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Late Triassic plant microfossils from Miers Bluff Formation of Livingston Island, South Shetland Islands, Antarctica

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Abstract: A moderately diverse assemblage of plant microfossils has been recovered from the Johnsons Dock Member of the Miers Bluff Formation, Livingston Island, including spores, pollen, acritarchs, wood fragments and cuticles. Containing a total of *c.* 45 of miospore taxa, the palynoflora is dominated by non-striate bisaccate pollen, but spores of pteridophytes and pollen of gymnosperms are proportionate in diversity. The palynoflora is similar in composition to those indicative of subzones C+D of the *Alisporites* Zone of Antarctica, and the upper *Craterisporites rotundus* Zone and the lower *Polycingulatisporites crenulatus* Zone of Australia as well as the upper *Polycingulatisporites crenulatus* Zone and *Foveosporites moretonensis* Zone of New Zealand, suggesting a Late Triassic (possibly Norian–Rhaetian) age. This determination is supported by the sporadic occurrence of *Aratrisporites* and *Classopollis* in the palynoflora as well as by the absence of striate bisaccate grains.

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Key words: Livingston Island, Miers Bluff Formation, palynofloras, plant microfossils, Late Triassic

Introduction

The plant microfossils considered here were recovered from the Miers Bluff Formation on Livingston Island, South Shetland Islands, West Antarctica. This formation and its assumed equivalents, such as the Trinity Peninsula Group (TPG) (the Hope Bay, Cape Legoupil and Paradise Harbour Formations) on Graham Land of the northern Antarctic Peninsula, and the Greywacke-Shale Formation (GSF) in the South Orkney Islands, have been usually regarded as "basement rocks" in these areas and interpreted as submarine fan deposits (Arche *et al.* 1992, Doktor *et al.* 1994, Smellie *et al.* 1995, Andreis *et al.* 1997). The successions are mainly composed of deformed and metamorphosed greywackes, mudstones/shales and sandstones, attaining a thickness of 1000–3000 m. Their geological ages generally have been poorly constrained, ranging from late Palaeozoic to early Mesozoic (Carboniferous–Permian, Permian–Triassic, Early Triassic or pre-Jurassic), because fossils in the turbidites are mostly sparse and too poorly preserved to be identified. Some plant remains have been found in the Miers Bluff Formation on Livingston Island, but their poor preservation has prevented precise identification; (Taylor & Taylor 1989, Arche *et al.* 1992) suggested a post-Carboniferous, possibly Mesozoic age. Grikurov & Dibner (1968) reported Early and Middle Carboniferous miospores from the Hope Bay Formation of the Trinity Group, but the spores were reasonably doubted by some authors to have resulted from laboratory contamination (Truswell 1991, Playford 1989). Later palynological investigation indicated that the Hope Bay Formation is devoid of sporomorphs (Birkenmajer 1992), but, a few marine fossils obtained from these and related formations in several localities have provided evidence for dating the rocks. For instance, poorly preserved bivalves, e.g. ?*Myalinella* sp., *Backevellia* (*Backvelloides*) aff. *hekiensis*, and *Neoschizodus halperni* have been found from the Cape Legoupil Formation at Cape Legoupil, northern Antarctic Peninsula and inferred to be Triassic in age (Thomson 1975). A few radiolarians and conodonts (*Neogondoella* sp.) recovered from the GSF indicate a Late Triassic age (Dalziel *et al.* 1981). This type of lithofacies also extends to Potranca Islands (45°28'S, 74°09'W), the Chonos Archipelago, southern Chile, i.e. the Potranca Formation of the Chonos Metamorphic Complex. The Potranca Formation had been dated as Late Silurian–Early Devonian, but bivalves represented by *Monotis* (*Entomonotis*) sp. aff. *M.* (*E.*) *subcircularis* Gabb and *Lima* sp. recently found from this formation indicate a Late Triassic (Norian) age (Fang *et al.* 1998). These scattered fossil data demonstrate that these sets of greywacke-shale/mudstone sequences were most likely contemporaneously deposited in Late Triassic times.

The low-grade metasedimentary sequences of the Miers Bluff Formation (MBF), that crop out on the Hurd Peninsula of Livingston Island (Fig. 1), consist of up to 3000 m of mainly greywackes, mudstones, sandstones and pebbly-mudstones. According to the nomenclature of Smellie *et al.* (1995), the formation is composed of, in ascending order, the Johnsons Dock Member (*c.* 1700 m) and the Napier Peak Member (< 1300 m), and the overlying Moores Peak breccias (> 200 m) which "may be part of the MBF or represent a younger, unrelated unit". Doktor *et al.* (1994) restricted the MBF to the lowermost 1600 m of turbidite rocks in the west of the Hurd Peninsula, but their re-definition was challenged by Willan *et al.* (in Tokarski *et al.* 1996). The MBF mudstones yielded an Rb–Sr errorchron age of 243 ± 8 Ma and were interpreted as probably deposited in Early Triassic times (Willan *et al.* 1994), although other isochron ages (204 ± 19 Ma or 221 ± 34 Ma) have been also reported (Pankhurst 1983, Hervé 1992, *vide* Willan *et al.* 1994).

