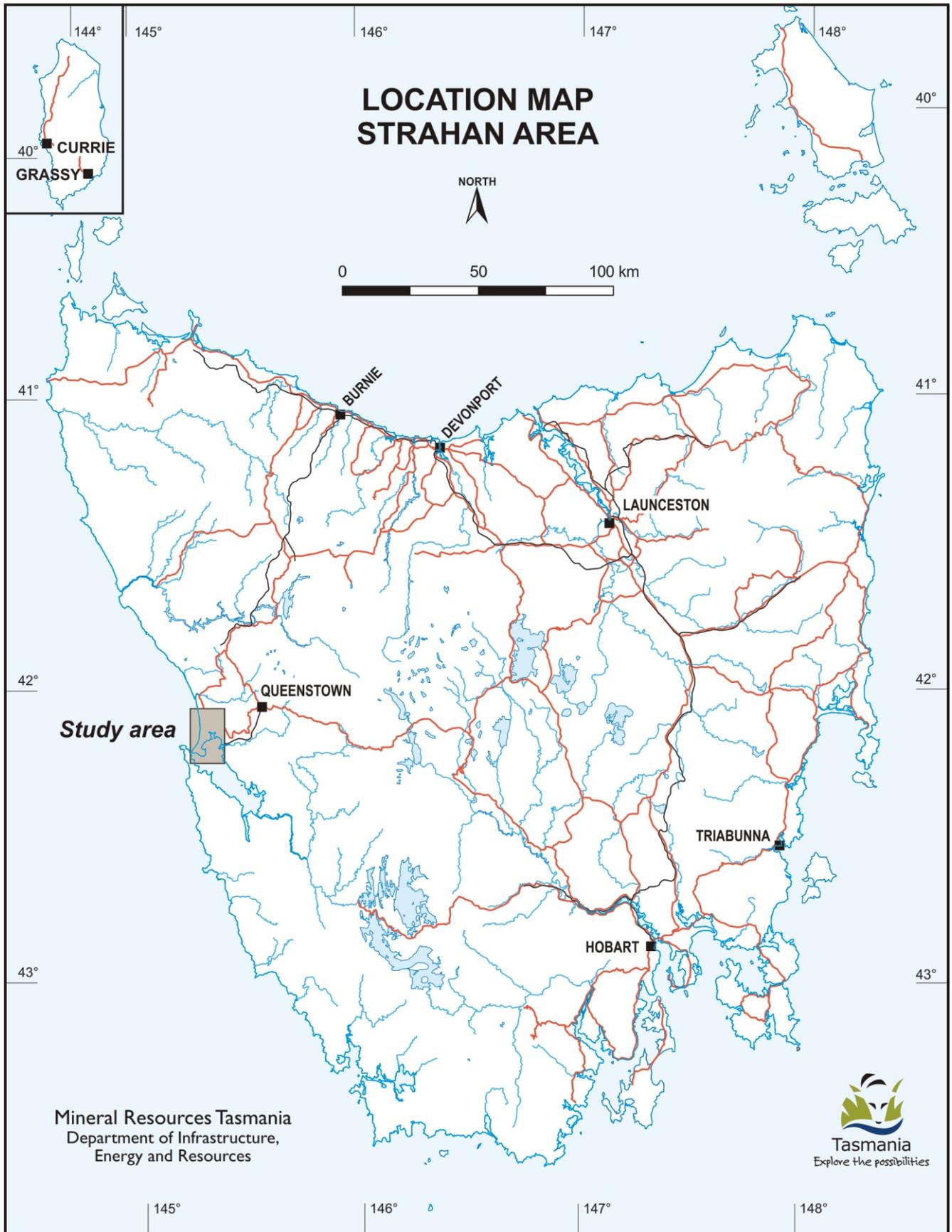


**Tasmanian Geological Survey  
Record 2013/08**

**Preliminary palynostratigraphic  
age determinations on core from  
Strahan BH-1, Macquarie Harbour,  
western Tasmania**

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## Executive summary

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- The Strahan BH-1 cored hole was drilled in sand-dune terrain north of Strahan, Macquarie Harbour Graben, by the Tasmanian Geological Survey (Tasmania Department of Mines) in 1983 to test a magnetic anomaly (found to be a dolerite boulder bed).
- The drill hole intersected 184 m of presumed Quaternary sand overlying 165 m of interbedded organic-rich clay and fine sand. The basal 15 m to TD at 364 m depth was not sampled. The core was logged by Dr Keith Corbett in 1983 but otherwise remained virtually un-analysed.
- Forty-eight samples of the Strahan BH-1 core were collected in April 2011 at the Mineral Resources Tasmania core store in Hobart, as part of an ongoing project researching Early Eocene climates, flora and vegetation preserved in the Macquarie Harbour Formation exposed at Strahan (Strahan Point, Regatta Point, Lowana Road).
- A trial set of six samples from near the top (184.1 m, 184.6 m depth), middle (267.5 m, 285.9 m depth) and base (346.5 m, 349.0 m depth) was processed for fossil dinoflagellates, spores and pollen by Core Laboratories (Australia) in Perth using funds supplied by Professor R. S. Hill, University of Adelaide.
- Palynostratigraphic analysis of these six samples:
  - Confirms that the interbedded organic clay and sand between 184.1 m to 349.0 m depth are Early Eocene Macquarie Harbour Formation.
  - Supports other evidence that at this time the Macquarie Harbour Graben was located at the eastern end of an E–W seaway (Australo–Antarctic Gulf) separating the Australian and Antarctic continents.
  - Indicates that the interval is likely to have been deposited during early to middle Early Eocene (Lower to Middle *Malvacipollis diversus* Zone), with the maximum and minimum age limits being early Early (Lower *Malvacipollis diversus* Zone) to latest Early (*Proteacidites asperopolus* Zone) Eocene, respectively.
  - Shows sediments near the base of the core were deposited in an estuarine environment during the late early Early to middle Early Eocene *Apectodinium homomorphum* Zone marine transgression under near-tropical sea surface and air temperatures.
  - Shows sediments in the middle section and top of the core were deposited in freshwater swamps under markedly cooler conditions, probably during the middle Early Eocene.
- A comparison of the Strahan BH-1 data and outcropping Macquarie Harbour Formation at Strahan indicates:
  - The section of Macquarie Harbour Formation intersected in Strahan BH-1 pre-dates the outcrops of this formation at Strahan Point, Regatta Point and Lowana Road.
  - The Macquarie Harbour graben was periodically isolated from the Australo–Antarctic Seaway during the middle Early Eocene although it is uncertain whether this was due to eustasy (lower sea levels) or tectonism.
- The combined data confirm Early Eocene deposits in Macquarie Harbour archive arguably ‘world class’ evidence of a flora and vegetation growing under near-tropical conditions at a palaeolatitude (65°S) corresponding to the present day edge of ice in Antarctica.

