Late Miocene vegetation and palaeoenvironments of the Drygalski Formation, Heard Island, Indian Ocean: evidence from palynology

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Abstract : Well sorted, fine lithic sandstone within the Drygalski Formation at Cape Lockyer on the southern tip of Heard Island, preserves a diverse terrestrial palynoflora as well as marine diatoms and a few foraminifera. A combination of these elements suggests a Late Miocene age (10–5 Ma). The palaeovegetation was markedly different from that presently on the island, and appears to comprise at least two ecologically distinct communities: open heath or herbfield dominated by grasses and Asteraceae , and a more mesophytic community dominated by ferns but also including lycopods and angiosperms such as *Gunnera.* This may have represented a coastal flora similar to the 'fern-bush' community that exists now on Southern Ocean islands north of the Antarctic Polar Frontal Zone, and in Tierra del Fuego; however, there is no evidence of tree species in the local flora and trace amounts of tree pollen present may have blown in from other landmasses in the region.

Introduction

Heard Island is the southernmost area of outcrop on Kerguelen Plateau. It is poorly known geologically and no complete geological map exists. What is known is summarized by Clarke *et al.* (1983), Quilty *et al.* (1983), Barling *et al.* (1994), Quilty & Wheller (2000) and Stephenson *et al*. (in press). Heard Island, McDonald Islands and Iles Kerguelen, are the only subaerial exposures of Kerguelen Plateau, the second largest submarine plateau after Ontong Java Plateau (Nougier & Thomson 1990, Frey *et al.* 1991, 2000, Quilty & Wheller 2000, Borissova *et al.* 2002, Quilty in press). Little is known of the origin and evolution of the islands, nor the history of the fauna and flora that inhabit them. The marine history of the region has, however, been the subject of significant international research effort, particularly through the Ocean Drilling Program (ODP: Barron *et al*. 1989, Schlich *et al.* 1989, Shipboard Scientific Party 2000, Ingle *et al.* 2002), Australian and French national programs (Ramsay *et al.* 1986, Wicquart & Frölich 1986) and through earlier programs such as those of USNS *Eltanin* (for example, Markl 1974), and the Deep Sea Drilling Project. Schlich (1982) and Frey *et al.* (2000) described the tectonic evolution of the region.

Heard Island has a 'basement' of dipping Palaeogene limestone (originally calcareous ooze). This is best exposed on the south-eastern side of Laurens Peninsula and in Corinthian Bay (Fig. 1), and it probably lies close to sea level under the entire island. These sediments have been peneplaned to serve as the pavement for the 250–350 m thick, flat-lying Drygalski Formation (originally described as Drygalski Agglomerate, Lambeth 1952) which is a prominent, cliff-forming unit visible around the island and, in turn, forms the foundation for the modern volcano of Big Ben (Quilty & Wheller 2000, Quilty in press). A second active volcano occurs on nearby McDonald Island (Quilty 1995).

Clarke *et al.* (1983) suggested that the modern form of the island is less than one million years old, due to the growth of the present active volcano. Earlier phases of volcanism include that responsible for deposition of much of the Drygalski Formation and an earlier, undated phase, associated with the uplift of the island to its present elevation. Quilty *et al.* (1983) provided palaeontological support for the conclusions of Clarke *et al.* (1983) and referred to a Palaeogene phase which deposited the Laurens Peninsula limestone, which has no formal stratigraphic nomenclature. Quilty *et al.* (1983) reported dark siltstone in the Drygalski Formation from Cape Lockyer and recorded a Late Miocene–Early Pliocene age on the basis of several fossil groups.

This paper reports on the analysis of sediments and microfossils from a single sample collected by G.E.W. from Cape Lockyer, Heard Island, central southern Indian Ocean
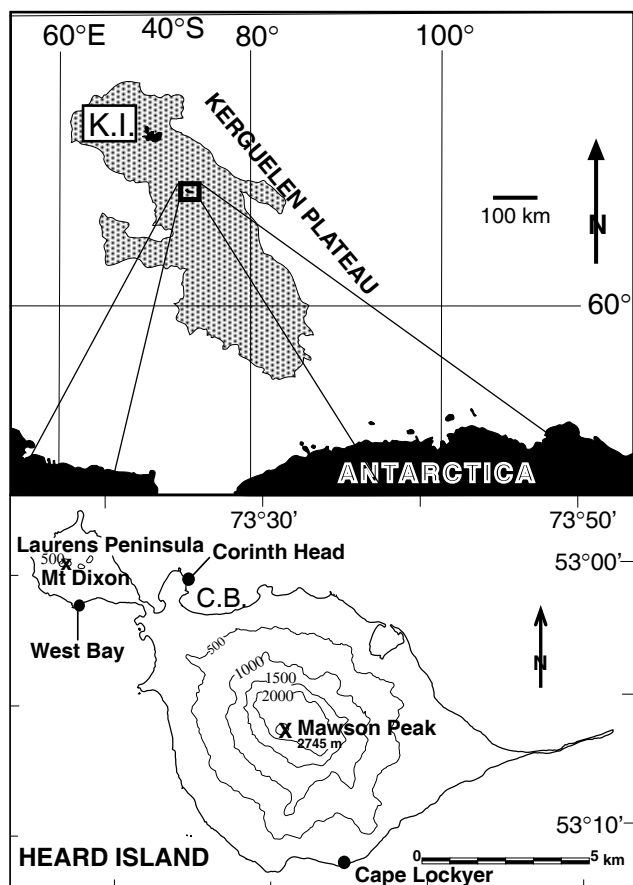
Fig. 1: Locality map, Heard Island and localities mentioned in the text. K.I = Iles Kerguelen. C.B. = Corinthian Bay.

(Fig. 1) in 1987 as part of Australian National Antarctic Research Expeditions (ANARE) activity in the 1986/87 summer. The purpose of the paper is to refine the understanding of the age and environment of deposition of part of the Drygalski Formation, to integrate the results with what is known of the history of Kerguelen Plateau, and to add to the growing body of information on the transoceanic dispersal of plants around the southern hemisphere.

Drygalski Formation

The Drygalski Formation is poorly studied. It contains a variety of facies including pillow lavas and volcaniclastic sediments (Stephenson 1964) but the field relationships between these components have not been fully studied. Lambeth (1952) and Stephenson (1964) also referred to glacial sediments in the Drygalski Formation but these have not been documented. The Drygalski Formation was the source of the bivalve *Austrochlamys heardensis* (Fleming) (Fleming 1957, Jonkers 2003, Quilty 2004) on the southern side of Laurens Peninsula, close to the locality chosen by Lambeth (1952) as part of the type locality for the Drygalski 'Agglomerate', where there are said to be '…glacial

sediments with associated lavas…' (Stephenson 1964). The original location of the fossil in the section is unknown. Further sediments containing specimens of *A. heardensis* associated with *Laternula elliptica* (King & Broderip) were located at Corinth Head (Fig. 1) by R.S. Cohen and D. Lawton in 1969 (Jonkers 2003, Quilty 2004). This find enlarged the known extent of the fossiliferous sediment facies of the Drygalski Formation and also the distribution of the bivalve around the island.

Jonkers (2003) reported that a basalt clast from the rock that contains the type specimen of *A. heardensis* was dated by Ar–Ar techniques as slightly younger than 9.4 ± 2.4 Ma (Late Miocene).

Stephenson (1964) referred to 'thick deposits of sedimentary rocks' at Cape Lockyer and both the dark siltstone of Quilty *et al.* (1983) and the sediment studied in this paper come from this sequence. The new material described herein allows considerable refinement of that age and environmental significance.

The sample is of very well sorted buff volcanolithic fine sandstone from near the base of the cliffs at Cape Lockyer. It is highly porous but indurated and lacks obvious cement. It contrasts markedly with the dark siltstone recorded earlier (Quilty *et al.* 1983) which was very dark and friable and lacks many of the microfossil groups recorded here. The bed yielding the sample is typical of the Drygalski Formation in cliff section and is about 10–12 m thick, massive, and highly and irregularly jointed. It is overlain by partly bedded volcanolithic breccia, including hyaloclastites, which form most of the 50–80 m high cliff sequence. The general composition of the breccia is basaltic, as is the bulk of Big Ben volcano, and is largely of well-sorted, sub-angular fragments and hydration products of olivine, pyroxene, plagioclase and magnetite.