Palynological investigations of Triassic and Jurassic sediments in Antarctica have been made mainly in the Transantarctic Mountains (e.g. Gair *et al.* 1965, Norris 1965, Helby & McElroy 1969, Kyle 1977, Tasch 1977, Askin 1981, Tasch & Lammons 1978, Farabee *et al.* 1989, Shang 1997, Truswell 1991). The results were often compared with those from other parts of Gondwana, particularly Australia. Kyle (1977) proposed an informal palynological zonation for the Permian–Triassic Victoria Group from southern Victoria Land, including an *Alisporites* Zone with four subzones (A–D) covering the whole Triassic (the uppermost Feather Conglomerate to Lashly Formation). Two phytogeographical provinces of Middle–Late Triassic age in southern Gondwana have been recognized by Australian palynologists and others subsequent to the identification of two distinct palynofloral types by Dolby & Balme (1976): the Ipswich type which appears to have occupied higher palaeolatitudes, and the Onslow type which was roughly latitudinally controlled, reflecting a cooler temperate climate (Zavattieri & Batten 1996). Attempts to recover microfossils from the MBF on Hurd Peninsula have been unsuccessful hitherto (e.g. Doktor *et al.* 1994). Thus, our discovery of plant microfossils in this formation is of some importance because it provides evidence for biostratigraphic correlation and hence for assisting in tectonic and stratigraphic interpretations of the south-western margin of Gondwana prior to the break-up of Gondwana in Early or early Middle Jurassic times.

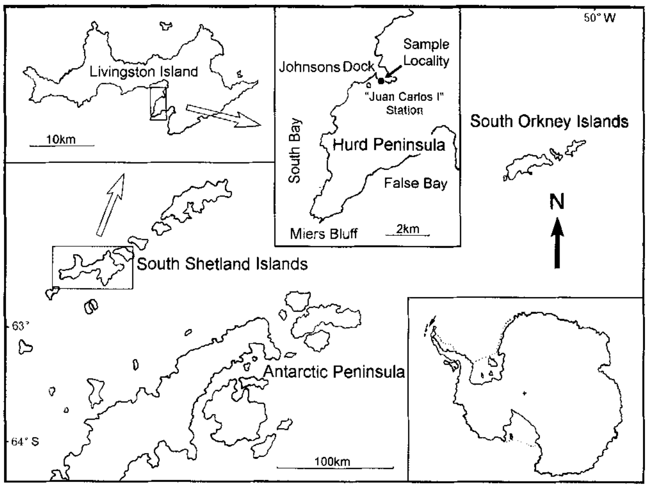


Fig. 1. Map showing sampling location.

Material and methods

More than 130 samples were collected mainly for lithological studies from the Miers Bluff Formation on the Hurd Peninsula, Livingston Island by two of the authors (Deng Xi-guang and Zheng Xiang-shen) in December 1997. Twelve of these, all are black mudstones, were selected for palynological processing. Their figure was redrawn here (Fig. 2) with the sampling horizons marked. Only one macerated sample (A97D002) is derived from another locality about 250 m of southern Johnsons Dock section.

Conventional palynological methods were used: That the samples (each 20–30 g) were digested in HC (38%) and HF (38%) and the organic residues oxidized using HNO_3 followed by treatment with alkali ($KClO_3$).

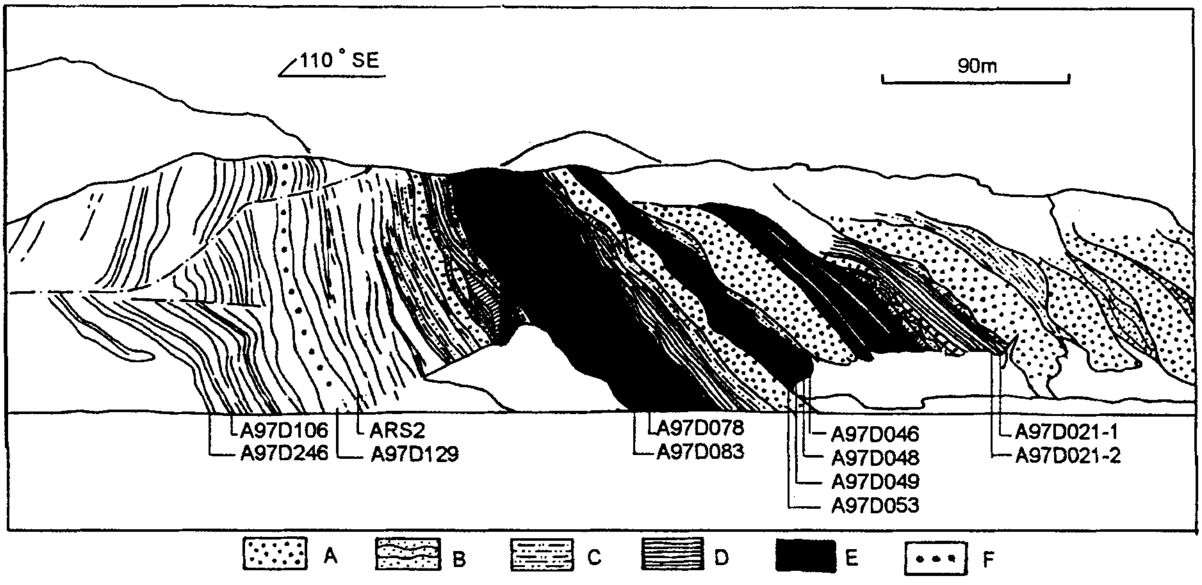


Fig. 2. Map showing sampling horizons in the stratigraphical section (modified from Doktor *et al.* 1994, fig. 51). A = thick sandstone, B = stratified siltstone, C = sandy mudstone, D = rhythmical sandy mudstone, E = dark mudstone, F = pebbly mudstone.

All the macerated samples but one (A97D002) yielded poorly preserved plant microfossils. These however, are comparatively diverse only in sample D021-2, and for this sample 200 specimens were counted.