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## Introduction

This report presents and discusses palynostratigraphic ages inferred for six core chip samples of Macquarie Harbour Formation (Pole, 1998) from the Strahan BH-1 hole, drilled by the Tasmanian Geological Survey (Tasmania Department of Mines) in 1983 (fig. 1). The primary aims were to:

- Determine the period of geological time represented by the Macquarie Harbour Formation in Strahan BH-1 by analysing samples at the top (184.1–184.6 m) and base (346.5–349 m) of the cored interval.
- Reconstruct long-term changes in palaeoenvironment (if any) over this period by analysing samples in the approximate middle of the cored interval (267.5–285.9 m) and comparing the results with the top and basal samples.
- Correlate the sampled intervals in Strahan BH-1 with Macquarie Harbour Formation outcropping on the eastern shoreline of Macquarie Harbour, in particular the late Early Eocene Lowana Road and Regatta Point sequences near Strahan (Pole and Macphail, 1996).

The results are summarised in Table 1 and the age determinations justified and discussed in the *Biostratigraphy* and *Conclusions* sections.

## Background to study

With few exceptions (e.g. the very thin Pember Mudstone of the upper Wangerrip Group at Princetown in southwest Victoria; see McGowran *et al.*, 2004), much of the current information on the Early Eocene in Australia is based on subcrop intersected in exploration wells in the offshore Bass, Gippsland and Otway basins centred on Bass Strait and the lower Eyre Formation in Central Australia.

An important exception is Macquarie Harbour, where thick sequences of Early Eocene sediments (Macquarie Harbour Formation) infilling this graben are exposed in sea cliffs at and to the south of Strahan (fig. 1) as well as occurring in the offshore Sorell Basin (Cape Sorell-1) and sediments transported into the abyssal zone by rotational faulting (M. K. Macphail, unpublished data). One outcrop of Macquarie Harbour Formation at Lowana Road preserves the globally-youngest known macrofossils of a seed fern (Pteridospermatata), the most southern population of the tropical mangrove palm *Nyssa*, now restricted to the tropics, and what may prove to be the oldest known *Eucalyptus* leaf in Australia, as well as evidence that sea surface

temperatures at near-Antarctic palaeolatitudes were as high as ~24°C (Pole and Macphail, 1996; McLoughlin *et al.*, 2008; Carpenter *et al.*, 2012; G. Jordan, pers. comm.).

Determining the age of the Lowana Road section and correlative mudstone outcropping at Regatta Point has proved to be difficult as most of the plant microfossils (spores, pollen and dinoflagellates) are long-ranging morphospecies. On present indications, the Lowana Road section accumulated in estuarine tidal channels between 50–53 Ma (late Early Eocene). The maximum (Upper *Malvacipollis diversus*/*Homotryblum tasmaniense* Zone) and minimum (*Proteacidites asperopolus* Zone) age limits correspond to the upper part of tropical foram zone P6b and P9-10, respectively (see Partridge, 2006). Dinoflagellates preserved at a now destroyed section on Strahan Point provide circumstantial evidence for the slightly older minimum (*Wilsonidium ornatum*/Upper *Malvacipollis diversus* Zone) age limit, correlated with tropical foram zone P8 (Cookson and Eisenack, 1967; Wilson, 1989; Partridge, 1999, 2006).

Attempts to improve the age control for the Lowana Road section (and the Macquarie Harbour Formation in general), e.g. by correlating the microfloras with those recovered from Cape Sorell-1, proved unsuccessful due to the low sample quality and density in Cape Sorell-1 (Boreham *et al.*, 2002; R. Helby, M. K. Macphail and A. D. Partridge, unpublished data). Accordingly, Dr Clive Calver of Mineral Resources Tasmania was contacted to see if alternative samples, especially conventional core, were available. This query revealed that a cored hole (Strahan BH-1), drilled to the north of Strahan by Tasmania Department of Mines in 1983, had intersected a ~165 m thick section of graben infill sediments overlain by a similar thickness of Quaternary sand.

## Strahan BH-1

A copy of the geological log for Strahan BH-1 (MRT drillhole 13534), prepared by Dr Keith Corbett in 1983, was made available by Mineral Resources Tasmania. Key details for the hole, which was drilled to test a magnetic anomaly (found to be a dolerite boulder bed), are:

- The drill site is located at an elevation of 38.2 m in sand dunes behind Ocean Beach north of Strahan at 358 395 mE, 5 335 294 mN (GDA94 Zone 55 coordinates).

**Table 1**  
Summary of age determinations

Depth (m)	Geological age	Zone		Confidence rating
		Dinocyst	Spore-pollen	
184.1	middle Early Eocene	-	Middle <i>Malvacipollis diversus</i>	low
184.6	middle Early Eocene	-	Middle <i>Malvacipollis diversus</i>	low
267.5	middle Early Eocene	-	Middle <i>Malvacipollis diversus</i>	very low
285.9	middle Early Eocene	-	Middle <i>Malvacipollis diversus</i>	low
346.5	early to mid? Early Eocene	<i>Apectodinium homomorphum</i>	Lower <i>Malvacipollis diversus</i>	low
349.0	early to mid? Early Eocene	<i>Apectodinium homomorphum</i>	Lower <i>Malvacipollis diversus</i>	low



**Figure 1**

Map showing approximate location of Strahan BH-1 and other fossil localities.

- The hole reached a total depth of 364 m and had been continuously sampled (friable sands) or cored (weakly lithified sediments) to a total depth of 349 metres.
- The 'lithified' interval between 184.1 m and 349 m comprises interbedded organic-rich clay and sand.
- A *Malvacipollis diversus* Zone age obtained near the base of the core confirmed that 'lithified' sediments were Macquarie Harbour Formation and no older than Early Eocene (S. Forsyth pers. comm.)

### Samples

Forty-eight core chips from both organic-rich clay and clay-rich fine sand facies were collected by M. K. Macphail and G. Jordan (University of Tasmania) on 24 April 2011 from the Mineral Resources Tasmania core store at Mornington, Hobart (Appendix I).

Professor Bob Hill (University of Adelaide) kindly funded processing of a trial batch of six samples by Core Laboratories (Australia) in Perth. These comprised two samples each from near the top (184.1 m, 184.6 m depth), the middle (267.5 m, 285.9 m depth) and the base (346.5 m, 349.0 m depth) of the cored section of Macquarie Harbour Formation.

Dr Peter Bijl (University of Utrecht, Netherlands) offered to process the remaining forty-two samples as part of a Utrecht project investigating Early Eocene dinoflagellate sequences in the mid to high latitudes of the Southern Hemisphere. Unoxidised/filtered organic residues will be repatriated to Australia for spore-pollen analysis.