Material and methods

The rock disaggregated poorly and with difficulty into constituent grains. Foraminifera, radiolarians, diatoms and abundant sponge spicules were obvious in thin section but were not easily released as individual specimens during processing. The specimens of foraminifera separated from fragments of rock were cleaned under the microscope and identified but were characterized by adherent material, which made identification difficult. Radiolaria were rare and very poorly preserved, and there were fragments of echinoid spines. Calcareous nannoplankton were not recovered. Palynomorphs, mostly spores and pollen, were abundant: their recovery is documented below. Diatoms could be identified in thin section but could not be extracted from the rock.

The rock sample and thin section are housed in the collection of the School of Earth Sciences, University of Tasmania, Catalogue Number 153893. Palynological slides are housed in the Department of Earth and Marine Sciences,

Australian National University.

The major result to come from study of the sample derives from palynology. The material recovered is well-preserved, making detailed taxonomic comment and implications worthwhile, even though only one sample was available. Standard processing techniques of recovering palynomorphs were employed. These involve removal of inorganic sand, silt and clay using a combination of hydrofluoric acid and heavy liquid separation employing zinc bromide, followed by oxidation of organic compounds with Schulze solution. The extracts were sieved on a 5 μm Millipore sieve cloth and mounted on microscope slides using Eukitt. Photomicrographs were taken on a Leitz Orthoplan (895191) microscope in the Department of Earth and Marine Sciences, Australian National University; co-ordinates of this microscope are those shown in figure explanations.

Age determination

Fleming (1957) believed the Drygalski Formation to be Pliocene (or possibly Late Miocene or earliest Pleistocene) on the basis of the occurrence of *Austrochlamys heardensis*, which he described as *Chlamys* (Jonkers 2003, Quilty 2004). The range of marine and terrestrial microfossils preserved in the Cape Lockyer sample suggests that the former (late Miocene) age limit is more probable and thus consistent with the radiometric dating reported by Jonkers (2003).

Foraminifera

Foraminifera are very rare (approximately one specimen per gram), stained a light orange colour (possibly representing some iron staining), commonly fragmented, and the only species identified are:

Globorotaloides variabilis Bolli
Pyrgo sp.
Dentalina sp.
Saracenaria sp.
Melonis cf. *barleeanum* (Williamson) (12 chambers in the final whorl, umbilici perhaps not as clearly defined as in *M. barleeanum*)
Gyroidinoides subplanulatus Echols
Globocassidulina globosa (Brady).
Several unidentified specimens were seen in thin section

The only species of any age control significance is *Globorotaloides variabilis* which indicates that the age is Miocene. Berggren (1992) recorded *G. variabilis* from nearby ODP Leg 120 Site 747 in the Early Miocene although its global range is late Early and younger Miocene (Kennett & Srinivasan 1983).

The environment of deposition appears to be inner continental shelf, although the foraminiferal control is poor.
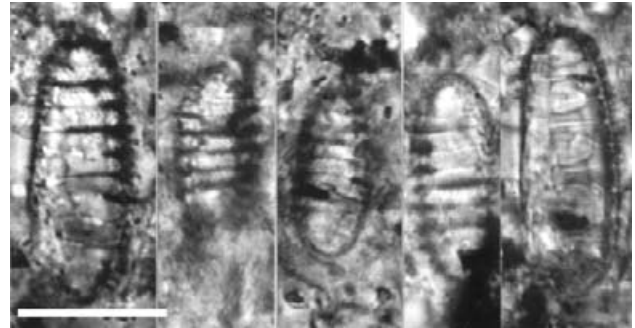

Fig. 2. Diatom species from Cape Lockyer sample. All are *Denticulopsis hustedtii* (Simonsen and Kanaya) Simonsen. Scale bar = 25 microns.

Diatoms

Diatoms are abundant and could be seen easily in thin section but not separated from the rock. This made precise identification difficult and the identified species list is incomplete.

The diatom assemblage consists of:

Denticulopsis hustedtii (Simonsen & Kanaya) Simonsen (Fig. 2)
Coscinodiscus spp.
Rhizosolenia costata Gersonde
Dactyliosolen antarcticus Castracane
Actinocyclus ingens Rattray
Thalassiothrix spp.
Thalassiosira spp.

The assemblage is dominated by *Denticulopsis hustedtii,* which has an independently dated stratigraphic range of 14.2–5.6 Ma (Harwood & Maruyama 1992), thus constraining the age of the sample. The maximum age is defined by occurrence of *Actinocyclus ingens* that has a similar First Appearance Datum (FAD) to that of *D. hustedtii*, of 16.4 Ma (Harwood & Maruyama 1992). All taxa other than *D. hustedtii* have stratigraphic ranges extending into the Pleistocene (*A. ingens*) or are extant. The diatoms constrain the age of the sample to the Middle or Late Miocene. The flora lacks benthic species and thus water depth at the time of deposition was approximately 50 m or greater.

Palynomorphs

The residue yielded spores, pollen, plant tissue, and a single species of dinoflagellate cyst. Also present were plant tissue fragments, fungal remains (including germlings of Microthyriaceae) and a variety of foraminiferal test linings. The composition of the palynomorph assemblage is given in Table I. Details of selected taxa are provided in the Appendix.

The palynomorphs from Cape Lockyer, by themselves, can provide only a broad guide to the age of the enclosing

Table I. Composition, relative abundance and affinities of palynomorphs recovered from Cape Lockyer, Heard Island (*denotes taxa that are now extinct on Heard Island).

Fossil taxon	Nearest Living Relative (NLR)	%
Ferns & fern allies		
Baculatisporites sp. cf. *B. comaumensis* (Cookson) Potonie, 1956	* Hymenophyllaceae?	1.5
Coptospora sp.	* Davalliaceae, Polypodiaceae	trace
Cyathidites australis Couper, 1953	* Cyatheaceae	4.5
Foveotriletes sp. cf. *T. palaequetrus* Stover & Partridge, 1973	*Lycopodium*	trace
Laevigatosporites spp.	* monolete ground ferns	6.0
Polypodiaceoisporites sp.	* *Pteris*	trace
Retitriletes sp. cf. *R. eminulus* (Dettmann) Srivastava, 1975	* Lycopodiaceae	2.0
Triletes sp. cf. *T. tuberculiformis* Cookson, 1947	* Dicksoniaceae	42.5
GYMNOSPERMS		
Microalatidites sp. cf. *M. varisaccatus* Mildenhall & Pocknall, 1989	* *Phyllocladus*	0.5
Phyllocladidites mawsonii Cookson ex Couper, 1953	* *Lagarostrobos*	trace
Podocarpidites ellipticus Cookson, 1947	* *Podocarpus*/*Prumnopitys*	1.5
ANGIOSPERMS		
Chenopodipollis chenopodiaceoides (Martin) Truswell *et al.* 1985	Chenopodiaceae–Amaranthaceae	+
Corsinipollenites sp. cf. *C. epiloboides* Krutzsch, 1968	* Onagraceae cf. *Epilobium*	trace
Cyperaceaepollis neogenicus Krutzsch, 1970	Cyperaceae	0.5
Graminidites spp.	Poaceae	6.0
Liliacidites sp.	Liliaceae (*sensu lato*)	trace
Luminidites sp. cf. *L. phormoides*	* Agavaceae?	trace
Malvacearumpollis mannanensis Wood, 1986	* Malvaceae	0.5
Nothofagidites sp. cf. *N. lachlaniae* (Couper) Pocknall & Mildenhall, 1984	*Nothofagus* (*Fuscospora*) sp.	trace
Periporopollenites spp.	Caryophyllaceae	0.5
Phormium sp.	* *Phormium* sp.	trace
Tricolpites reticulatus Cookson ex Couper, 1953	* *Gunnera*	15.0
Tricolporites spp.	unidentified angiosperms	3.0
Tubulifloridites sp. cf. *T. antipodica* Cookson ex Potonie, 1960	Asteraceae	14.0

sediments. There are a number of reasons for this:

- Almost all of the spore and pollen species recovered are long-ranging in those well-dated Australian and New Zealand sequences that provide reference sections for stratigraphic ranges elsewhere in the middle to high latitudes of the Southwest Pacific and Indian oceans. It should be noted that comparisons with Antarctica are insecure because of limited information on Tertiary sequences from that continent.