Composition of the palynoflora, and identification remarks for some taxa

The plant microfossils found include moderately diverse, although generally poorly preserved spores, pollen, and a few acritarchs in association with various wood fragments (tracheids) and several cuticle remains. The preservation state of the palynomorphs makes exact species identification impossible in most cases. Some 45 taxa have been recognized; most are illustrated on Figs 3–5. [Explanation of Figs 3–5. All figures x600 unless otherwise indicated. Specimens are curated at Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences. The sample number is followed, in brackets, by the slide number and then the coordinates.] The palynoflora is composed of the following taxa:

Spores (18 spp./17 genera): *Leiotriletes*? sp., *Deltoidospora directa*, *Punctatisporites* sp., *Dictyophyllidites harrissi*, *Granulatisporites* cf. *G. minor*, *Converrucosisporites* sp., *Uvaesporites verrucosus*, *Osmundacidites* cf. *O. parvus*, *Lophotriletes* cf. *L. novicus*, *Acanthotriletes* sp., *Apiculatasporites* sp., *Nevesisporites* sp., *Duplexisporites*? sp., *Densosporites*? sp., *Cingulatisporites*? sp., *Kraeuselisporites* sp., *Kraeuselisporites*? sp., *Aratrisporites* sp..

Pollen (22 spp. /15 genera): *Minutosaccus*? sp., *Vitreisporites subtilis*, *V. pallidus*, *V. microsaccus*, *Pityosporites* sp., *Accinctisporites*? sp., *Densipollenites*? sp., *Vesicaspora*? sp., *Alisporites* cf. *A. australis*, *A.* sp., *Pteruchipollenites* cf. *P. parvus*, *P.* sp., *Platysaccus queenslandi*, *Platysaccus* sp., *Platysaccus*? sp., *Podosporites* sp., *Araucariacites australis*, *Cycadopites* sp. a, *Cycadopites* sp. b, *Exesipollenites*? sp., *Classopollis* cf. *meyiana*, *Classopollis*? sp..

Acritarchs (5 spp./5 genera): *Leiosphaeridia* sp., *Micrhystridium* sp., *Schizosporis*? sp., two forms unidentified

Cuticles: Type A of possibly Bennettitales, Type B of unknown affinity

Wood fragments (tracheids): Araucaroid type-Form 1-4; Abietoid type-Form 1-3; Abietoid–araucarioid transitional type-Form 1-2; Tracheid with spiral thickenings-Form 1-2; Tracheid of gymnosperm unknown affiliation; Tracheid with scalariform thickenings of unknown affiliation.

It is impossible to present here a formal description and comparison of the microfossil taxa due to limited space. Brief comparative notes on some important taxa follow.

1. *Dictyophyllidites harrisii* Couper, 1958 (Fig. 3.3; 35 µm): *D. harrisii* is similar to *D. mortoni* (De Jersey) but shows thinner exine thickenings about the laesurae. The present specimen with a thin (1.5–3.0 µm broad) kyrtome thus stands closer to the former (for discussion see Playford & Dettmann 1965, p. 132; De Jersey & Hamilton 1967, p. 5, pl. 1, fig. 12). Both species are known from the Triassic and Jurassic.

2. *Converrucosisporites* sp. (Fig. 3.8a, 3.8b; 48 µm): The specimen is somewhat similar to *C. cameroni* (De Jersey) Playford & Dettmann 1965 recorded mainly from the Triassic in Australia (Playford & Dettmann 1965, pl. 12, figs 11–13; De Jersey 1970a, pl. 1, fig. 7; Playford *et al.* 1982, pl. 8, fig. 14), but differs from the latter in having smaller sculpture elements (coni, verrucae, short bacula).

3. *Uvaesporites verrucosus* (De Jersey) Helby in De Jersey 1971 (Fig. 3.13a, 3.13b; 25 µm): Among those specific synonyms assigned to this species (De Jersey 1971, p. 6–7), the present specimen stands closest to those described and illustrated from the Bundamba Group (Aberdare Conglomerate and Raceview Formation) of Queensland (De Jersey 1970b, p. 18, pl. 6, figs 4–7) in spite of the fact that the species ranges from Middle Triassic (Moolayember Formation) to Middle Jurassic (Hutton Sandstone) in Australia (De Jersey & Hamilton 1967) or throughout the whole Triassic in Antarctica (Kyle 1977).

4. *Osmundacidites* cf. *O. parvus* De Jersey, 1962 (Fig. 3.11, 3.12, 3.16; 32–33 µm): The specimens characterized by a mixed sculpture of small coni and grana and a trilete with labra are comparable to *O. parvus* De Jersey, 1962 (p.4, pl. 1, figs. 11 & 12) from the Ipswich coals, the latter (28–39 µm), however, differs in having "granular–papillate" sculpture and in the absence of well-developed labra about the laesurae although De Jersey mentioned that in the Ipswich specimens " the laesurae are somewhat more distinct" than in *O. wellmanii* Couper. *Osmundacidites wellmanii* is larger (40–63 µm).

5. *Lophotriletes* cf. *L. novicus* Singh, 1964 (Fig. 3.10, 27 µm): The specimen is more or less comparable to *L. novicus* Singh (1964, p. 247, pl. 44, figs 24–25; Foster 1979, p. 37, pl. 5, figs 1–5) from the Permian, especially that recorded from the Esk Beds of Middle Triassic age (De Jersey 1972, p. 6, pl. I, fig. 9), and it is also similar to *L. rectus* Bharadwaj & Salujha (see Mandal & Maithy 1981, pl.2, fig. 4) from the Upper Permian of India. *Lophotriletes bauhinae* De Jersey & Hamilton, 1967 differs in having larger size (35–60 µm, 40 µm on average; see Playford *et al.* 1982, p. 10–13).