### Geological background

Macquarie Harbour occupies the northern half of a northwest–southeast trending graben that extends from Ocean Beach at Strahan (357 000 mE, 5 330 000 mN) to Birchs Inlet (374 000 mE, 5 297 000 mN) and southwards along the Sorell River valley. The graben is separated from the offshore Sorell Basin by Cambrian–Precambrian rocks of the Cape Sorell peninsula and, because of the similar structural lineaments, is presumed to share the same Late Mesozoic–Cenozoic tectonic history as the latter basin (references in Baillie *et al.*, 1989; Hill *et al.*, 1997; Corbett, 2003). Prior to the development of deep water circulation between Tasmania and Antarctica at the Eocene/Oligocene boundary, the harbour was located at the eastern end of the Australo-Antarctic Gulf (see Exon *et al.*, 2004) and local air and sea surface temperatures may have been influenced by warm water currents (gyres) circulating within this partially occluded seaway up to the Middle Eocene.

Sedimentation in the Strahan Sub-basin of the Sorell Basin, located seaward of the entrance to Macquarie Harbour, began in the Late Cretaceous, if not earlier (Boreham *et al.*, 2002), although the oldest known sediments infilling the graben (Macquarie Harbour Formation) are Paleocene (S. M. Forsyth, pers. comm.). Dinoflagellates preserved in the formation at Strahan confirm that a marine connection between Macquarie Harbour and the offshore Sorell Basin existed at various times during the middle and late Early Eocene (Cookson and Eisenack, 1967; Macphail *et al.*, 1993; Carpenter *et al.*, 2011; this study).

Graben infill deposits underlie Late Quaternary sand dunes at Ocean Beach and outcrop in sea cliffs southwards along the eastern shoreline of Macquarie Harbour, for example at Regatta Point and at Lowana Road about five kilometres south of Strahan. Subaerially-exposed marginal marine strata demonstrate that the Macquarie Harbour Formation has undergone uplift, presumed due to tilting of the Australian continent during the Late Tertiary as well as down-to-basin (*en echelon*) faulting during separation of Australia and Antarctica during the Late Cretaceous and Early Tertiary.

Raised shorelines on the Cape Sorell peninsula (I. Houshold, pers. comm., 2008) hint that uplift may have continued into the Late Quaternary, reflecting tilting of the Australian continent and other manifestations of 'dynamic topography' observed elsewhere in southern Australia (Rowell *et al.*, 2001; Clark *et al.*, 2011; Heine *et al.*, 2010; Quilty and Seymour, 2010; Quigley *et al.*, 2010). Outcrops of Macquarie Harbour Formation at Lowana Road and Regatta Point are unconformably overlain by Middle to Late Quaternary glaciofluvial outwash, based on microfloras recovered from lignitic clay and sand overlying the unconformity at Lowana Road (Macphail *et al.*, 1993; M. K. Macphail, unpublished data).

### Biostratigraphy

Ages inferred for the Strahan BH-I samples are based on species time distributions in the Gippsland Basin (Partridge, 1999, 2006) and Bass Basin (Partridge, 2002), with additional age control provided by spore-pollen and dinoflagellate time distributions in ODP Leg 189 cores from the East Tasman Plateau (Site 1172) (see Macphail, 2002; Brinkhuis *et al.*, 2003). A selection of the better-preserved dinoflagellate and spore-pollen species are illustrated in Plates 1 and 2.

#### Basic data

Plant kerogen and microfossil yields are given in Table 2.

#### Interpretive data

Quantitative and stratigraphic data are presented in Table 3. Where possible, the spore-pollen time distributions used are from Esso Australia's 1970s vintage Bass Basin wells where, in contrast to some recent wells drilled in this basin, the samples are high quality cores and SWCs.

The lack of short-ranging zone index species has meant that considerable weight has been given to:

- (a) the first (FAD) and last (LAD) appearance of zone accessory species in the Gippsland Basin and Bass Basin, in particular the LAD of the rare fossil Triprojectacites species *Integricorpus antipodus* at 184.1 m depth (Plate 3), and;
- (b) negative evidence, namely the absence of species that first occur in the *Homotryblium tasmaniense* (dinoflagellate) Zone and Upper *Malvacipollis diversus* (spore-pollen) Zone. It is emphasised that the age determinations may need to be revised in the light of additional samples from Strahan BH-I as and when these are analysed.

**Table 2**  
Sample data

Depth (m)	Lithology	Yield			Preservation	
		kerogen	dinocysts	spore-pollen	dinocysts	spore-pollen
184.1	pallid clay	very high	–	high	–	good
184.6	organic-rich clay	very high	–	very high	–	fair
267.5	organic-rich clay	medium	–	low	–	fair
285.9	pallid clay	very high	–	high	–	good
346.5	silty very fine sand	very high	very low	very low	fair	poor
349.0	silty fine sand	medium	very low	medium	fair	poor

**Sample:** 184.1 m depth

**Sample type:**

Core chip.

**Depositional environment:**

Fluvio-deltaic, based on the presumed hydrophyte (*Dicotetradites clavatus*) and low to trace numbers of algal cysts (*Botryococcus*, *Circulisporis*) and *Retistephanocolpites* sp. [Nearest living relative (NLR) Callitrichaceae].

**Age:**

middle Early Eocene.

**Preferred dinocyst zone:**

n/a

**Preferred spore-pollen zone:**

Middle *Malvacipollis diversus* Zone, based on LAD of *Integricorpus antipodus* and absence of species that first occur in the Upper *Malvacipollis diversus* Zone, e.g. *Myrtaceidites tenuis* and *Homotryblium tasmaniense*.

**Confidence rating:**

Low.

**Maximum age:**

Lower *Malvacipollis diversus* Zone, based on *Intratropipollenites notabilis*, *Nothofagidites goniatus* and *Myrtaceipollenites australis*.

**Minimum age:**

Middle *Malvacipollis diversus* Zone, based on LAD of *Integricorpus antipodus* (otherwise *Proteacidites asperopolus* Zone, based on *Intratropipollenites notabilis*, *Myrtaceipollenites australis* and *Proteacidites grandis*).

**Comment:**

The extremely diverse spore-pollen component is dominated by gymnosperms, in particular *Dilwynites granulatus* (NLRs *Agathis* and *Wollemia nobilis*) and *Phyllocladites mawsonii* (NLR *Lagarostrobos*), Proteaceae and the extinct clade *Dicotetradites clavatus*. Apart from *Proteacidites latrobensis* (FAD Upper? *M. diversus* Zone), none of the distinctively ornamented fossil Proteaceae spp., whose FADs define the Lower/Middle *M. diversus* Zone in the Bass and Gippsland basins, were found. Unusual records include *Nothofagidites goniatus* and an undescribed *Tetradopollis* sp. also found in other samples in the study. Apart from multiple specimens of *I. notabilis* (NLR Tiliaceae) and trace *Anacolosidites acutullus* (*Anacolosia*) and palm pollen (*Longapertites* sp.), the strongest evidence that conditions remained warm is the extreme paucity of fossil *Nothofagus* (*Nothofagidites*) pollen relative to Middle–Late Eocene microfloras in Tasmania.



**Plate 3**

*Integricorpus antipodus* ms [LAD Middle *Malvacipollis diversus* Zone]

**Sample: 184.6 m depth**

**Sample type:**

Core chip.