- Comparisons with dated palynological zones in southern hemisphere continental basins are complicated by the fact that ranges are unlikely to be the same in island sequences where floras were probably specialized, and evolved independently of mainland floras.

- Related to this, continental vegetation has, in the main, been dominated by tree species, and abundances of tree pollen, or distributions of individual forest taxa, have provided the basis for delineation of biostratigraphic zones in continental sedimentary basins. The Heard Island flora, by contrast, has very few species that could have represented tree-sized taxa.

With these caveats, the following observations support a late Miocene age for the sample (Table I):

- The high relative abundance of Asteraceae pollen (as *Tubulifloridites* sp. cf. *antipodica*) - around 14% - in the Cape Lockyer material is significant. In Australian sequences, such as those of the relatively well-known Murray Basin (summarized by Macphail 1999), this species group is present in very low frequencies before the Late Miocene. In New Zealand, Mildenhall & Pocknall (1989) noted that Asteraceae pollen is common in sequences in central Otago from the Middle Miocene. Forms akin to the pollen of *Silene* first appear in the late Miocene or Early Pliocene.

- The abundance of grass pollen (*Graminidites* spp.) is in accord with a post-Middle Miocene age on the basis of comparison with continental sequences (Martin 1989, Macphail 1999). Polyporate pollen, herein referred to broadly as *Periporopollenites* spp. which is present in low, but significant frequencies at Cape Lockyer, shows similar patterns of increase in the Neogene, with abundances in Australia increasing markedly after the Late Miocene, and after the Middle Miocene in New Zealand.

These, admittedly broad, similarities between the Cape Lockyer microflora and those of Australia and New Zealand, accord with an age as young as Late Miocene. A finer resolution of this age, with age minimum limits is not possible on the basis of available data but the result is
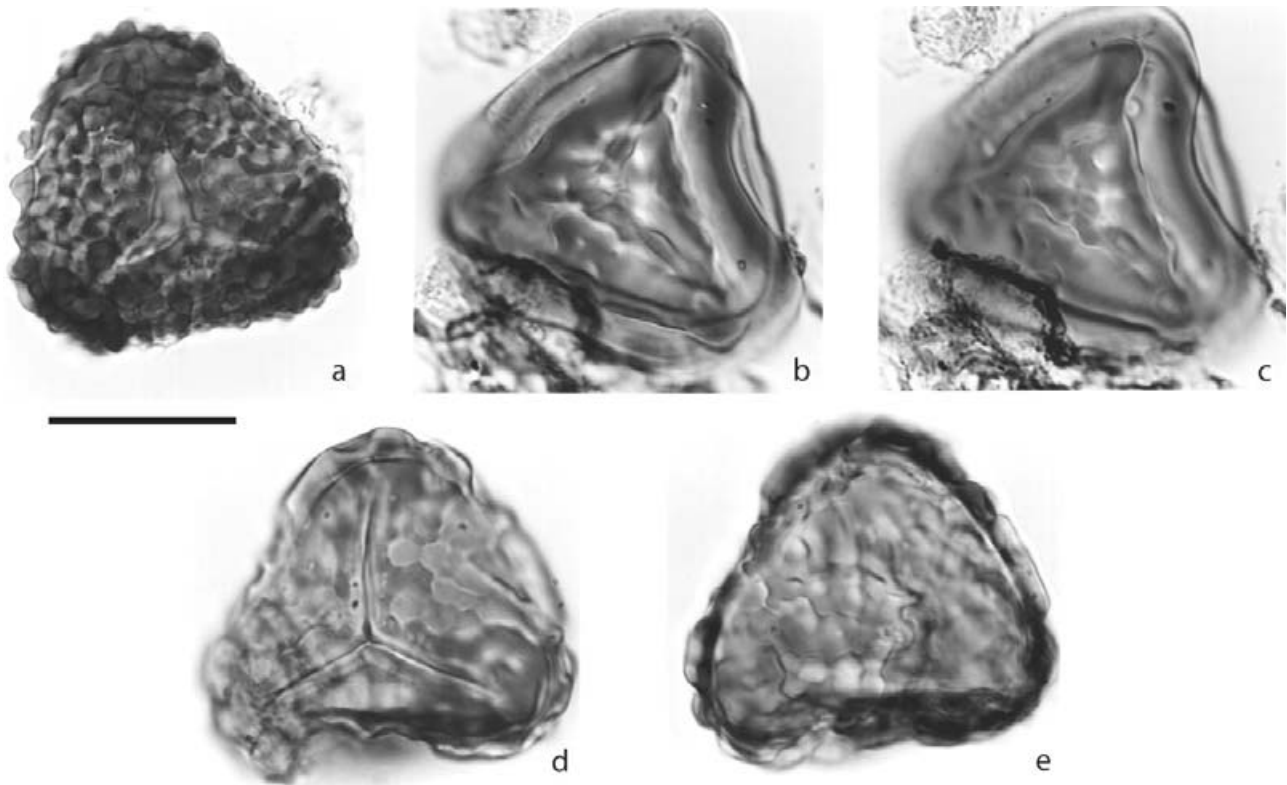
Fig. 3. Spores from Drygalski Formation, Cape Lockyer, Heard Island. All specimens photographed under light micrography; scale bar = 20 microns. **a, d–e.** *Trilites* sp. cf. *Trilites tuberculiformis*. **a.** HQ1/2: 110.6,18.1, median focus. **d–e.** HQ3/ 94.9, 43.8, proximal and distal foci. **b, c.** *Polypodiaceoisporites* sp., HQ2/100.5, 24.1, proximal and distal foci.

consistent with the Ar–Ar dating of the basalt clast from Laurens Peninsula.

Uncommon to rare species occurring in common between the Heard Island assemblage and those of Australia and New Zealand, but which are either long-ranging, or have apparently discordant ranges, include the following:

Malvacearumpollis mannanensis (Eocene to Late Miocene in Australia and New Zealand; Wood 1986, Macphail 1999, Mildenhall & Pocknall 1989),

Cyperaceaepollis neogenicus (Miocene–Pleistocene in New Zealand; Eocene–Pleistocene in Australia; Mildenhall & Pocknall 1989, Macphail 1999),

Tricolpites reticulatus (Turonian to Quaternary on a global basis; Jarzen & Dettmann 1989),

Trilites tuberculiformis (Cretaceous to Pliocene in Australia; Macphail 1999).

Pollen of southern conifers, assigned to *Phyllocladidites, Podocarpidites* and *Microalatidites*, which are sparse in the Cape Lockyer material, are generally long ranging in continental sequences and are known to be transported over long distances by wind.

Palaeovegetation

Diversity and dominance

Examination of the processed material from the Drygalski Formation identified 24 fossil pollen and spore types that can be assigned to formally described fossil genera and species (Table I). The table includes data on nearest living relatives (if identifiable) and percentage frequencies based on a count of 250 grains. A plus sign indicates rare taxa observed on the slide but not in count.

The assemblage is dominated by fern spores, in particular by *Trilites* cf. *tuberculiformis* (Dicksoniaceae) with other fern groups, such as *Laevigatosporites* and *Cyathidites* (Cyatheaceae) species also common. Of the angiosperm pollen, those of Asteraceae (as *Tubulifloridites* sp. cf. *antipodica*) and Gunneraceae (as *Tricolpites reticulatus)* are most abundant. Pollen of Poaceae – the grasses – are present with a frequency of around 6%. All other taxa are present in trace amounts, with observed frequencies of 1% or less. Other angiosperms observed in the count included pollen of Cyperaceae (*Cyperaceaepollis neogenicus*), Liliaceae *(Liliacidites* sp), Malvaceae/Euphorbiaceae (*Malvacearumpollis mannanensis*) and possibly Caryophyllaceae (*Periporopollenites* spp.).