6. *Nevesisporites* sp. (Fig. 3.9; 30.5 µm): In general morphology, the spore is similar to *Limatulasporites limatulus* (Playford) Helby & Foster 1979 (in Foster 1979) (e.g. De Jersey 1970a, pl. 2, fig. 2), a species widely known from Triassic, however, due to the absence of a distal crassitude, it is more appropriate to assign it to *Nevesisporites*.

7. *Duplexisporites*? sp. (Fig. 3.15; 55 µm): A cinguilum and 4–5 distal parallel ribs are discernible though the spore has been strongly degraded. It is somewhat similar to *Contignisporites cooksoniae* (Balme) Dettmann as recorded

from the Eagle Mills Formation (Carnian), east-central Texas (Traverse 1988, p. 215, fig. 11-2, j), the latter being about 50 µm in size. But typically this species has more widely spaced muri and clear proximal sculpture (Reiser & Williams 1969, p. 12) which can not be judged from our specimen due to poor preservation. The broad muri, and failure of the muri to join the equatorial cingulum, plus the union of muri (upper right in figure) seem to point to *Duplexisporites* (*Asseretospora*) (Ian Raine, personal communication 1999). The specimen is comparable to *Duplexisporites problematicus* (Couper) Playford & Dettmann (e.g. De Jersey 1971, p. 8, pl. 2, fig. 3; De Jersey 1972, pl. 3, fig. 1), ranging from Middle Triassic to Early Jurassic (Filatoff 1975), but the latter differs in having distal muri with a tendency of spiral arrangement.

8. *Cingulatisporites*? sp. (Fig. 4.4; 38 µm): The specimen is questionably assigned to *Cingulatisporites* (Thompson) Potonié because it is somewhat similar to *C. pallidus* De Jersey, 1962 (p. 6, pl. 2, fig. 5) from the Ipswich coals in having a thin and broad cingulum (or zona?), a labrate trilete mark and small size, but differs from the latter in the absence of body ornamentation (an indistinct and incomplete distal reticulum).

9. *Aratrisporites* sp. (Fig. 3.18; 35 x 21 µm): Only one specimen has been observed but its generic assignment is beyond question. In spore size, exine ornamentation, it seems to be closer to *A. wollariensis* Helby, 1967 (e.g. De Jersey 1970a, p. 11, pl. 4, figs 8–10, 12, 13) from the Lower–Middle Triassic of Australia but its poor preservation prevented an accurate specific identification.

10. *Vitreisporites subtilis* (De Jersey) De Jersey, 1962 (Fig. 4.9; 41 x 22 µm): This pollen grain is undoubtedly conspecific with *V. subtilis* recorded from the Triassic and Jurassic of Queensland by De Jersey (1962, p. 11, pl. 4, figs 8 & 9; De Jersey 1970b, pl. 5, fig. 7) because it shows all the features of the latter (22–48 µm in overall breadth). As De Jersey mentioned, *V. subtilis* differs from *V. contectus* (De Jersey) in having sacci with lesser overlap on the corpus and "from *V. signatus* Leschik by the lack of marked saccus ornament and of a short trilete tetrad-scar observed in some of the European specimens".

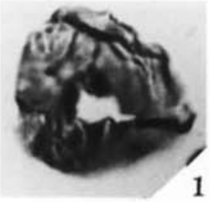
11. *Vitreisporites pallidus* (Reissinger) Nilsson, 1958 (Fig. 4.12; 33 x 16 µm, side view): The present specimen differs from *V. subtilis* noted above in having smaller corpus, however, as suggested by De Jersey (*in* Playford & Dettmann 1965), *V. subtilis* "may well be conspecific with *V. pallidus*". *Vitreisporites pallidus* has been widely reported from the Upper Permian and Mesozoic in both Southern and Northern hemispheres.

12. *Alisporites* cf. *A. australis* De Jersey (Fig. 4.1; 62.5 x 45 µm): This pollen grain characterized by a very narrow distal sulcus and a vertically spindle-shaped corpus is quite similar to *A. australis* De Jersey, 1962 (p. 8, pl. 3, fig. 3; 68 µm) and an "indeterminate monosaccate pollen" (De Jersey 1962, pl. 3, fig. 6; *c.* 90 µm) from the Ipswich coals, but shows more inflated sacci than *A. australis*. It is also comparable to *A. gottesfeldii* of Traverse (1988, p. 216, fig. 11-2, x; *c.* 62.5 x 50 µm) from the Middle–Late Triassic Chinle Formation, Arizona of the American south-west.

13. *Platysaccus queenslandi* De Jersey 1962 (Fig. 4.2; 52 x 35 µm): Compared with the holotype of *P. queenslandi* (De Jersey 1962, p. 10, pl. 4, fig. 5; 88 µm), the present specimen has smaller size and less inflated sacci, but it is quite similar to that identified by Playford *et al.* (1982, pl. 12, fig. 7; *c.* 60 µm) from the Middle Triassic Moolayember Formation, Queensland.