**Depositional environment:**

Freshwater swamp based on abundant *Podosporites microsaccatus*, associated with low to trace algal cysts (*Botryococcus*), *Retistephanocolpites* sp. and *Dicotetradites clavatus*.

**Age:**

middle Early Eocene.

**Preferred dinocyst zone:**

n/a

**Preferred spore-pollen zone:**

Middle *Malvacipollis diversus* Zone, based on FAD of *Proteacidites nasus*, a possible specimen of *P. leightonii*, and absence of species that first occur in the Upper *Malvacipollis diversus* Zone.

**Confidence rating:**

Low.

**Maximum age:**

Middle *Malvacipollis diversus* Zone, based on FAD of *Proteacidites nasus* (otherwise Lower *Malvacipollis diversus* Zone, based on *Myrtaceipollenites australis*).

**Minimum age:**

*Proteacidites asperopolus* Zone, based on *Myrtaceipollenites australis*.

**Comment:**

Despite the very high spore-pollen yield, the diversity of this gymnosperm-dominated microflora is low relative to 184.1 m depth. The reason may be cooler climates as *Nothofagidites emarcidus* is unusually frequent for an Early Eocene sample. Unusual records include the undescribed *Tetradopollis* sp. and a small *Proteacidites* sp. that resembles the Late Eocene species *P. truncatus* (NLR *Isopogon*).

**Sample: 267.5 m depth**

**Sample type:**

Core chip.

**Depositional environment:**

Freshwater swamp, based on abundant *Podosporites microsaccatus* and frequent *Phyllocladidites mawsonii*.

**Age:**

middle Early Eocene.

**Preferred dinocyst zone:**

n/a

**Preferred spore-pollen zone:**

Middle *Malvacipollis diversus* Zone, based on FAD of *Proteacidites nasus* and absence of species that first occur in the Upper *Malvacipollis diversus* Zone.

**Confidence rating:**

Very low.

**Maximum age:**

Middle *Malvacipollis diversus* Zone, based on FAD of *Proteacidites nasus* (see Comment).

**Minimum age:**

*Proteacidites asperopolus* Zone, based on *Proteacidites grandis*.

**Comment:**

The sample is unique in this study in that species restricted to the Early Eocene are absent and it includes apparently *in situ* specimens of *Sapotaceoidaepollenites rotundus* (FAD *Proteacidites asperopolus* Zone) and *Evansispora senonica* (LAD Late Cretaceous). The latter may be reworked but *S. rotundus* illustrates the point that a species may be present in a region long before becoming 'visible' in the fossil record elsewhere.

**Sample: 285.9 m depth**

**Sample type:**

Core chip.

**Depositional environment:**

Freshwater swamp based on *Phyllocladidites mawsonii* and frequent *Retistephanocolpites*.

**Age:**

middle Early Eocene.

**Preferred dinocyst zone:**

n/a

**Preferred spore-pollen zone:**

Middle *Malvacipollis diversus* Zone, based on *Peninsulapollis gillii* in a microflora lacking species that first occur in the Upper *Malvacipollis diversus* Zone.

**Confidence rating:**

Low.

**Maximum age:**

Middle *Malvacipollis diversus* Zone, based on geographic variant of *Tricolporites adelaidensis*.

**Minimum age:**

Middle *Malvacipollis diversus* Zone, based on *Peninsulapollis gillii*.

**Comment:**

The low diversity, gymnosperm-dominated microflora includes significant numbers of *Phyllocladidites mawsonii*, *Proteacidites rectus* and *Tricolpites phillipsii* (FAD Early Paleocene) plus a scabrate pollen tetrad that may be a new morphospecies of *Ericipites* (NLR Ericaceae). Fossil *Nothofagus* species include *Nothofagidites emarcidus* and ( frequent) *N. flemingii*. As for the sample at 267.5 m depth, the impression given is of a relatively cool-climate flora.

**Sample: 346.5 m depth**

**Sample type:**

Core chip.

**Depositional environment:**

Estuarine (tidal channel), based on low numbers of marine dinoflagellates and foram trochospiral liners in a spore-pollen dominated microflora.

**Age:**

early to middle? Early Eocene.

**Preferred dinocyst zone:**

*Apectodinium homomorphum* Zone, based on rare *Kenleyia leptoceratallophophora*, *Muratodinium fimbriatum* and rare specimens belonging to the 'long-spine' complex of *Apectodinium* spp. (*A. homomorphum/longispinosum* complex).

**Preferred spore-pollen zone:**

Lower *Malvacipollis diversus* Zone, based on *Crassiretitriletes vanraadshoovenii*, *Polypodiaceoisporites varus* ms, *Drytopollenites semilunatus*, *Intratropipollenites notabilis*, *Myrtaceoipollenites australis* and *Spinizonocolpites prominatus*.

**Confidence rating:**

Low.

**Maximum age:**

Lower *Malvacipollis diversus* Zone, based on *Crassiretitriletes vanraadshoovenii*, *Polypodiaceoisporites varus* ms, *Drytopollenites semilunatus*, *Intratropipollenites notabilis*, *Myrtaceoipollenites australis* and *Spinizonocolpites prominatus*.

**Minimum age:**

Middle *Malvacipollis diversus* Zone, based on *Apectodinium homomorphum/longispinosum* in a dinocyst flora lacking confirmed specimens of *A. hyperacanthum* (LAD Lower *M. diversus* Zone) and *Homotryblum tasmaniense* and *Wetzeliellioideae* spp. (FAD ~Upper *M. diversus* Zone).

**Comment:**

The assemblage is a slightly more diverse analogue of that recovered at 349.0 m depth (see below). Unusual records include *Dilwynites tuberculatus*, a pentacolporate morphospecies (aff. *Quintiniapollis psilatispora*) and *Milfordia homeopunctata* (NLR Anarthriaceae). *Nothofagidites* spp. are absent.

**Sample: 349.0 m depth****Sample type:**

Core chip.

**Depositional environment:**

Estuarine (lagoonal?), based on large numbers of foram trochospiral liners, marine dinoflagellates and *Spinizonocolpites prominatus* (NLR *Nypa*).

**Age:**

early to middle? Early Eocene.

**Preferred dinocyst zone:**

*Apectodinium homomorphum* Zone, based on rare *Kenleyia leptoceratallophophora*, *Muratodinium fimbriatum* and frequent? *Apectodinium homomorphum* sensu A. D. Partridge.

**Preferred spore-pollen zone:**

Lower *Malvacipollis diversus* Zone, based on *Crassiretiritriletes vanraadshoovenii*, *Myrtaceipollenites australis*, *Tricolporites moultonii* ms and (abundant) *Spinizonocolpites prominatus*.

**Confidence rating:**

Low.

**Maximum age:**

Lower *Malvacipollis diversus* Zone, based on *Intratrirporopollenites notabilis*, *Myrtaceipollenites australis* and *Spinizonocolpites prominatus*.

