger (Early Pleistocene) sedimentary rock at the same site is also referred to as Regatta Point (Hill & Macphail 1985). The context usually clarifies which material is being referred to. The Eocene fossils from this site represent a near-coastal flora, including mangroves (Pole & Macphail 1996) and other lowland forest types. They are the most comprehensive Early Eocene fossil assemblage in Tasmania.

A site in a cutting on the abandoned Zeehan–Strahan railway has been known for over 40 years (Banks & Ahmad 1959). In fact it may be the same site as Johnston's (1891) 'Henty lignites'. It contains a variety of seeds and mummified fragments of angiosperm leaves. These have not been studied in any detail, but more intensive study may be rewarding. Their age is unknown, although the large angiosperm leaves suggest Palaeocene or Eocene age. This is supported by the fact that the site is within the Macquarie Harbour Graben.

Sites in Other Regions

Monpeelyata

The fine, fossiliferous sedimentary rock at this well-studied site on the Central Plateau has been dated palynostratigraphically to the Late Oligocene–Early Miocene (Macphail *et al.* 1991). It underlies basalt; local basalts have potassium argon dates ranging from 22.4 to 24.2 million years (Sutherland & Wellman 1986), i.e. earliest Miocene. The sediment was exposed by excavation for a canal. It contains a moderately diverse range of mummified leaves (Hill 1988b, 1990b, c, d, 1991a, 1992b, 1994a, c, 2001a, Hill & Carpenter 1989, 1991a, b, Wells & Hill 1989, Read *et al.* 1990, Britton 1993, Hill *et al.* 1993*b*, Carpenter *et al.* 1994, Jordan & Hill 1994, 1996, 1999, Macphail *et al.* 1994, Hill & Scriven 1997). They form a very early record of a distinctly cold climate flora (Hill & Gibson 1986, Macphail *et al.* 1991, Hill & Scriven 1997).

Richmond

Sandstone in the Coal River Graben near Richmond, southeastern Tasmania, contains a range of impression fossils. The age is probably Palaeocene–Middle Eocene, based on its stratigraphic context, and the presence of fossil leaves of *Nothofagus* (Hill & Carpenter 1999). This site gains its significance from the presence of the only Cenozoic record of *Gingko* in the Southern Hemisphere (Hill & Carpenter 1999). Although there is no sign that the sediment is directly associated with basalt, the Coal River Graben was volcanically active during the Palaeogene.

Buckland

The Eocene Buckland site described by Townrow (1965a, b) contained well-preserved macrofossils of conifers and angiosperms. The fossiliferous mudstone was exposed on the bank of Tea Tree Rivulet. However, the site has not been found again despite careful searching; the exposure was probably destroyed by flood erosion some time in the last 35 years. The fossils are of considerable interest, but little material remains for analysis. The few species recorded at the site include *Athrotaxis*, six other conifers (Townrow 1965a, b) and two species of Proteaceae (Jordan *et al.* 1998).

Dispersed silicified fossils

Silicified fossils of wood, twigs, leaves and fruit of probable Cenozoic age occur in several places in southeastern Tasmania. These are either pieces of wood or leaf and stem fragments embedded in a siliceous matrix. They are usually found spread across the ground, and their origins are not clear. At present they are undatable. A site at Gavins Tier under the Central Plateau includes *Nothofagus* leaves and *Araucaria* stems (see Jordan & Hill 1998 for details). A site near Longs Hill near Richmond contains petrified wood and silicified leaves. Silicified wood has been found near Swansea (Legge 1895), at several sites in the Midlands (Banks 1971, Forsyth 1989), near Burnie, near Bridgewater (Johnston 1888a) and in several places in the Launceston Basin (e.g. Scott circa 1937).

Other sites

Macrofossils have been recorded from a number of other sites, but in each case some aspects of preservation limit their scientific value. Ferruginised fossils can be found at Shark Point, and near Midway Point (southeastern Tasmania) and north of Deloraine (northern Tasmania). No anatomical details are preserved, and dating is problematic. The sites are probably Palaeogene in age, perhaps Palaeocene or Eocene, considering the distinctly broad-leaved floras. Some well-preserved mummified wood can be found at Granville Harbour (Waterhouse 1915, Blisset 1962).

For a large number of sites, there are records of plant macrofossils in museum collections, in notes on old geological maps, or as asides in other publications. None of these sites has been identifed. Details are given in Jordan & Hill (1998).