14. *Classopollis* cf. *meyeriana* (Klaus) De Jersey, 1973 (Fig. 3.27, 3.28; 30 µm and 32.5µm): The specimens are characterized by a narrow equatorial girdle and a subequatorial rimula, and on one specimen (Fig. 3.27) a triangular opening is observable. These psilate pollen are similar to *Classopollis meyeriana* (Klaus) De Jersey 1973 (pl. 4, figs 4 & 5) as suggested by Askin & Raine (personal communication 1999), but the latter appears to have a broader distance between the rimula and amb. They are also comparable to *Praecirculina* Klaus, 1960 (see Jansonius & Hills 1976, Card 2138) with type species *P. granifer* (Les.) Klaus of Carnian–Norian age, but differ from the latter in the absence of exine ornamentation.

Fig. 3. (see opposite) **1.** *Leiotriletes*? sp., A97D129 (1), 41.5/99.0; **2.** *Deltoidospora directa* (Balme & Hennelly) Norris, 1965, ARS2 (5), 36.0/101.5, x1000; **3.** *Dictyophyllidites harrisii* Couper, 1958, A97D021-2 (17), 31.0/100.0; **4.** *Punctatisporites* sp., D002 (2), 43.5/106.8, x700; **5, 6.** *Granulatisporites* sp. cf. *G. minor* De Jersey, 1959, **5.** A97D021-2 (27), 45.4/104.7, **6.** A97D021-2 (20), 32.0/97.0; **7.** *Acanthotriletes* sp., A97D021-2 (28), 38.0/99.5; **8a–b.** *Converrucosisporites* sp., A97D078 (9), 29.2/105.8; **9.** *Nevesisporites* sp., ARS2 (2), 35.0/111.0, x1000; **10.** *Lophotriletes* sp. cf. *L. novicus* Singh, 1964, A97D021-2 (17), 32.0/104.0, x1000; **11, 12, 16**. *Osmundacidites* sp. cf. *O. parvus* De Jersey, 1962, **11.** A97D021-2 (17), 31.5/99.0; **12.** A97D021-2 (30), 40.1/108.0; **16.** A97D129 (8), 35.5/100.0; **13a–b.** *Uvaesporites verrucosus* (De Jersey) Helby in De Jersey 1971, A97D021-2 (32), 31.3/101.8, x1000; **14, 19.** *Kraeuselisporites* sp., **14.** A97D021-2 (30), 42.0/101.0; **19.** A97D021-2 (19), 40.8/106.5, x1000; **15.** *Duplexisporites*? sp., A97D129 (12), 46.5/104.9; **17.** *Densosporites*? sp., A97D078 (1), 40.0/103.0, x1000; **18.** *Aratrisporites* sp., A97D021-2 (19), 44.8/106.5, x1000; **20.** *Araucariacites australis* Cookson, A97D078(3), 36.8/106.8, X500; **21.** *Kraeuselisporites*? sp., A97D021-2 (19), 39.2/110.1; **22–24.** *Classopollis*? sp., **22.** A97D129 (13), 39.6/100.0; **23.** A97D021-2 (28), 41.0/107.0, x1000; **24.** A97D129 (4), 41.5/ 106.1, showing a degraded tetrad of *Classopollis*? sp., the rimula (upper) is discernible; **25, 26.** *Cycadopites* sp. a, **25.** A97D021-2 (6), 31.0/102.0; **26.** A97D021-2 (12), 39.3/103.0; **27, 28.** *Classopollis* cf. *C. meyeriana* (Klaus) De Jersey, x1000. **27.** ARS2 (3), 29.8/100.0; **28.** ARS2 (5), 41.0/105.0; **29.** Rimulate, unidentified, A97D129 (9), 36.0/104.5; **30.** *Cycadopites* sp. b, A97D021-2 (27), 42.0/110.0; **31.** Rimulate(?), unidentified, A97D078 (1), 34.0/107.0, x1000.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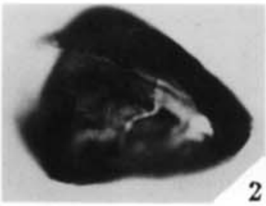
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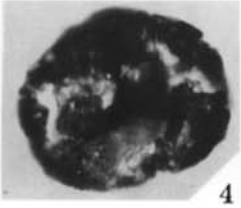
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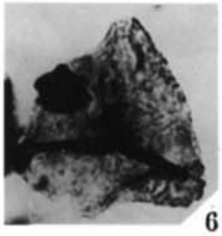
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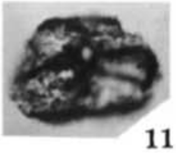
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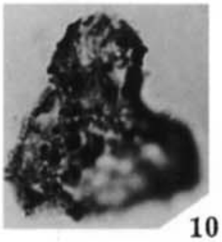
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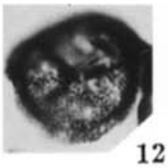