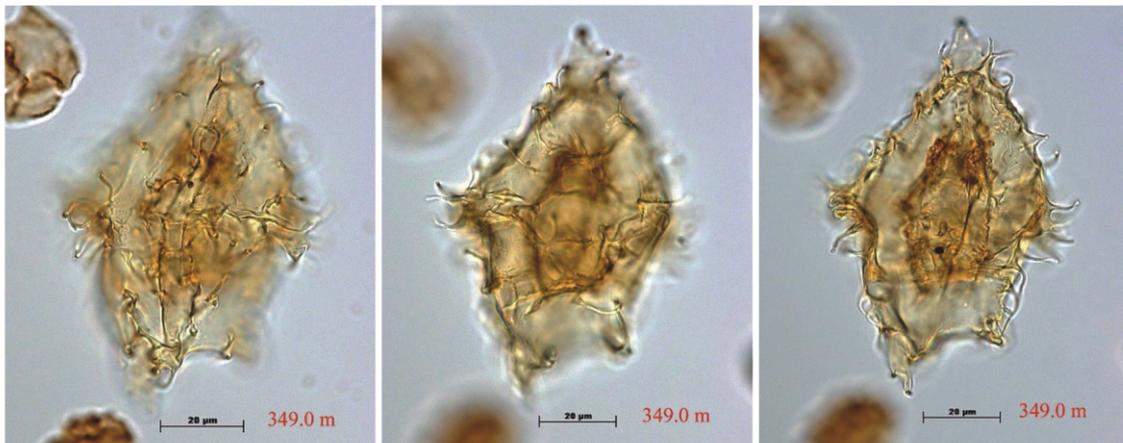
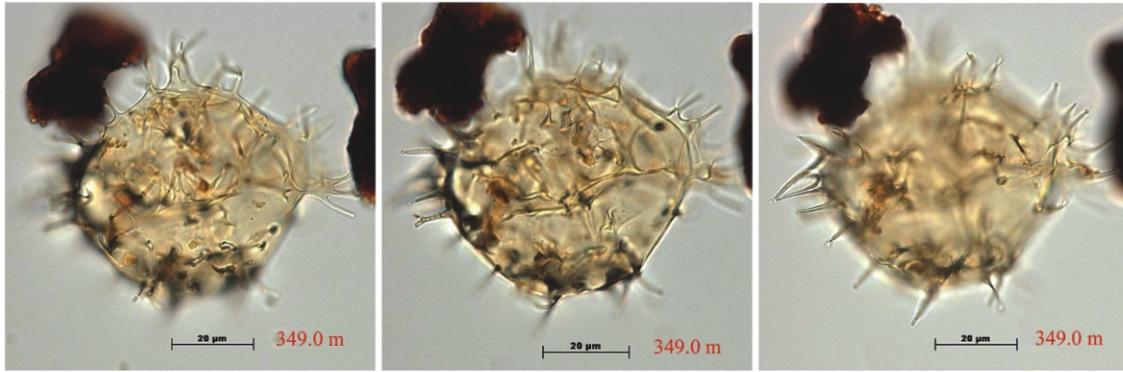
**Minimum age:**

Middle *Malvacipollis diversus* Zone, based on the absence of *Homotryblium tasmaniense* and *Wetzeliellioideae* spp.

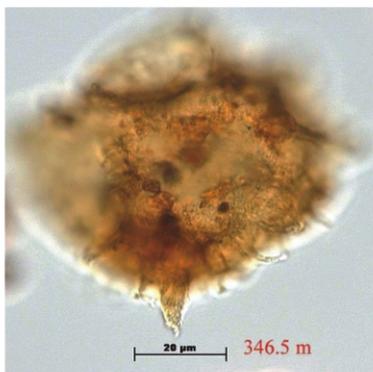
**Comment:**

The *Spinizonocolpites prominatus*-dominated microflora is unlikely to be as old as the Paleocene-Eocene thermal maximum (PETM) although the presence of the parent plant, the mangrove palm *Nypa*, in the Macquarie Harbour Graben is likely to reflect regional warming initiated during this hyperthermal event. However this age limit is difficult to confirm due to the poor orientation and crumpled condition of many specimens. It is noted that some *Apectodinium* specimens possess well-developed antapical horns that are atypical of *A. homomorphum* or the variant with long processes informally named *A. longispinosum* by A. D. Partridge (compare Plate 2, this study with Plate 2 and Figures 4, 7 in Wilson, 1989). It is emphasised that there is nothing in the data at hand to rule out a Middle *M. diversus* Zone age, or confirm the proposed Lower *M. diversus* Zone age unless or until *Apectodinium hyperacanthum* and/or spore-pollen species that last appear in this zone, are found, e.g. *Matonisporites gigantis*.

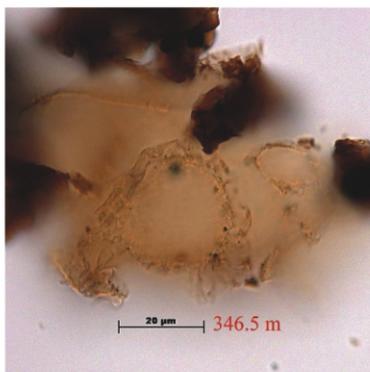
Unusual records include *Milfordia homeopunctata*, an oblate tetracolporate species whose nearest morphological analogue is *Psilastephanocolporites micus*, and a specimen of the Cenomanian auriculate morphospecies *Auriculiidites reticulatus* whose nearest living relative is *Bomarea* (Amaryllidaceae) (Macphail and Partridge, 2012).



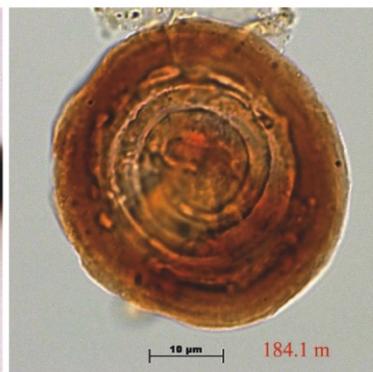
*Apectodinium homomorphum/longispinosum* complex



*Kenleyia leptocerata/lophophora*



*Muratodinium fimbriatum*



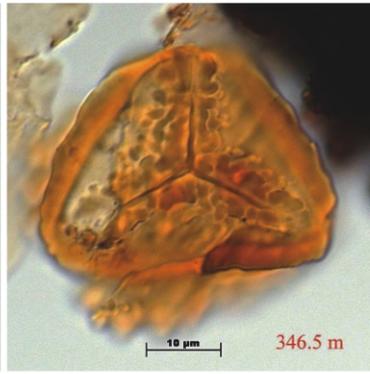
*Circulisporis parvus*

**Plate I**

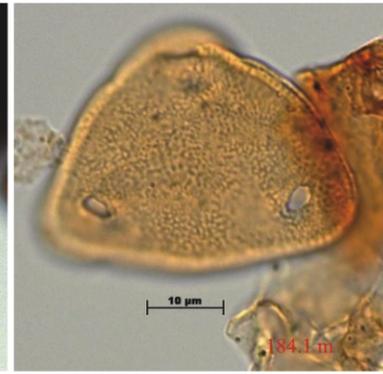
Dinoflagellates and other algal cysts.