Spores of *Huperzia/Lycopodium* are present. Conifer pollen comprises three species, viz. *Phyllocladidites*
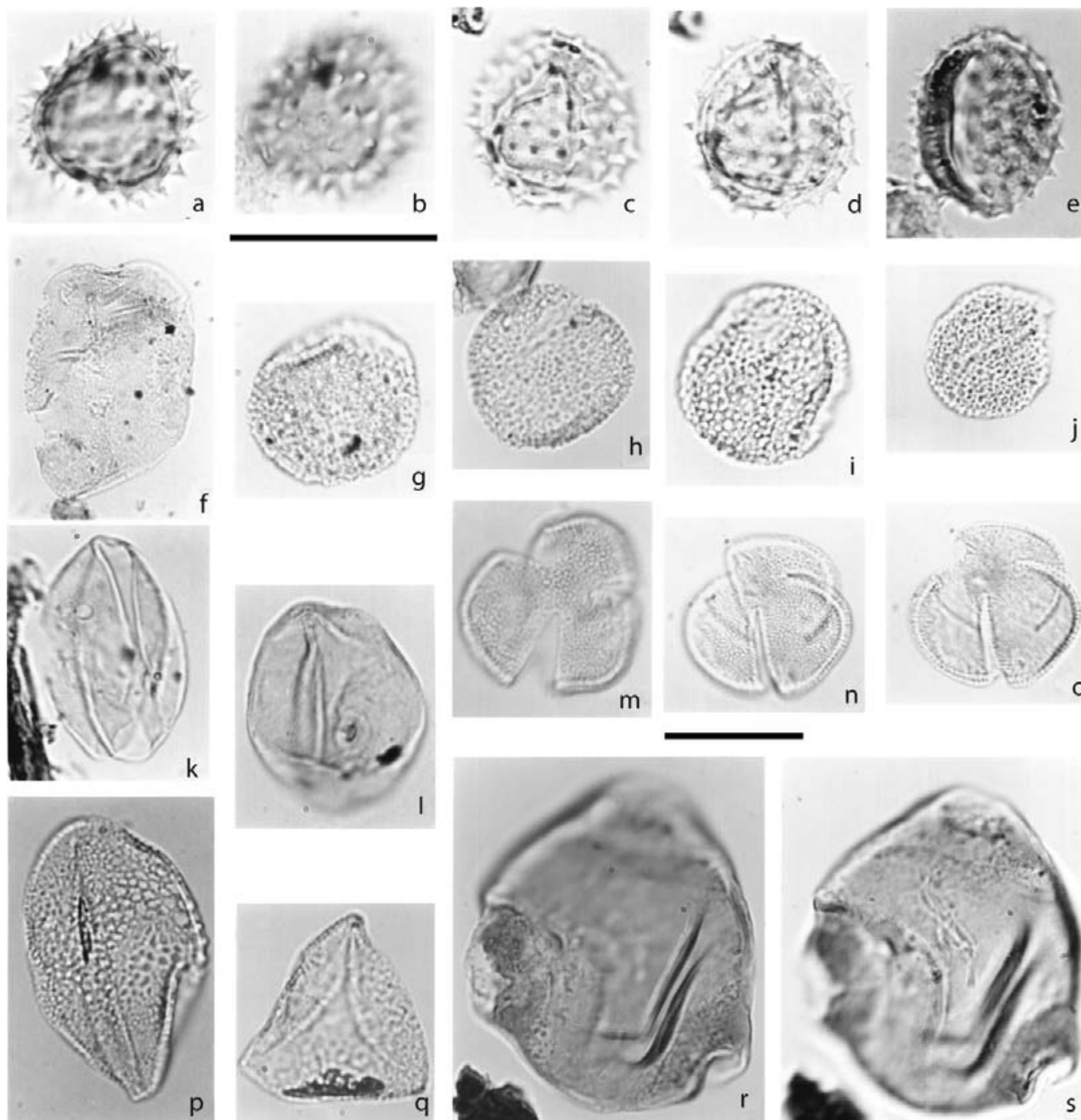
Fig. 4. Spores and pollen from Drygalski Formation, Cape Lockyer, Heard Island. Scale bars represent 20 microns; that under part **b** applies to **a–e**, **g–j** and that under part **n** applies to other images. **a–e.** *Tubulifloridites* sp. cf. *T. antipodica*. x 1400. **a, b.** HQ3/101.2, 31.4. Oblique equatorial view, sectional and high foci. **c, d.** HQ3/98.2, 10.5. Equatorial views. **e.** HQ2/105.8, 31.0. Equatorial view in section.
f. *Cyperaceaepollis neogenicus* HQ3/106.2, 13.7. **g–j.** *Periporopollenites* sp. x 1400. **g,** HQ2/96.9, 26.4. **h.** HQ3/102.0, 33.5.
i. HQ3/102.0, 33.5. **j.** HQ2/109.4, 41.0. **k, l.** *Graminidites* sp. **k.** HQ2/104.9,35.0. **l.** HQ2/ 101.1, 26.1. **m–o.** *Tricolpites reticulatus*.x 1400.
m. HQ2/97.2, 38.6. **n–o.** HQ2/103.5,39.6. Oblique equatorial views, high and median foci. **p.** *Liliacidites* sp. HQ2/98.3, 28.2.
q. *Luminidites* sp. cf. *L. phormioides* HQ3/109.6, 9.7. **r, s.** *Corsinipollenites* sp. cf. *C. epiloboides* HQ2/93.3, 23.7. foci on pores, viscin threads visible in **s**.

mawsonii and *Microalatidites palaeogenicus*, probably representing *Lagarostrobus* and *Phyllocladus*, and a diversity of forms referable to *Podocarpidites*, reflecting *Podocarpus* and/or *Prumnopitys*.

Two specimens of pollen of *Nothofagus*, probably referable to *Nothofagidites lachlanieae* (Couper) Pocknall & Mildenhall 1984, were observed outside the pollen count. The very low frequency of this pollen, which is produced in

large quantities by most members of the genus, suggests that it was not part of the local vegetation, but may rather have been a wind-borne contaminant.

The fungal remains are mostly those of epiphyllous Microthyriaceae, including germlings (Fig. 5k) and mature fruiting bodies. The dinoflagellate cysts observed belong to a single, apparently undescribed species that has earlier (Quilty *et al*. 1983) been referred to *Cymatiosphaera*.

Previous description

The microflora from siltstone at Cape Lockyer was described briefly in a wide-ranging account of sediments from Heard Island given by Quilty *et al.* (1983). Most of the species described in the present account were identified then, and frequencies of major taxa are comparable, but there are differences. For instance, the form species *Spinizonocolpites prominatus* was listed in the 1983 study. This species, which is characteristic of the Early to Middle Eocene in Australia (Stover & Evans 1973), was instituted to accommodate pollen of the tropical mangrove palm, *Nypa*. The presence of this taxon in the Heard Island assemblage is anomalous; it possibly represents a misidentification of forms assigned here to *Malvacearumpollis mannanensis*. Neither *Cycadopites* nor *Tricolporites leuros* were identified in the present study.

Conversely, the present study has contributed *Corsinipollenites* sp. cf. *epiloboides* (Onagraceae, cf. *Epilobium*)*, Periporopollenites* spp. (cf. Caryophyllaceae), *Graminidites* spp. (Poaceae), *Liliacidites* sp. cf. *phormioides* (Agavaceae?), *Cyperaceaepollis neogenicus* (Cyperaceae), *Baculatisporites* (Hymenophyllaceae?)*, ?Coptospora* sp. (Davalliaceae/Polypodiaceae?), *Phyllocladidites mawsonii* (*Lagarostrobus*) and *Microalatidites palaeogenicus* (*Phyllocladus*). The presence of microthyriaceous fungi was not reported hitherto. The two studies combined provide a potentially more comprehensive representation of the parent vegetation.