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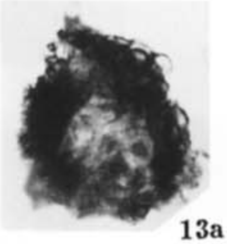
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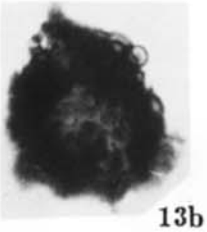
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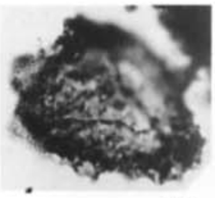
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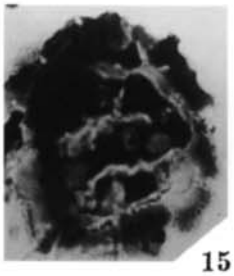
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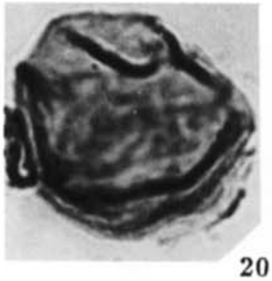
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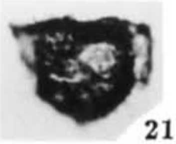
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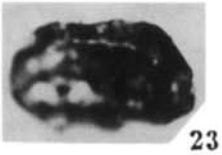
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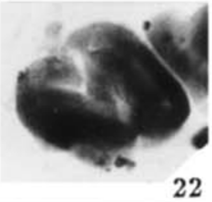
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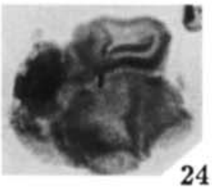
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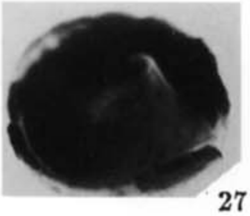
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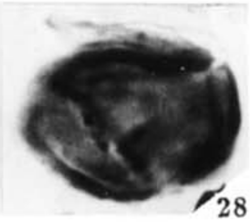
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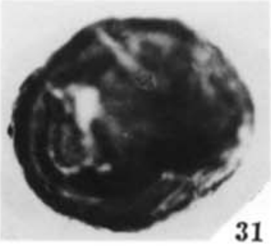
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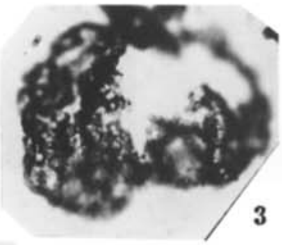
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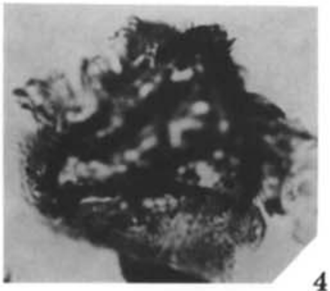
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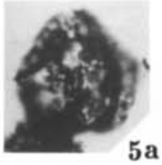
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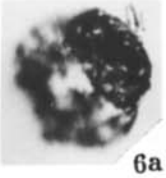
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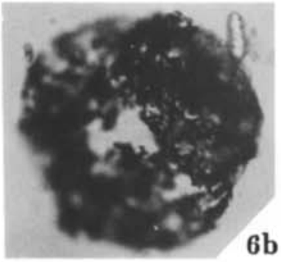
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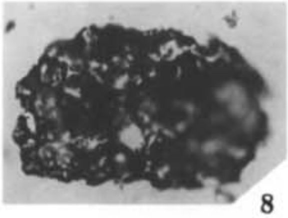
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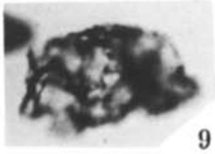
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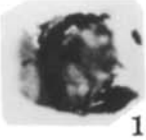
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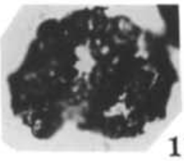
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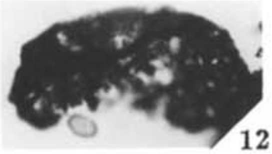
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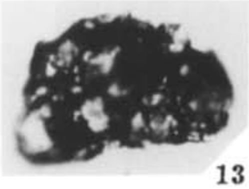
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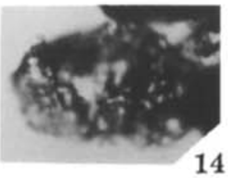
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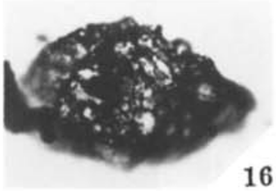
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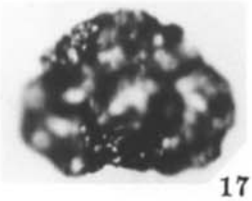
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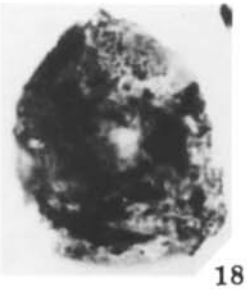
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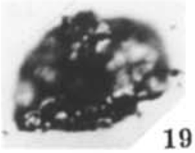
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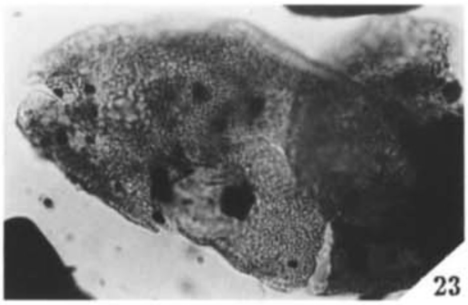
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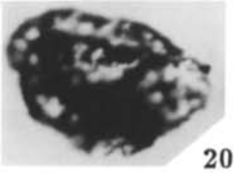
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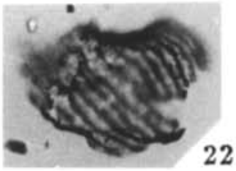
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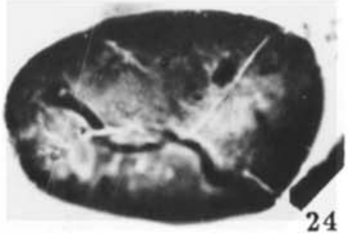
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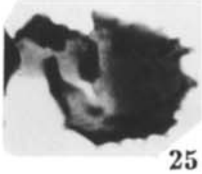
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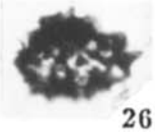
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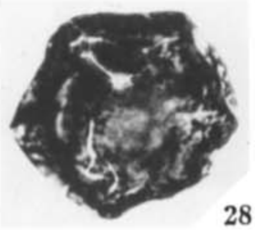
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Rimulate (?) grains are also shown on Fig. 3.29 and 3.31 (60 µm and 33 µm).