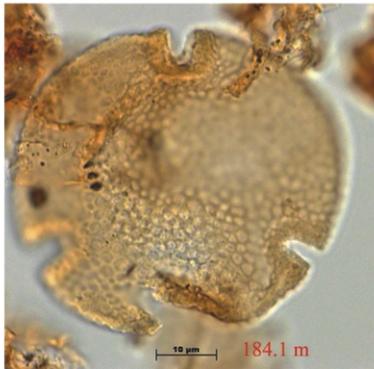
*Crassirettriletes vanraadshoovenii*



*Polypodiaceoisporites varus ms*



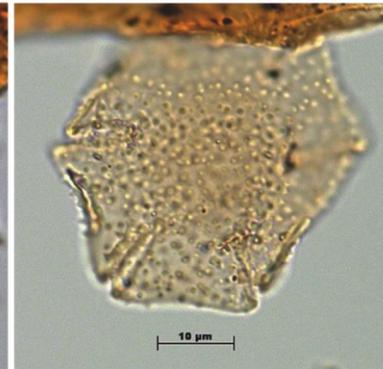
*Anacolosidites acutullus*



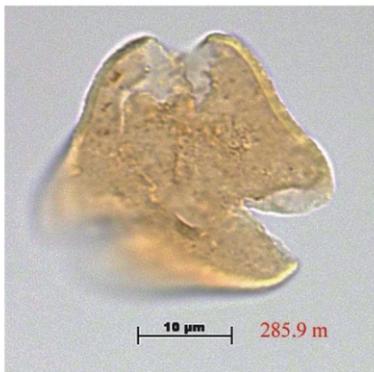
*Intratriporopollenites notabilis*



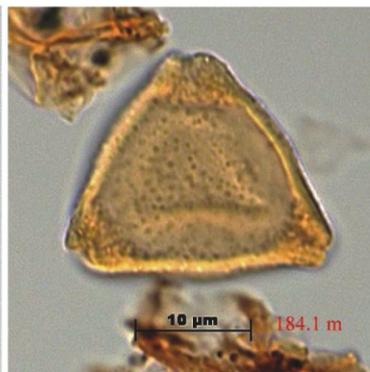
*Myrtaceoipollenites australis*



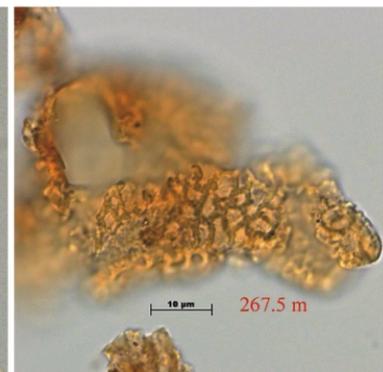
*Nothofagidites goniatus*



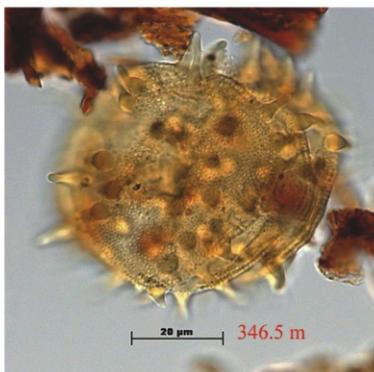
*Peninsulapollis gillii*



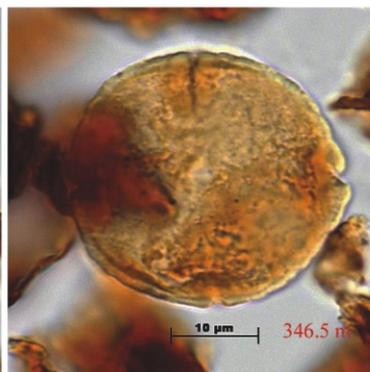
*Proteacidites latrobensis*



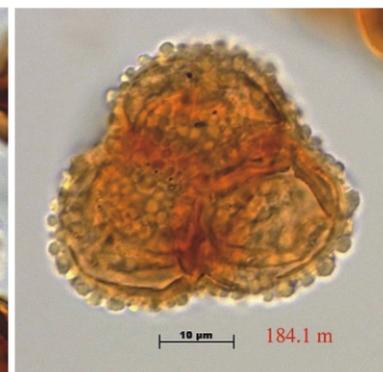
*Proteacidites nasus*



*Spinizonocolpites prominatus*



*Tetrastephanocolporites sp. nov.*



*Tetradopollis sp. nov.*

**Plate 2**  
Spore-pollen.

**Table 3**

Stratigraphic distribution of morphospecies (key species highlighted in blue)  
(relative abundance values expressed as a percentage of the spore-pollen count)

Depth (m)	184.1	184.6	267.5	285.9	346.5	349.0
<b>Freshwater Algae</b>						
<i>Botryococcus</i>	1%	1%	2%		1%	
<i>Circulisporis parvus</i>	1%	X				
<i>Saeptodinium</i>				cf.		
<b>Zygnemataceae</b>						
unassigned algal cysts	X	X	X	X	8%	X
<b>Dinoflagellates</b>						
<i>Achomospaera</i>						X
<i>Apectodinium homomorphum</i> complex					1%	5%
<i>Apectodinium</i> cf. <i>hyperacantha</i>						X
<i>Hystrichokolpoma</i> sp.						X
<i>Kenleyia leptocerata/lophophora</i>					1%	X
<i>Muratodinium fimbriatum</i>					X	X
<i>Paracaniella indentata</i>						X
<i>Spiniferites</i> spp.					X	3%
<i>Turbiosphaera filosa</i>						?
indeterminate dinocysts					7%	16%
foram trochospiral liners					1%	17%
<b>Fungal spores</b>	4%	1%	39%	1%	20%	17%
<b>Gymnosperms</b>						
<i>Araucariacites</i> spp.	X	X	5	1%	2%	X
<i>Dacrycarpites australiensis</i>	X			X		
<i>Dilwynites granulatus</i>	24%	3%	28%	8%	32%	28%
<i>Dilwynites tuberculatus</i>	X				2%	12%
<i>Lygistepollenites florinii</i>	X	1%	2%	X	3%	1%
<i>Microcachrydites antarcticus</i>				1%		
<i>Microalaticites palaeogenicus</i>						X
<i>Phyllocladites mawsonii</i>	X	X	5%	3%	1%	1%
<i>Podocarpidites</i> spp.	12%	22%	23%	31%	15%	11%
<i>Podosporites microsaccatus</i> complex	2%	39%	18%	18%		1%
Unassigned gymnosperms	X				1%	1%
<b>Angiosperms</b>						
<i>Ailanthipites paenestriatus</i>		X	X		X	X
<i>Anacolosidites acutullus</i>	X					
<i>Arecipites</i> spp.					X	
<i>Australopollis obscurus</i>					X	1%
<i>Cupanieidites orthoteichus</i>					X	
<i>Dicotetradites clavatus</i>	13%	3%		X	3%	X
<i>Dryptopollenites semilunatus</i>					X	
cf. <i>Ericipites</i> spp.				18%		
<i>Haloragacidites harrisii</i>	5%	8%	3%	1%	9%	5%
<i>Illexpollenites</i> sp.	X	1%	1%			
<i>Integricarpus antipodus</i>	X					
<i>Intratiporopollenites notabilis</i>	1%				X	
<i>Leptolepidites</i> cf. <i>verrucatus</i>	X					
<i>Liliacidites</i> spp.	2%		X			X
<i>Longapertites</i> sp.	X					
<i>Malvacipollis diversus</i>	X					X
<i>Malvacipollis robustus</i>		X			X	