Vegetation

Depositional environment strongly influences not only the types of plants that are represented by fossil pollen spores, but also their relative abundance for two reasons.

a) Plants differ markedly in the numbers of pollen or spores they produce and the extent to which these are dispersed into the surrounding environment by wind, water or animals.

b) Fossil pollen and spores are sedimentary particles and are subject to the same sorting processes during transport and deposition as inorganic fine silts.

The inner neritic environment inferred for the sample indicates that the closest modern analogues will be microfloras deposited on the inner continental shelf. An example of such deposition is that from deepwater sites in Queensland, where Kershaw *et al.* (1994) argued that most terrestrial palynomorphs at the ODP Site 820 were transported by water (rather than by wind) because of their association with large numbers of spores from ferns that grow along drainage lines.

If, as we propose, the fossil pollen and spores recovered from the Drygalski Formation were primarily water-transported to the site, then the relative abundance data (Table I) indicate that at least two ecologically distinctive plant associations were present on Heard Island during the Late Miocene. These were

a) Dicksoniaceae-dominated fern heath or tree-fern 'forest' lining the banks of coastal streams, and

b) Asteraceae–Poaceae dominated communities on drier or more exposed (interfluve) areas along the coast or adjacent higher ground.

The Asteraceae includes genera that range in size from low herbs to small trees on present-day sub-Antarctic islands, and it is unclear whether the fossil association represents a herbfield or shrubland. Some commonly occurring taxa, notably *Gunnera* (*Tricolpites reticulatus*) could have been part of these vegetation types or formed distinct communities in their own right.

1. Dicksoniaceae fern-heath or forest

The dominance of the fossil assemblage by the large and heavy-walled fern spore *Trilites* sp. cf. *tuberculiformis,* which was probably produced by a member of the Dicksoniaceae, suggests that there is a significant fern or tree-fern component in the source vegetation. Other fern spores present in substantial quantities include *Cyathidites* and *Laevigatosporites* species. Input of these elements to the site came probably from a stream draining through a nearby damp gully. At least two lycopod species (*Foveotriletes palaequetrus* and *Retitriletes* cf. *eminulus*) accord with such an interpretation. Such an environment may also have been the habitat for a member of the genus *Gunnera*, parent taxon for the dispersed pollen *Tricolpites reticulatus.* In their review of the distribution of *T. reticulatus*, Jarzen & Dettmann (1989) noted that the floras associated with this taxon were usually reflective of temperate conditions with high humidity.

2. Asteraceae–Poaceae heath or herbfield

Pollen of Asteraceae (as *Tubulifloridites* sp. cf. *T. antipodica*) and Poaceae (as *Graminidites* spp.) may represent drier environments, although these families do today sometimes occur as cushion forms in boggy habitats. Given that the Cape Lockyer sediments are marine, these vegetation elements may have been from coastal communities. The location of trees or shrubs that produced
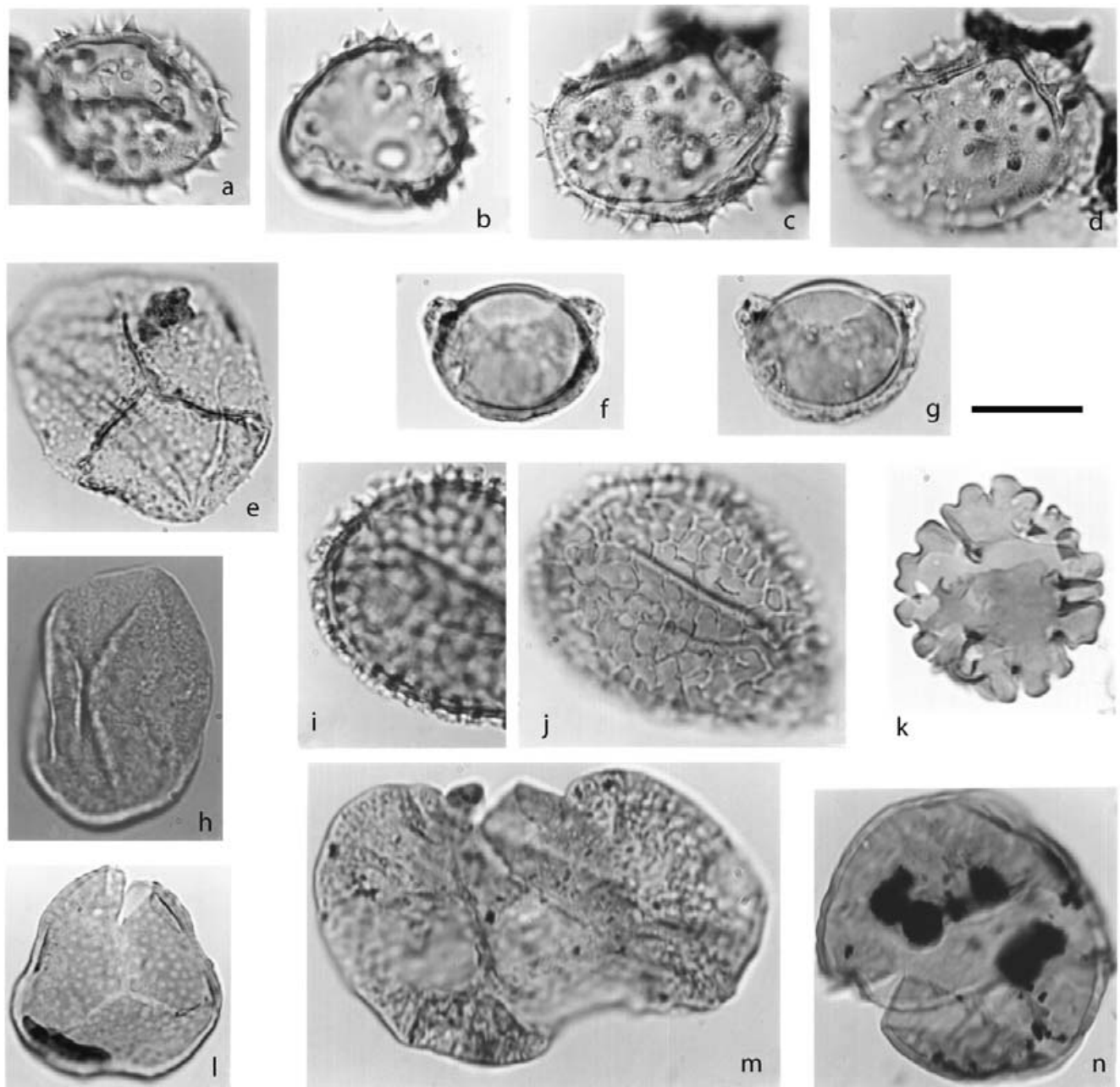
Fig. 5. Spores and pollen from Drygalski Formation, Heard Island. Scale bar = 20 microns. **a–d.** *Malvacearumpollis mannanensis.* **a.** HQ2/98.0, 35.0. Focus on processes in section. **b.** HQ3/110.3, 33.5. **c, d.** HQ3/ 109.7, 33.5. Median and high foci. **e.** *Baculatisporites* sp. cf. *B. comaumensis* HQ3/107.0, 11.3. **f, g.** *Phyllocladidites mawsonii*, HQ2/ 106.4, 25.8. **h.** *Microalatidites* sp.cf. *M. varisaccatus* HQ3/103.5, 39.6. **i, j.** *Retitriletes* sp. cf. *R. eminulus* HQ2/98.5, 32.1. Median and high foci on reticulum. **k.** Microthyriaceous germling HQ2/ 104.8, 20.0. **l.** *Foveotriletes* sp. cf. *F. palaequetrus* HQ2/109.3, 38.0. **m.** *Podocarpidites* sp. HQ3/ 100.8, 39.5. **n.** *?Coptospora* sp. HQ1/109.7, 12.5.

pollen of the Podocarpaceae is unknown; the sparseness of these pollen types may mean that the parent plants were some distance from the coast.