Late Pliocene and Quaternary Sites of Western Tasmania

Idaho Formation

The Idaho Formation, near Queenstown (western Tasmania), has been dated as latest Pliocene, based on a combination of palynostratigraphy and its geological context (Macphail *et al.* 1995). The only macrofossils known are specimens of *Phyllocladus* wood. However, the primary significance of this flora comes from the pollen and spore flora. It is the only onshore Late Pliocene flora in Tasmania and therefore significant in interpreting palaeoclimates (Colhoun *et al.* 1988, Hill & Jordan 1996, Jordan 1997a).

Regatta Point Early Pleistocene site (RPU)

Quaternary sand and gravel overlying the Early Eocene sediments at Regatta Point are exposed in cuttings. At the base of these sediments, mummified leaves, fruit and stems can be found in angular mudstone clasts embedded in cobbles. The clasts were originally interpreted as having been rafted on ice, but a simpler explanation is that they were derived locally from the collapse of a river bank. The age of most of the fossiliferous mudstone is Early Pleistocene, based on palynostratigraphy (Macphail *et al.* 1993), although one block may be Early–Middle Pleistocene (Jordan *et al.* 1995). The fossil flora is the richest Early Pleistocene flora known from the Southern Hemisphere (e.g. Jordan 1992, 1997b, Macphail *et al.* 1993). It is significant in understanding processes of evolution and extinction in the development of the modern flora (Hill & Macphail 1985, Carpenter *et al.* 1994, Hill & Jordan 1995, 1996, Jordan &

Hill 1991, 1994, 1996, 1999, Jordan 1995a, b, 1997b, 1999, Jordan & Dalton 1995, Jordan *et al.* 1995, 1998, Hill *et al.* 1999, Barnes & Jordan 2000).

Marionoak Formation

Tillite exposed in a west-facing road cutting near a ridgetop between the Huskisson and Marionoak rivers in western Tasmania is underlain by lacustrine mudstone that contains preserved leaves and fruit. Palynostratigraphy and palaeomagnetic data imply that the sediments are Early Pleistocene in age (Macphail *et al.* 1993, Augustinus *et al.* 1997). Only four types of macrofossil have been identified. They, like the fossil pollen (Augustinus *et al.* 1997, Macphail *et al.* 1993), imply a cold climate (Jordan 1997a), and therefore give an indication of the vegetation of near-glacial climates of the Early Pleistocene.

Coal Head

Over 300 tree stumps are preserved in growth position in an area of about 50 m by 25 m on a beach about 1 km north of Coal Head on the eastern shore of Macquarie Harbour (Fowler 1993, Rowell 1995, Rowell *et al.* 2001). The fossils are probably of Late Pleistocene age, although a Middle Pleistocene age is also possible (see Rowell *et al.* 2001 for an explanation). Leaf macrofossils occur in peat between the stumps, and pollen has also been extracted.

City of Melbourne Bay

Jennings (1959) documented wood and pollen fossils from peaty layers at the mouth of Yarra Creek on King Island. One log from the site has a radiocarbon date of 39 000 years BP, although groundwater contamination means that the real age may be considerably greater (D'Costa *et al.* 1993). The peaty sediment at this site contains abundant leaf and fruit fossils, mainly *Phyllocladus* and *Nothofagus*, and is currently being investigated. The more widely known Calcified Forest on the west coast of King Island is in fact calcified root casts of relatively recent origin.

Mersey/Cathedral

Two small outcrops of finely laminated sediment are exposed in a natural cutting on the southern bank of the Mersey River underneath Cathedral Mountain. They are dated as Middle–Late Pleistocene, based on a radiocarbon date of 43 000 years BP and the lack of any extinct species in the pollen flora (Beta–62408; Bresnehan 1993). They contain diverse and well-preserved macrofossils of extant species. All are consistent with sub-alpine to alpine vegetation, and, together with the pollen flora, imply that these fossils come from considerably cooler climates than at present.