Depth (m)	184.1	184.6	267.5	285.9	346.5	349.0
<b>Angiosperms (continued)</b>						
<i>Malvacipollis subtilis</i>	1%	1%			2%	1%
<i>Margocolporites</i> sp.	1%		X	X		
<i>Milfordia homeopunctata</i>					X	X
<i>Myrtacidites parvus</i>	X					X
<i>Myrtacidites verrucosus</i>						
<i>Myrtaceipollenites australis</i>	X	X			1%	X
<i>Nothofagidites brachyspinulosus</i> complex	2%	1%	X	X		X
<i>Nothofagidites emarcidus</i> complex	4%	11%	4%	3%		
<i>Nothofagidites flemingii</i>	2%	X	X	1%		
<i>Nothofagidites goniatus</i>	X					
<i>Pentacolporate</i> sp. aff. <i>Quintiniapollis</i>	X		X		X	
<i>Peninsulapollis gillii</i>	?		?	X		
<i>Periporopollenites</i> cf. <i>demarcatus</i>	X	X				
<i>Periporopollenites polyoratus</i>	X	X	X	1%	X	X
<i>Propylipollis annularis</i>	X					
<i>Proteacidites adenanthoides</i> complex	X	X	X	X		
<i>Proteacidites crassus</i>	X					
<i>Proteacidites</i> cf. <i>differentipolis</i>						X
<i>Proteacidites dilwynensis/grandis</i> complex	X	1%	X			X
<i>Proteacidites incurvatus</i>	cf.		cf.	cf.		
<i>Proteacidites</i> cf. <i>ivanhoensis</i>		X				
<i>Proteacidites latrobensis</i>	X					
<i>Proteacidites leightonii</i>		cf.				
<i>Proteacidites nasus</i>		X	X			
<i>Proteacidites obscurus</i>	X					
<i>Proteacidites pseudomoides</i>	X	X				
<i>Proteacidites</i> cf. <i>recavus</i>	X		X			
<i>Proteacidites reticulosabratus</i>			X			
<i>Proteacidites rectus</i>	X	X	X	X		
<i>Proteacidites</i> cf. <i>sinulatus</i>	X		X			
<i>Proteacidites</i> aff. <i>tripartitus</i>	X		X			
<i>Proteacidites</i> cf. <i>truncatus</i>		X				
<i>Proteacidites</i> spp.	12%	5%	3%	3%	X	
<i>Retistephanocolpites</i> sp.	X	X		2%		
<i>Rhoipites</i> spp.	3%	X			2%	1%
<i>Sapotaceoidaepollenites rotundus</i>			X			
<i>Spinizonocolpites prominatus</i>					5%	20%
cf. <i>Suprapollis</i>	X	X		X		
<i>Tetradopollis</i> sp. nov.	X		X			
<i>Tricolpites asperus/trioblatus</i>	X	X		X		
<i>Tricolpites</i> cf. <i>eogigantis</i> ms	X					
<i>Tricolpites phillipsii</i>		X	1%	X	X	X
<i>Tricolpites phillipsii</i> forma <i>durus</i> Stough					X	
<i>Tricolpites</i> spp.	3%	X	X	4%		
<i>Tetrastephanocolporites</i> sp. nov.		X			3%	5%
<i>Tricolporites adelaidensis</i> vars.	X	X	1%	X		
<i>Tricolporites moultonii</i> ms	X		cf.			X
<i>Tricolporites sphaerica</i> complex	X	X	X	X	3%	2%
<i>Tricolporites</i> spp.	3%	2%	X	2%	4%	4%
unassigned angiosperms	2%	X	2%	1%	4%	2%

Depth (m)	184.1	184.6	267.5	285.9	346.5	349.0
<b>Cryptogams</b>						
<i>Baculatisporites</i> spp.			4%		1%	1%
<i>Crassiretitriletes vanraadshoovenii</i>					X	1%
<i>Cyathidites australis/minor</i>	4%	2%	2%	1%	6%	9%
<i>Cyathidites splendens</i>	X		X		X	5%
<i>Dictyophyllidites</i> cf. <i>arcuatus</i>						
<i>Gleicheniidites</i> spp.			X	X		1%
<i>Herkosporites elliotii</i>						
<i>Laevigatosporites major/ovatus</i>	1%	X		X		X
<i>Latrobosporites crassus</i> complex						
<i>Latrobosporites marginis</i>						
<i>Polypodiaceosporites varus</i>						
<i>Polypodiisporites</i> spp.		X				X
<i>Retitriletes australoclavatidites</i>				X		
<i>Retitriletes</i> spp.						
<i>Ruffordiaspora australiensis</i>						
<i>Rugulatisporites mallatus</i>	X		X	X	X	
<i>Stereisporites antiquasporites/australis</i>	X			1%		
<i>Stereisporites maastrichtiensis</i>	X				X	X
<i>Trilites tuberculiformis</i>	X					
unassigned trilete spores	1%				1%	5%
<b>Reworked taxa</b>						
<i>Auriculiidites reticulatus</i>						X
<i>Evansispora senonica</i>			X			
<i>Protohaploxypinus</i> spp.						X

'X' denotes species recorded outside the formal pollen count  
(i.e. found during scanning of the strew mount(s) for very rare morphospecies)

## Discussion and conclusions

Unlike the Middle–Late Eocene, short-ranging dinoflagellate species make it possible to subdivide Early Eocene marine sediment into unusually short intervals of geological time.

At present, the only ‘firm’ dinoflagellate-based dates for the Macquarie Harbour Formation are from Strahan Point (foram zone P8: 50.2–50.8 Ma) and, less certain, Lowana Road (~foram zone P9: 50–53 Ma). The absence of short-ranging dinoflagellate species makes it difficult to establish precisely when the sampled intervals of Macquarie Harbour Formation in Strahan BH-1 were deposited although this uncertainly might be resolved when samples submitted to Utrecht University are processed and analysed for dinoflagellates.

In the interim, a number of moderately firm conclusions can be made from the available dinoflagellate and spore-pollen evidence in Strahan BH-1; the geological implications are more speculative:

- Macquarie Harbour Formation between the unconformity surface at 184.1 m depth and the lowest sample at 349.0 depth was deposited during the early to middle Early Eocene and, as such, pre-dates Macquarie Harbour Formation outcropping at Lowana Road, Regatta Point and Strahan Point.