The total pollen and spore assemblage from the Cape Lockyer material suggests that this Miocene vegetation may have had some similarities with the 'fern-bush' communities that exist today on islands such as those of the Tristan–Gough Group, New Amsterdam Island, and on Tierra del Fuego (Wace 1960, Bliss 1979). In this formation, however, ferns usually form a dense understorey to a canopy layer of small trees or shrubs. On Gough Island, for instance, the small tree *Phylica* forms the canopy above a layer of dwarf tree ferns such as *Blechnum palmiforme*. Islands supporting such communities today are situated well

north of the Antarctic Polar Frontal Zone (APFZ), and enjoy mean annual temperatures at sea level of about 11–12°C.

The spore and pollen assemblage described here indicates vegetation dramatically different from any communities that grow on Heard Island today. At present, only about 5% of the total area of Heard Island is covered by substantial vegetation (Bergstrom & Selkirk 2000), with low-growing herbaceous flowering plants and bryophytes being the major elements. Some 12 vascular plant species and 60 bryophytes are recorded from Heard Island (Australian Antarctic Division 1995, Bergstrom & Selkirk 2000, Bergstrom, personal communication 2004). Of the vascular plants, all are angiosperms, and no ferns are recorded in the extant vegetation. This is the strongest area of contrast with the fossil suite - the Cape Lockyer assemblage contains at least five fern taxa, and numerically, these are the dominant element. There is a contrast too in the bryophyte representation; the modern flora is rich in liverworts and mosses, but these are scant in the fossil assemblage.

Modern vegetation on Heard Island presents only a handful of plant communities: tussock grassland, herbaceous vegetation dominated by Rosaceae, brassicaceous and bryophyte species, pool complexes, feldmarks and the most abundant *Azorella* cushion carpet. Of these, only tussock grassland (or its precursor) could possibly be identified in the fossil record. The flowering plant suite differs significantly between the extant and the fossil floras. Only the grasses (and possibly the Caryophyllaceae) are held in common. Taxa which were prominent in the Late Miocene, such as Gunneraceae and the Asteraceae, are now extinct on Heard Island. The same applies to less common elements such as Malvaceae, Onagraceae, Cyperaceae and to the gymnosperms (Podocarpaceae).

Comparison with other southern hemisphere spore and pollen assemblages

Comparisons with assemblages described earlier from Iles Kerguelen and from former islands on Ninetyeast Ridge in the Indian Ocean are most relevant in discussing the Heard Island material. Not only are these sites geographically close, but they also reflect island floras, which were thus subject to similar conditions of isolation and climate. A comparison is also made with middle Cenozoic floras recently described from the Antarctic margin during drilling operations at Cape Roberts in the Ross Sea (Raine 1998, Askin & Raine 2000).

Iles Kerguelen

Microfloras were extracted and described by Cookson (1947) from lignites collected by the British, Australian and New Zealand Antarctic Research Expedition (BANZARE) in 1931/32, under the command of Sir Douglas Mawson

(1932). The lignites that furnished the microfloras described by Cookson came from a locality designated 'Waterfall Gorge', near Port Jeanne d'Arc. The coaly deposits are interbedded with extensive tholeiitic basalts; these were described as being of approximately Middle Miocene age (Nougier 1970), but a more recent evaluation of the age of the basalts (Nicolaysen *et al.* 2000) suggests that sequences in the vicinity of Port Jeanne d'Arc Peninsula have an age of around 25 Ma, shortly before the main period of basalt eruption ceased. While it has not been possible to obtain a precise link between the Waterfall Gorge section and the basalts sampled by Nicolaysen *et al.*, it seems likely that the 25 Ma age most closely applies to Cookson's material. This would make the spore and pollen assemblages of latest Oligocene age.

There are significant differences in the proportion of major plant groups between the Iles Kerguelen and Heard Island microfloras, but some similarities are apparent within groups, especially in the angiosperms. The key difference lies in the predominance of conifer pollen on Iles Kerguelen. Although she provided no percentage figures, Cookson (1947) described conifer pollen as the most conspicuous element in the Waterfall Gorge assemblages, outnumbering all other types. Pollen of Araucariaceae, resembling both *Agathis* and *Araucaria,* was abundant. Saccate pollen of Podocarpaceae (including trisaccate forms assigned to *Microcachryidites*) was also a prominent element. In contrast, no araucarian pollen was observed in the Cape Lockyer material. The podocarpaceous element of the flora at Iles Kerguelen was poorly diversified, and no trisaccate pollen observed.

The angiosperm component is one of both contrasts and similarities between the two sites. Cookson described only five angiosperm taxa: from Cape Lockyer there are at least ten. The species reported by Cookson, i.e. the grass pollen, pollen of Asteraceae, and the tricolpate Gunneraceae type, are all present as significant components of the Cape Lockyer suite. Fern spores are grossly similar between the two sites. *Trilites tuberculiformis*, probably representing Dicksoniaceae, was originally described from Iles Kerguelen, and is the dominant form at Cape Lockyer. However, another distinctive fern type, *Cyathidites annulatus,* originally described from Iles Kerguelen, and which has been shown to be of considerable biostratigraphic and phytogeographic interest in the southern hemisphere (Hill *et al.* 2001)**,** was not observed at Cape Lockyer.

Ninetyeast Ridge

In their earlier discussion of the palynology of the Heard Island sediments, Quilty *et al.* (1983) drew attention to an apparent close similarity between those microfloras and those described from Ninetyeast Ridge (Kemp & Harris 1977). Of the 24 species recorded from Cape Lockyer in the present study, 10 also occur on Ninetyeast Ridge. However,

gross differences between the spore and pollen assemblages appear to outweigh the similarities. In the first place, Ninetyeast Ridge floras are much more diverse, with some 37 taxa described from probable Paleocene sediments at Site 214, and 48 from Oligocene suites at Site 254. The other significant difference is that Ninetyeast Ridge floras display a much greater similarity with Tertiary assemblages from Australia and New Zealand, suggesting stronger phytogeographic pathways. The 'continental' components of Ninetyeast Ridge include a higher percentage of conifers, including Araucariaceae and Podocarpaceae, and significant representation of Proteaceae and Myrtaceae. Both of the sites on Ninetyeast Ridge are older than the estimated age of the Cape Lockyer material. The possible presence of mangrove (*Avicennia*) type pollen in Ninetyeast Ridge sediments suggests conditions may have been much warmer.

Antarctica

Assemblages of Miocene to Pliocene age are not confidently known from Antarctica, as most post-glacial sediments are beset by problems of reworking of microfossils. However, recent drilling at Cape Roberts, in the Victoria Land Basin in the Ross Sea, penetrated Oligocene through early Miocene sediments. In their description of terrestrial palynomorphs from these sites, Raine (1998) and Askin & Raine (2000) have argued that some of the sparse spore and pollen taxa may be in place, and reflect contemporaneous vegetation. The assemblages are dominated by *Nothofagus* pollen in some diversity, with pollen of Podocarpaceae also common, along with an important component of herb and moss taxa. The assemblages are considered to reflect a tundra vegetation rich in mosses and liverworts, with woody taxa growing in more favourable areas. It is thus essentially a continental vegetation, modified into a tundra formation, and differs considerably from the Cape Lockyer material. There are, however, common elements among the minor taxa. For example, a species described herein as ?*Coptospora* sp. may be synonymous with *Coptospora* sp. b of Raine (1998), and *Coptospora archangelskyi* Zamaloa 2004 which may have stratigraphic significance in the Cape Roberts sequences. Pollen resembling that of the extant New Zealand species *Phormium* occurs at both localities, as does pollen of Cyperaceae.

Summary and conclusions

The sedimentary facies of the Drygalski Formation exposed at Cape Lockyer is Late Miocene in age based on criteria of palynology and diatoms. The foraminifera recovered are consistent with this determination, which is, in turn consistent with the radiometrically-determined age for a basalt clast within the type section of the Drygalski Formation.

The flora of spores and pollen indicates that there existed a variety of habitats close to sea level.