Melaleuca, Regency, Rosebery, Langdon River, Pieman Dam, Newton Creek and Dante Rivulet

Several sites containing Middle–Late Pleistocene macrofossils are now no longer collectable for various reasons. The Melaleuca Inlet site in far southwestern Tasmania is possibly the most significant of these. This site is considered to be of Late Pleistocene age, although a Middle Pleistocene age is also possible, based on two radiocarbon dates (38 800 ± 1300, SUA 5038; 43 600 ± 1100, NZA 6745) and palynostratigraphy (Jordan *et al.* 1991, cf. Macphail *et al.* 1993). Note that the latter radiocarbon date has not been previously documented. The site has the youngest record of an extinct plant species in Australia (excluding post-European extinctions). It also contains *Lomatia tasmanica*, now known only as a gigantic clone of great age (Lynch *et al.* 1998). Fossils sedgeland/heath species imply that this kind of vegetation probably grew in the region before humans arrived. The original site was destroyed by mining activities long before it was researched, and no new material can be obtained.

The remaining five sites are near the west coast. They are all now destroyed. The Regency Formation, Langdon River, Pieman Dam (Stringer Creek) and Newton Creek sediments were discovered as a result of excavation or hydro-electric development and the Rosebery site as a result of mine development. All had well-preserved macrofossils. The Regency site is probably of Middle Pleistocene age (see Jordan 1997) although it was originally interpreted as Early Pleistocene (Fitzsimons *et al.* 1990). The other sites are of Middle–Late Pleistocene age (Colhoun 1980, Colhoun & van der Geer 1986, Colhoun *et al.* 1989, 1993). Material from most of these sites still exists in collections. Beds of Last Glacial age on the King River, near Dante Rivulet, contained fossil bolsters of *Donatia novaezelandiae* (Gibson *et al.* 1987). This site was inundated for hydro-electricity.

DISCUSSION

Although Cenozoic plant fossil deposits are widespread in Tasmania (fig. 1), several regions have significant concentrations of sites. Palaeogene and early Neogene sites are concentrated in three types of areas. The first is in the northwest, with associated basalt. The second is in the major block-faulted valleys of the Derwent Graben, the Launceston Basin, around Macquarie Harbour and the Coal River Graben (appendix). The third is the region of fluvial gravels of northeastern Tasmania. Quaternary sites occur across much of western Tasmania, but none is known from the east (fig. 1), probably because low rainfall created unfavourable conditions for the burial and preservation of plant material.

The sites studied intensively over the last 20 years have a narrower geographic range. Most research on Palaeogene and early Neogene fossils in Tasmania has focused on a handful of sites, notably Little Rapid River, Cethana and Lea River in the northwest, Pioneer and Hasties in the northeast, Monpeelyata on the Central Plateau and Regatta Point on the west coast. This is largely due to the excellent preservation at these sites (except possibly at Monpeelyata). However, new finds will no doubt be made at each of these sites.

Fossils have been recorded at a few other sites (Wilsons Creek, Locharbour, Brooker, Macquarie Plains, New Norfolk, Styx River, Buckland, Lemonthyme and Balfour) but only a few in each case. For some sites this reflects limitations of the fossil material. For example, the preservation of fossils at New Norfolk and Brooker is mostly poor, and very limited material is known from Balfour, Buckland and Macquarie Plains. However, the Wilsons Creek fossils are very diverse and well-preserved. Many species — probably dozens or more — remain undescribed from this site. The Styx River, Lemonthyme, Lochabour and perhaps Browns Bluff sites are intermediate between these extremes. In each case the amount of material is small, but each contains fossils warranting description and interpretation. These sites deserve attention to provide broader spatial and temporal coverage of the Palaeogene in Tasmania.

Geological Relationships of the Fossil Sites

Although basalt covers only about 5% of Tasmania's land area (Burrett & Martin 1989), most of the late Palaeogene and early Neogene fossil sites are directly associated with basalt. The soils at many of these sites would probably have contrasted markedly with most other substrates in Tasmania at most times during the Palaeogene. Young lava flows are unusual habitats because they can provide dry, nutrient-poor substrates for plant growth, even in very wet climates. Thus, young lava flows may have provided dry microsites in the otherwise ever-wet conditions believed to have prevailed during the Palaeogene. Weathering of volcanic rocks often leads to the development of highly fertile soils on both weathered basalt and on alluvium derived from volcanic areas. However, large areas of Tasmania are on rock types (quartzites, metamorphics, sandstones and conglomerates) that weather slowly and produce very infertile soils. There is no reason to suggest that this was not also true in the late Palaeogene and Neogene. The contrast between basalt-derived soils and most other Tasmanian soils is well-known (Jackson 1999). Some sites (e.g. Little Rapid River) are overlain by basalt but directly overlie old, nutrient-poor rocks. The nutrient status of the habitats that produced these fossil floras is difficult to determine; the lack of nutrients in the underlying quartzitic rocks may have been compensated by inputs from volcanic ash and from run-off from weathering of nearby basalt.