15. *Classopollis*? sp. (Fig. 3.22, 40 µm; Fig. 3.23, 26 µm; Fig. 3.24, a tetrad, 42 µm): Only a few grains of this type are present in the MBF assemblage. These pollen have been carbonized or degraded after oxidation, however, the thick equatorial band and subequatorial rimula are clearly shown, and the size as well as the general appearance quite resemble *Classopollis* although the identification is made with reservation.

16. Acritarchs: In addition to several specimens of psilate acritarchs, a few spinose acritarchs have been observed. One type (Fig. 4.26, *c*.20 µm) may be identified as *Micrhystridium* sp. The other (Fig. 4.25, 32 µm) possibly with a tetragonal opening is hard to identify and tentatively ascribed to Acanthomorphic acritarch.

17. Cuticles. Mainly two types of fragmentary cuticles are present in the slides. One is represented by several specimens (Type A: Fig. 5.18, 5.19): This type of cuticle is of some significance because it shows sinuous anticline walls. Sinuous cell walls in Mesozoic plants are almost an exclusively diagnostic feature of bennettitalean cuticles (Meyen 1987). The other (Type B: Fig. 5.17) is rather common, in lacking stomata etc., its cuticle nature and affinity (alga?, higher plant?, even insect?) is difficult to ascertain.

18. Wood fragments (tracheids) (Fig. 5.1–5.16). Various but isolated and incomplete tracheids have been observed in the slides. These are recorded and illustrated here for reference in future palaeobotanical study. Tracheid morphology is an important character both in living and fossil xylotomical studies. However, without evidence of other essential characters, such as primary and secondary xylem, early or late wood, pith, rays, resin canals, parenchyma and pitting in cross-fields etc. as conventionally shown in the three-plane sections (radial, tangential and transverse) (Greguss 1955), tracheids alone are of little use for identifying unknown plants, let alone isolated dispersed and fossil tracheids (Sah & Jain 1964). Many fossil wood genera for Paleozoic and Mesozoic have been proposed under comparative or artificial nomenclature systems, but they can hardly be applied to the present material, even though in a few cases their applications appear feasible, for example, *Araucarioxylon* sp. (Fig. 5.3) and *Xenoxylon*? sp. (Fig. 5.7, 5.12, 5.13). For this reason, the present tracheids are artificially differentiated into several types without using form-genera. The main ones include "araucaroid-type" with contiguous, alternate and typically hexagonal pits (e.g. Fig. 5.3, 5.2), "abietoid-type" with discontinuous, uniseriate or opposite and circular or oval pits (Fig. 5.9, 5.10 with Sanio's bar), and a few are transitional between these two types (Fig. 5.1, 5.16), each containing two or more forms. One type with scalariform thickenings (Fig. 5.14) was possibly derived from cycads or pteridophytes (Greguss 1966), but is uncertain from what group of Gymnospermae the other with spiral thickenings (Fig. 5.4, 5.8) derived.

Due to characters shared by all samples, such as the absence of bisaccate Striatiti and the presence of similar kinds of tracheids, also because of the poverty of the overall recovery, the spores, pollen, and acritarchs are treated as a single palynological assemblage. In the assemblage spores and pollen are proportionate in specific diversity, but quantitatively non-striate bisaccate pollen occupy a dominant position (*c*. 60% as roughly counted in the sample D021-2), and the latter point is somewhat comparable to the *Alisporites* Zone of Kyle (1977) from the Triassic of southern Victoria Land which "is characterized by abundant non-striate bisaccate pollen of the genus *Alisporites*" and the Late Triassic Timber Peak assemblage of northern Victoria Land in which the "unidentified bisaccate grains" account for 72.3% (Norris 1965). Except for a few grains of *Platysaccus* (Fig. 4.2), *Pteruchiopollenies* (Fig. 4.23) and *Alisporites* cf. *A. australis* (Fig. 4.1), most of the bisaccates are rather small in size (30–52 µm, generally 40 µm) and assigned to *Vitreisporites* (Fig. 4.9, 4.10, 4.12, 4.14) and partly *Alisporites* (Fig. 4.11) as well as *Pteruchipollenites* cf. *P. parvus* (Fig. 4.16).

According to our present knowledge of *in situ* spores (Potonié 1962, Traverse 1988, Balme 1995), the terrestrial parent flora might have been composed of various pteridophytes and gymnosperms, including pteridosperms,