The Late Miocene vegetation consisted of at least two distinct communities: a low, open association of grasses and Asteraceae, and a possibly taller fern-heath community dominated by Dicksoniaceae, other cryptogams and *Gunnera*. The former association is likely to have colonized drier, more exposed interfluve habitats whilst the latter is more typical of communities growing in wet gullies, lining the banks of streams (*Gunnera*) or growing on substrates within the channel. The closest extant community appears to be 'fern bush' which forms the understorey in the coastal vegetation of sub-Antarctic islands north of the APFZ and in Tierra del Fuego. However, since there is no unequivocal evidence for tree-sized species, the Late Miocene vegetation at Cape Lockyer has no known close modern analogue, and is more likely to have been a unique ecological response to contemporary climatic conditions in a maritime setting.

The diversity of vegetation and of environments suggests that Heard Island was north of the APFZ at the time and thus either (a) the area south of the APFZ was smaller, or (b) the configuration of the APFZ was significantly different from the present.

Further work is necessary on sediments of the Cape Lockyer section to document floral change with time, and on other volcanic and glacial facies within the Drygalski Formation to refine understanding of the age and environment of deposition of this enigmatic rock unit.

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APPENDIX

Taxonomy – notes on important taxa

Trilete spores

Genus *Trilites* Erdtman ex Couper emend. Dettmann, 1963
Trilites sp. cf. *T. tuberculiformis* Cookson, 1947

cf. 1947 *Trilites tuberculiformis* Cookson, p. 136, pl. xvi, figs 61, 62.

Fig. 3a, d–e

Remarks: This highly variable species probably falls within the morphological range of *T. tuberculiformis*, described by Cookson (1947) from Waterfall Gorge, Iles Kerguelen (see emended description provided by Dettmann 1963). All specimens have a rugulo-verrucate distal face: some show a pronounced valvate thickening. Most have elevated labra and rugulae on the proximal face, an aspect that may distinguish them from the Iles Kerguelen species.

Affinity: The relationship of the dispersed spores lies probably with the widespread tree fern family Dicksoniaceae. Some of the Heard Island forms show a strong resemblance to the spores extracted from the fossil frond *Dicksonia dissecta*, from Early Oligocene sediments in Tasmania (Jordan *et al.* 1996; see especially their pl. 1, figs 4–6). It should be noted, however, that these authors point out that the *in situ* spores may be related to a wide morphological complex of dispersed spores in Australian Mesozoic and Cenozoic sediments, including those assigned to the genera *Ischyosporites* and *Rugulatisporites*

At Cape Lockyer, this dispersed form dominates the assemblage, making up some 42% of the spectrum. This suggests a very local source.

Genus *Foveotriletes* van der Hammen ex Potonie, 1956
Foveotriletes sp. cf. *F. palaequetrus* Partridge, 1973

cf. 1973 *Foveotriletes palaequetrus* Partridge, in Stover & Partridge, p. 248, pl. 14, figs 4 & 5.

Fig. 5l

Remarks: This spore species is close to *F. palaequetrus*, reported by Partridge (Stover & Partridge 1973) from the Late Eocene–Early Miocene of the Gippsland Basin, southeastern Australia. It differs only in the less pronounced 'shoulders' shown in equatorial views of the grain. The species occurs in other Australian basins, including the Murray Basin (Macphail 1999). It is reported here particularly because it is known from another Indian Ocean locality, i.e. Ninetyeast Ridge, where it is present in Paleocene to Oligocene sediments (Kemp & Harris 1977).

Affinity: Lycopodiaceae; Kemp & Harris (1977) noted the similarity to spores of *Lycopodium fuegianum* Roivainen;

Macphail (1999) noted affinity to *Lycopodium australianum* type.

Genus *Retitriletes* Pierce emend. Doring, Krutzsch, Mai & Schulz in Krutzsch, 1963
Retitriletes sp. cf. *R. eminulus* Dettmann, 1963

cf. 1963 *Lycopodiumsporites eminulus* Dettmann, p. 45, pl. 7, figs 8–12
cf. 1975 *Retitriletes eminulus* (Dettmann) Srivastava, p. 58

Fig. 5i & j

Remarks: The specimens observed in the Cape Lockyer material have a smooth proximal face, and a distal reticulum of erect, narrow muri. The reticulum formed by the muri is finer than that in *R. (al. Lycopodiumsporites) eminulus* described by Dettmann (1963) from Australian Early Cretaceous sediments. It may be conspecific with forms recorded by Askin (2000) from erratics of probable Middle to Late Eocene age at McMurdo Sound, Antarctica.

Affinity: Lycopodiaceae.

Genus *Polypodiaceoisporites* Potonie, 1956
Polypodiaceoisporites sp.
Fig. 3b & c

Remarks: Robust trilete spores with a well-defined cingulum, some 5–6 μm wide, and pronounced distal sculpture, are here included within *Polypodiaceoisporites.* While there is some morphological variation shown among the observed specimens, all are characterized by a triangular arrangement of broad, flat muri about the distal pole. The muri enclose a polar area with a coarse reticulum; muri bounding this reticulate area are parallel to the spore margins, and join at the apices to form round-ended projections. In polar view these projections give a valvate appearance to the spores. On the proximal face, the laesurae are labrate, with bounding labra 2–3 μm wide; occasionally other sculptural elements, muri or verrucae occur on the proximal face.

The species differs from others reported from the southern hemisphere. *Polypodiaceoisporites tumulatus* Partridge, from the Miocene of the Gippsland Basin (Stover & Partridge 1973) has a distal face showing much finer sculpture; a comparable form was reported from Ninetyeast Ridge, Indian Ocean, by Kemp & Harris (1977).

Affinity: Probably with *Pteris* (Adiantaceae).

Hilate spores

Genus *Coptospora* Dettmann, 1973
?*Coptospora* sp.
Fig. 5n

Remarks: A single specimen tentatively assigned to

Coptospora was observed. It shows a surficial sculpture of shallow verrucae, and a smooth region that may or may not be an apertural feature. Although poorly preserved, the specimen is noted here because of its apparent similarity to specimens referred by Raine (1998) to his category *Coptospora* sp. b, from the Pleistocene part of the section penetrated in the Cape Roberts-1 drillhole in the Ross Sea, Antarctica. Similar forms were previously recorded by Truswell (1983) as recycled elements in Recent sediments in the Ross Sea. It has also been observed in ?Pleistocene glacial sediments at ODP Site 1166 in Prydz Bay, East Antarctica (Macphail & Truswell 2004). *Coptospora* sp. A of Dettmann (1963) from the Early Cretaceous of eastern Australia shows similar low verrucae, but is larger and thicker-walled. *Coptospora archangelskyi*, described by Zamaloa (2004) from the Early to Middle Miocene Cullen Formation of Tierra del Fuego is similar, but thicker-walled and sturdier in appearance.

Affinity: The affinity of this taxon is controversial. Raine (1998) suggested an affinity with the bryophyte *Conostomum*; Zamaloa (2004) concurred with this assignment. However, Macphail & Truswell (2004) suggested that a relationship with living fern taxa, such as Davalliaceae (*Davallia*) or Polypodiaceae (*Microsorium*) might be more likely.

Tricolpate pollen

Tricolpites reticulatus Cookson ex Couper, 1953
Fig. 4m–o

Selected synonymy
1947 *Tricolpites reticulatus* Cookson, p. 134, pl. 15, fig. 45.
1953 *Tricolpites reticulatus* Cookson ex Couper, p. 61.
1954 *Gunnerites reticulatus* (Cookson) Cookson & Pike, p. 201, pl. 1, fig. 19.
1960 *Tricolpites waiparaensis* Couper, p. 66, pl. 11, figs 13–15.
1965 *Tricolpites microreticulatus* Belsky, Boltenhagen & Potonie, p. 75, pl. 12, fig 8, 9.
1977 *Tricolpites reticulatus* Cookson. *In* Kemp & Harris, p. 30; pl. 5, figs 1 & 2.