Finally, volcanic activity initiates disturbances, and several taxa in the Tasmanian fossil record are related to disturbance-dependent living species (e.g. *Fitzroya*, Hill & Whang 1997, *Nothofagus* subgenus *Brassospora*, Hill 1987a, *Nothofagus* subgenus *Nothofagus*, Hill 1994, *Lophosoria*, Hill *et al.* 2001). However, ecological disturbance was probably rare in most of the southwestern half of Tasmania even during periods of high volcanic activity, because of the geological stability and hard rocks. As a result, the source vegetation for those fossil sites associated with basalt probably grew in environments that were quite atypical of the Tasmanian palaeo-environments of the time. The overall fossil record for Tasmania may therefore be biased towards plants with disturbance ecology.

The bias towards disturbance plants would be exacerbated by the well-known biases in the fossil record towards riverine and lacustrine environments. In particular, most Tasmanian fossil sites unassociated with volcanic activity are near the bottoms of major valleys (e.g. Macquarie Harbour). The Tertiary fossil record, therefore, probably provides an unbalanced view of past Tasmanian environments.

A few fossil sites, however, are very significant because they are from contrasting environments and may help overcome these imbalances. Cethana is a critical case. This site appears to have no association with basalt and is not in a major river valley. The fossil flora is distinct, and nutrient-poor soils and possibly dry substrates in some part of the catchment at Cethana have been suggested as explanations of the differences between this flora and other well-known Little Rapid River and Lea River floras of similar age (Carpenter 1991b, Carpenter *et al.* 1994, Carpenter & Jordan 1997, Hill & Scriven 1997). In addition to rainforest taxa, it contains many scleromorphic species, including some 15 species of scleromorphic Proteaceae, none of which has been recorded at any other fossil site (Carpenter & Jordan 1997, Jordan *et al.* 1998). The Middle–Late Eocene floras from Hasties and Lochabour and the Late Oligocene–Early Miocene floras at Pioneer and Balfour are also significant assemblages with no association with basalt.

The ages of the various fossil sites associated with basalt suggests that the period of maximum volcanic activity in northwestern Tasmania was the Early Oligocene. Almost all the fossil sites in this region associated with basalt are of Early Oligocene or indeterminate Oligocene age. In particular, the four sites (Leven River, Waratah, Hatfield and Bells Plains) that are widely distributed on the largest coherent unit of basalt (the Guildford Plateau) are of this age. These include sites both near the base of the basalt making up the plateau, and higher up (Leven River and Hatfield). Thus, this plateau of about 900 km^2 may have been formed in a single, relatively short period of volcanic activity.

Future Prospects

The widespread occurrence of fossil sites, their small sizes and their idiosyncratic locations together suggest that new sites will be found. Almost all the sites were discovered serendipitously. A few were noted through geological mapping, many were drawn to our attention by word of mouth but few, if any, by systematic search for such fossil sites. Road-building and other excavations, mainly associated with hydro-electric development, mining and forestry, have exposed many sites. As landscape alteration continues, the exposure of new, significant fossil sites seems inevitable.

The most valuable material (e.g. at sites such as Little Rapid River, Lea River, Cethana and Regatta Point) has organic preservation of such quality that anatomical details of the cuticle are preserved. Such material often weathers quickly and degrades. For example, the surface material in the Early Pleistocene sediments at Regatta Point is heavily weathered, and the best material has been excavated. More extreme still is the degradation of R. M. Johnston's nineteenth-century sites, few of which now contain well-preserved fossils. As a result, exposures containing high-quality plant fossils could be considered temporary, although good preservation may persist in deeply buried parts. There are some exceptions. For example, well-preserved fossils can be easily found at the Lea River site because erosion of this natural river cutting is continually creating fresh exposures. The same is true at Wilsons Creek.

Silicified fossils by contrast weather very slowly, but are of little significance in the Cenozoic of Tasmania. Most sites of Cenozoic silicified plant fossils have been over-collected (e.g. Macquarie Plains) or contain only fragments transported from unknown sources. They are extremely difficult to date.