Whether the latter (late Early Eocene *Homotryblum tasmaniense* Zone) exposures are conformably underlain by early to middle Early Eocene correlates of Macquarie Harbour Formation intersected in Strahan BH-1 can only be determined by drilling at Lowana Road.

The significant difference in depth and geological age implies substantial erosion of the formation at the Strahan BH-1 drill site. However as Macquarie Harbour Formation outcrops up to ~30 m above present day sea level on the Strahan Highway above the township (M. K. Macphail, personal observation), it is also possible a major E–W fault occurs between the Strahan township and Strahan BH-1 drill site.

- The data available indicate that the interval between 346.5 m and 349.0 m depth correlates with the *Apectodinium homomorphum* Zone recognised by Partridge (1999) in the Gippsland Basin. If confirmed, the interval:
  1. Post-dates the geologically instantaneous warming event (PETM) that defines the Paleocene–Eocene boundary at 55.8 Ma.
  2. Is likely to pre-date the Early Eocene climatic optimum (EECO) at ~51 Ma (see fig. 2 in Zachos *et al.*, 2008), based on abundant pollen of

the tropical mangrove palm *Nypa* pollen in samples lacking *Homotryblum tasmaniense*.

A corollary is that the Lowana Road, Regatta Point and Strahan Point outcrops were deposited during the EECO.

- The Macquarie Harbour graben was isolated from the Australo–Antarctic Seaway during the middle Early Eocene, based on marine dinoflagellates at the base of Strahan BH-1 (and Strahan Point, Regatta Point and Lowana Road outcrops) but not in the middle and top samples in this drill hole.

This period of isolation was associated with significantly cooler temperatures within the graben, based on the absence of *Nypa* and (with rare exceptions) other pollen of other thermophilous taxa in the middle and top samples in Strahan BH-1.

With improved age control and analysis of additional samples, it may be possible to determine whether the reason is eustatic (sea levels falling to below the Hells Gate rock sill) or tectonic (uplift of the same sill or at the drill site).

- It is possible that the Macquarie Harbour Formation was largely, if not wholly, deposited during the Early Eocene. In view of the thickness of the formation in Strahan BH-1, this may also have tectonic implications given high temperatures inferred for this epoch are more likely to enhance chemical than physical weathering processes. However it is difficult to reconcile active tectonism at Macquarie Harbour with preservation of a thick Early Eocene sand body in the quarry immediately to the south of Regatta Point, inferred by Pole (1998).

On present indications, it seems probable that the Macquarie Harbour graben (and the Strahan area in particular) preserves a ‘world class’ archive of a flora and vegetation growing under near-tropical conditions at palaeolatitudes equivalent to the present edge of the Antarctic ice cap.

## Acknowledgements

Drs Clive Calver and Diane Rowe (Mineral Resources Tasmania) provided access to the Strahan BH-1 core and Dr Alan Partridge (Biostrata Pty Ltd) kindly undertook to review plant microfossils recovered from the basal sample at 349.0 m depth. Analysis of the samples would not have been possible without the assistance provided by Dr Greg Jordan (University of Tasmania) and Professor Bob Hill (University of Adelaide). These contributions and their time is gratefully acknowledged.

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[23 June 2011]

# APPENDIX I

## Sample lithology

### **Core chip samples, (M. K. Macphail and G. J. Jordan, 24 April 2011)**

<i>Depth</i>	<i>Description</i>
184.1 m	massive light grey clay/claystone with coalified macrofossil remains
184.6 m	light grey-brown organic-rich, finely-laminated claystone, plant macrofossils on bedding planes
191.0 m	laminated grey-brown lignite (coal)
192.8 m	dark-brown organic-rich claystone
195.4 m	massive light grey clay/claystone with finely dispersed coal? fragments
199.0 m	light grey-brown organic-rich, finely-laminated sandy claystone, plant macrofossils on bedding planes
207.3 m	light grey-brown organic-rich, finely-laminated claystone, plant macrofossils on bedding planes
211.3 m	laminated, medium brown lignitic sandy claystone
217.0 m	laminated, light grey-brown claystone with obliquely bedded plant macrofossils (coal)
223.0 m	massive light grey clay/claystone with finely dispersed coal? fragments
224.0 m	laminated medium grey-brown lignite/organic-rich claystone with plant macrofossil remains (coal)
229.0 m	dark brown laminated lignite
240.0 m	dark brown lignitic claystone with plant macrofossil remains (coal)
248.2 m	laminated medium grey-brown lignite/organic-rich claystone with plant macrofossil remains (coal)
255.4 m	massive light grey sandy claystone with rare coal? fragments
258.4 m	medium grey organic-rich claystone with plant macrofossil remains (coal)
267.5 m	medium grey organic-rich claystone with plant macrofossil remains (coal)
274.0 m	dark brown lignite with plant macrofossil remains (coal)
277.0 m	laminated medium grey-brown lignite/organic-rich claystone with possible ash lenses
282.4 m	massive light grey-brown claystone with dispersed plant macrofossil remains
285.9 m	massive light grey-brown claystone with dispersed plant macrofossil remains
286.5 m	dark brown lignite
291.3 m	medium brown lignitic silty fine sandstone, plant macrofossils on bedding planes
300.5 m	massive light grey claystone with finely dispersed coal? fragments
302.0 m	massive light grey-brown claystone with dispersed plant macrofossil remains
307.5 m	massive light grey claystone with finely dispersed coal? fragments
309.0 m	coarsely laminated light grey claystone, plant macrofossils on bedding planes
309.65 m	laminated yellow-grey pyritic fine sandstone clay, plant impressions? on bedding planes
317.3 m	coarsely laminated light grey sandy claystone, plant macrofossils on bedding planes
323.0 m	massive light grey-green pyritic claystone, scattered plant macrofossils (coal)
328.0 m	massive light grey claystone with finely dispersed coal? fragments
328.6 m	laminated/ light-grey sandy claystone underlying 'dolerite' interval
329.7 m	light grey-brown organic-rich, finely-laminated sandy claystone, plant macrofossils on bedding planes
329.7 m	weathered dolerite? clast in light-grey claystone
331.8 m	weathered dolerite? clast
332.2 m	massive light grey-green pyritic claystone, scattered plant macrofossils (coal)
333.2 m	yellow-grey massive claystone with pyritised plant remains
333.9 m	yellow-grey massive claystone
334.0 m	mottled red, weathered dolerite? clast
334.3 m	massive light grey-green pyritic claystone
335.5 m	'brecciated' dark brown lignite in grey-green silty, fine to medium sandstone
337.2 m	massive light grey-green claystone
338.6 m	yellow-grey massive claystone
346.5 m	grey-green silty, fine to medium sandstone (turbated?)
347.0 m	grey-green silty, fine to medium sandstone
349.0 m	grey-green silty, fine to medium sandstone