Remarks: Jarzen (1980) included fossil pollen referable to *Tricolpites reticulatus*, which was described initially by Cookson (1947) from the probable Miocene of Iles Kerguelen, within his list (table 1) of fossils with positive affinity to *Gunnera* (Family Gunneraceae). SEM studies of the grain surface (Wanntorp *et al*. 2004) confirm the view of Jarzen & Dettmann (1989) that specimens from Iles Kerguelen show isodiametric to elongate lumina and are thus most similar to pollen of the extant Malaysian species *G. macrophylla*. Light microscopic examination of specimens from Heard Island suggests a similar exine pattern. The fossil record spans the early Late Cretaceous to the present, and includes a former distribution that encompassed western North America. While *T. reticulatus* has been well described from the Late Cretaceous (Campanian to Maastrichtian) of the Antarctic Peninsula (Jarzen & Dettmann 1989), it does not appear to have been found in Tertiary sequences of that continent.

In the Heard Island material, *T. reticulatus* is common, making up some 15% of the spore and pollen assemblage.

Affinity: Gunneraceae. This genus of rhizatomous herbs is distributed today in tropical to southern cool temperate to cool, superhumid environments.

Tricolporate pollen

Genus *Tubulifloridites* Cookson ex Potonie, 1960
Tubulifloridites sp. cf. *T. antipodica* Cookson ex Potonie, 1960
cf. 1947 *Tricolpites* (*Tubulifloridites*) *antipodica* Cookson, p. 134, pl. 15, fig. 44
cf. 1960 *Tubulifloridites antipodica* Cookson: Potonie, p. 106.

Fig. 4a–e

Remarks: All specimens observed in the Cape Lockyer material have been grouped, in comparison with the form species *T. antipodica*, described by Cookson (1947) from Waterfall Gorge on Iles Kerguelen. This is an expedient solution to the problems posed by inadequate description, in contemporary terms, of this and other species within the genus, and by the apparent overlap and intergradation of morphological features between described species. These problems were noted by Kemp & Harris (1977), who called for re-description of Cookson's original material, a call reiterated by Mildenhall & Pocknall (1989).

The Cape Lockyer specimens are all distinguished by a distinctly columellate sexine, with columellae clearly evident at the spine bases. They show a range of variation in the presentation of apertural structures; in most, the colpi are distinct; a few specimens show clearly developed ora. This last feature is more typical of *T. pleistocenicus* Martin, but other features suggest closer relationships with *T. antipodica*. These morphological overlaps highlight the difficulty of trying to correlate this material with previously described form taxa.

Pollen referable to *Tubulifloridites* makes up some 14% of the assemblage from Cape Lockyer. Frequencies as high as these are rare before the Pliocene in Australia (see Martin 1973, Kershaw *et al*. 1994).

Affinity: An affinity with modern Asteraceae is clear.

Triporate pollen

Genus *Corsinipollenites* Nakoman, 1965
Corsinipollenites sp. cf. *C. epiloboides* Krutzsch, 1968

cf. 1968 *Corsinipollenites* e*piloboides* Krutzsch, p. 778,

pl. 2, figs 6 & 7.

Fig. 4r & s

Remarks: Specimens observed in the Cape Lockyer material are tentatively compared with *C. epiloboides*. They are similar in basic structure, and in fine points of detail, such as the presence of viscin threads on one face of the grains; they differ in having pore structures that, while still prominent, are less protuberant than in described species. Pollen types assigned to *Corsinipollenites* have been reported from Australia (Foster 1982, Tulip *et al.* 1982, Macphail 1999) and New Zealand (Daghlian *et al.* 1984, Mildenhall & Pocknall 1989).

Affinity: Onagraceae, possibly with *Epilobium*.

Polyporate pollen

Malvacearumpollis mannanensis Wood, 1986

Fig. 5a–d

1985 *Malvacearumpollis* sp. Truswell *et al.* p. 286, fig. 8P-8R
1986 *Malvacearumpollis mannanensis* Wood, p. 6, fig. 9.1–9.4
1989 *Malvacearumpollis mannanensis* Wood, *in* Mildenhall & Pocknall, p. 59, pl. 19, 3–6

Remarks: This distinctive species conforms closely with the type material, described by Wood (1986, pl. 9, fig 1–4). A columellate layer that thickens perceptibly to form a basal cushion beneath the prominent spines distinguishes it. The species was described initially from the Late Oligocene to Early Miocene of Queensland. Further reports from Australia include a closely related form in the Murray Basin (Truswell *et al*. 1985, Macphail 1999), while Mildenhall & Pocknall (1989) reported its rare occurrence from the Early to Middle Miocene of New Zealand. It has not been reported from higher latitudes.

Affinity: Malvaceae or Euphorbiaceae.

Genu*s Periporopollenites* Pflug & Thomson *In* Thomson & Pflug, 1953
Periporopollenites spp.
Fig. 4g–j

Remarks: Specimens grouped under this broad taxonomic heading are all characterized by a polyporate configuration, with some 30–40 pores distributed across the grain surface. The sexine is reticulate, but dimensions of the reticulum are highly variable, hence it is considered that more than one species may be involved in this grouping. In some cases it is difficult to distinguish the pores from the surrounding reticulum; only their circularity and a defined sexinal rim allow them to be discerned. Exine stratification is not clear.

The forms are assigned to *Periporopollenites* on the basis of this morphology. Comparable morphotypes have been assigned to the genus *Polyporina* but the latter type is now considered to represent a freshwater alga. Specimens within the Heard Island group show some resemblance to *Polyporina reticulata* Martin 1973, described originally from the late Miocene–Pliocene of eastern Australia, but the sexine of the Heard Island forms is thinner, and columellae are less clearly discernible.

Affinity: Macphail (1999, pl. 5, fig. 13) figured *Polyporina reticulata* Martin, and suggested affinity with Caryophyllaceae, perhaps *Silene*. The Heard Island material may reflect a similar affinity. Pollen of other genera within Caryophyllaceae – e.g. *Colobanthus* and *Scleranthus* - show generally similar morphologies (Jordan & Macphail 2003).

Genus *Cyperaceaepollis* Krutzsch, 1970
Cyperaceaepollis neogenicus Krutzsch, 1970

1970 *Cyperaceaepollis neogenicus* Krutzsch, p. 66, pl. 7, fig 6–8.
1989 *Cyperaceaepollis neogenicus* Krutzsch, in Mildenhall & Pocknall, p. 58, pl. 18, figs 8 & 9.

Fig. 4f

Remarks: Grains referable to *Cyperaceaepollis* are rare in the Heard Island material, and generally not well preserved. They do, however, retain their distinctive apertural distribution, with one central pore and several elongate, usually gaping, apertures. Variation is common in these forms, and has been noted in abundant material from the New Zealand Miocene (Mildenhall & Pocknall 1989). Macphail (1999) reported *C. neogenicus* from Middle Eocene to Pleistocene sediments in the Murray Basin.

Affinity: Cyperaceae, the sedges.

Monoporate pollen

Genus *Graminidites* Cookson ex Potonie, 1960
Graminidites spp.
Fig. 4k & l

Remarks: Specimens grouped within this category probably fall within *Graminidites media* described by Cookson (1947) (as *Monoporites (Graminidites) media)* from Iles Kerguelen. While there is considerable variation evident, most observed specimens show some thickening about the pore margins, and a finely granulate sexine wall. Grains of this Poaceae type represent around 6% of the spore and pollen spectrum at Cape Lockyer.

Affinity: Poaceae.

Syncolpate pollen

Genus *Luminidites* Pocknall & Mildenhall 1984
Luminidites sp. cf. *L. phormioides* (Stover & Partridge) Pocknall & Mildenhall 1984

cf. 1982 *Liliacidites phormioides* Stover & Partridge, p. 80, pl. 3, figs 4 & 5.

Fig. 4q

Remarks: Trichotomosulcate pollen with a fine mesh reticulum are rare in the Cape Lockyer material. The species figured here is close to that referred to the extant genus *Phormium* sp. by Pocknall & Mildenhall (1984), from the Late Eocene to late Miocene coal measures of Southland, New Zealand. Most forms described from Australia and New Zealand are distinguished by having a coarser, often graduated, reticulum. For example, see Couper's (1960) *Phormium reticulatus* and *Liliacidites phormioides* of Stover & Partridge (1982). Macphail (1999) figured *L*. cf. *phormioides* from the Murray Basin, again with a coarser reticulum.

Affinity: The affinity could lie with *Phormium* (Agavaceae) or with Liliaciae.