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APPENDIX
Cenozoic plant-fossil sites with known locations

Site	Age	Basalt*	Grid references†
Northwest Region			
Little Rapid River	Early Oligocene	overlying	3545 54400
Lea River	Early Oligocene	overlying (?underlying)	4157 54044, 4153 54046
Cethana	Early Oligocene	none	4280 54075
Lemonthyme	Early Oligocene	overlying	4291 53923
Leven River	Early Oligocene	overlying (?underlying)	4024 54098
Hatfield River	Early Oligocene	overlying (?underlying)	3796 53993
Cradle Mountain Link Rd	Early Oligocene	overlying (?underlying)	3945 53986
Waratah	Oligocene	overlying	?3765 54116
Bells Plains	Oligocene	overlying	3809 54215
Balfour	Oligo–Early Miocene	none	3239 54274
Fossil Bluff	Early Miocene	overlying	3932 54625
East Cam River	? Oligo–Miocene	overlying	4024 54502
Devonport	? Oligo–Miocene	overlying	4465 54410
Derwent Graben			
Wilsons Creek	Latest Eocene	overlying (?underlying)	4554 53146
New Norfolk	Oligo–Miocene	overlying	4962 52686
Brooker	Early Eocene	?overlying	5201 52618
One Tree Point	Palaeogene	overlying	5291 52485
Macquarie Plains	Palaeogene	overlying and overlying	4930 52721
Glenora Bridge	Palaeogene	overlying	4909 52724
Cornelian Bay	Tertiary	?indirect	5264 52548
Taroona	Early Tertiary	overlying (?underlying)	5290 52458
Burnett Street	?Palaeogene	none	5254 52516
Geilston Bay	Oligocene	overlying and underlying	5282 52569
Styx River	Early Eocene	?overlying	4918 52717
Lindisfarne Bay	?Palaeogene	overlying and underlying	5290 52552
Sandy Bay	?Palaeogene	?indirect	5270 52500
Elwick roundabout	?	?	5235 52578
Northeast Region			
Hasties	Middle Eocene	none	5745 54593
Pioneer	Early Miocene	? indirect	5779 54526
Lochabour	Middle Eocene	none	5850 54676
Pipers River	Cenozoic	overlying	5060 54480
Derby Deep leads	Cenozoic	overlying (?underlying)	5671 54448
Launceston Basin			
Brown's Bluff	Early Eocene	none	5030 54225
Breadalbane	Palaeogene	overlying (?underlying)	5180 54019
Corra Lynn	?Palaeogene	none (but in breccia)	5181 54072
Youngtown	?Early Eocene	none	5123 54073
Beaconsfield deep leads	?Palaeogene	?	4838 54403
Macquarie Harbour Region			
Regatta Point	mostly Early Eocene	none	3618 53303, 3625 53302, 3571 53474 etc
Mallanna	Palaeogene	none	3571 53474

APPENDIX cont.

Site	Age	Basalt*	Grid references†
Coal River Graben			
Richmond	Palaeogene	indirect	5367 52692
Shark Point	Palaeogene	?overlying	5409 52620
Longs Hill	?Palaeogene	?	5332 52703
Other sites			
Monpeelyata	Oligo–Miocene	overlying and underlying	4722 53453
Gavins Tier	?Palaeogene	?	5280 53374
Granville Harbour	Early Eocene	none	3452 53674
Buckland	? Early Eocene	none	5638 52810
Latest Pliocene/Pleistocene sites			
Idaho Formation	Latest Pliocene	none	3838 53421
Marionoak Formation	Early Pleistocene	none	3759 53847
Regatta Point	Early Pleistocene	none	3618 53303
Coal Head	Late Pleistocene	none	3705 53145
Mersey/Cathedral	Late Pleistocene	none	4256 53635
City of Melbourne Bay	Late Pleistocene	none	2535 55672
Newton Creek	Late Pleistocene	none	3816 53596
Regency Formation	Middle Pleistocene	none	3873 53307
Langdon River	Middle Pleistocene	none	3784 53525
Melaleuca Inlet	Late Pleistocene	none	4322 51914
Rosebery	Middle Pleistocene	none	3788 53744
Dante Rivulet	Late Pleistocene	none	3894 53452
Stringer Creek	Middle Pleistocene	none	3448 53787

* Associated Cenozoic basalt, and its position relative to the fossiliferous beds

† All grid references are based on Australian Geodetic Datum 1966 (to nearest 100 m).