Fig. 4. (see opposite) **1.** *Alisporites* sp. cf. *A. australis* De Jersey, 1962, A97D107 (1), 36.2/105.8; **2.** *Platysaccus queenslandi* De Jersey, 1962, A97D021-2 (21), 41.0/102.5; **3.** *Platysaccus* sp., A97D021-2 (32), 30.3/103.2; **4.** *Cingulatisporites*? sp., A97D021-1 (1), 33.0/108.0, x1000; **5a–b, 6a–b.** *Podosporites* sp. 5b, 6b, x1000. **5a–b.** A97D021-2 (7), 45.0/99.2; **6a–b.** A97D021 2 (12)35.0/95.2; **7.** *Platysaccus* sp., ARS2 (5), 33.2/103.0; **8.** *Vesicaspora*? sp., A97D021-2 (17), 33.6/104.3, x700; **9.** *Vitreisporites subtilis* (De Jersey) De Jersey, 1962, A97D021-2 (19), 43.0/108.6; **10.** *Vitreisporites microsaccus* De Jersey, 1964, A97D021-2 (8), 44.0/100.0; **11.** *Alisporites* sp., A97D021-2 (16), 38.0/99.0; **12.** *Vitreisporites pallidus* (Reiss.) Nilsson, 1958, A97D021-2 (2), 31.4/102.4, x1000; **13.** *Pityosporites* sp., A97D021-2 (9), 33.0/96.0; **14.** *Vitreisporites* sp. cf. *V. pallidus* (Reiss.) Nilsson, 1958, A97D021-2 (6), 38.0/107.0; **15, 16.** *Pteruchipollenites* sp. cf. *P. parvus* (De Jersey) Foster, 1975, A97D021-2 (11), 44.0/109.0; 15. x550; **17, 20.** *Accinctisporites*? sp., **17.** A97D021-2 (32), 36.0/96.0, x550; **20.** A97D021-2 (3), 30.5/101.5; **18.** *Exesipollenites*? sp., A97D021-2 (17), 45.0/108; **19.** *Densipollenites*? sp., A97D02102 (2), 43.0/97.5; **21.** *Minutosaccus*? sp. A97D021-2 (19),37.0/106.8, x1000; **22.** Fragment of a microfossil unidentified, ARS2 (2), 39.0/106.0; **23.** *Pteruchipollenites* sp., A97D078 (4), 34.0/99.5; **24.** *Leiosphaeridia* sp., A97D246 (1), 43.5/102.0; **25.** Acanthomorphic acritarch unidentified, A97D021-2 (19), 30.0/104.0; **26.** *Micrhystridium* sp., D002 (5), 31.0/102.8, x800; **27.** *Schizosporis*? sp., A97D021-1 (4), 27.0/100.0; **28.** An acritarch unidentified, A97D129 (9), 40.5/95.8.

conifers, ginkgoaleans, cycadaleans and possibly bennettitaleans. Tracheids in the assemblage are dominated by araucaroid- and abietoid-types, possibly mainly derived from pteridosperms and conifers (Greguss 1955, 1966, Pant & Singh 1987, Jefferson *et al.* 1983a, 1983b).

The MBF assemblage shows little similarity with those from the Triassic of Carnarvon Basin, Western Australia (Dolby & Balme 1976). Almost all taxa found from the latter have not been recovered from the MBF, including those zonal indices. Combined with the comparison discussed below, it is obvious that the MBF assemblage is essentially of the Ipswich-type.

Correlation and discussion

Bisaccate striate pollen

The absence of bisaccate Striatiti in the present assemblage deserves special attention. In Australia, these kinds of pollen first appeared in the earliest Permian (Playford 1989), and as in other continents of Gondwana (Playford 1989), reached their development acme in Middle–Late Permian and in general gradually decreased in species diversity and abundance in the Early–Middle Triassic (Foster 1979) and dramatically declined or disappeared in the Late Triassic (Playford & Dettmann 1965, Norris 1965, De Jersey & Hamilton 1967, De Jersey 1962, 1970a, 1972, 1979). On the other hand, they generally have not been recorded in the Jurassic assemblages of Australia (e.g. Playford & Dettmann 1965, Reiser & Williams 1969, McKellar 1974, Filatoff 1975). In short, the absence of the Striatiti in the present assemblage suggests an age not older than Late Triassic.

Aratrisporites

One single specimen of definite *Aratrisporites* sp. has been observed in the assemblage. Although sporadically earlier (e.g. the Early Permian Qipan Formation in Tarim Basin of China, Wang 1985) or later (e.g. the Early Jurassic strata in New Zealand, Zhang & Grant-Mackie 1997; the Early Jurassic Beipiao Formation in Liaoning of NE China, Wu & Zhang 1983; the lower Hettangian of NW Europe, Batten & Koppelhus 1996) records have been known in both hemispheres, this genus has been generally taken as an important marker of Triassic. In Antarctica, Kyle (1977) mentioned that *Aratrisporites* is "common to dominant in the older part but infrequent in the younger samples" of her *Alisporites* Zone, although in the Shackleton Glacier area they are abundant in the Middle and Late Triassic (Askin, personal communication 1999). This seems to be in favour of dating the MBF as Late Triassic.

Classopollis

In the present assemblage occur a few grains of *Classopollis*. *Classopollis* is one of the most important components of the latest Triassic–Middle Cretaceous palynofloras of the world. In the Northern Hemisphere, its first appearance was taken as at the base of the Norian (De Jersey 1970b, Warrington 1996). In Australia, it is first occasionally encountered in Rhaetian deposits (Aberdare Conglomerate; De Jersey 1971, 1973) of the Bundamba Group and became dominant in the Lower Jurassic, such as in the Precipice Sandstone and lower Evergreen Formation in Queensland (Reiser & Williams 1969, McKellar 1974), the upper part of the Leigh Creek Measures in southern Australia (Playford & Dettmann 1965) and the Cockleshell Gully Formation in the Perth Basin of Western Australia (Filatoff 1975). In New Zealand, *Classopollis* first appears in the upper part (Rhaetian) of the Otapirian Stage and becomes locally abundant in the Hettangian sediments (De Jersey & Raine 1990, Zhang & Grant-Mackie 1997). Zavattieri & Batten (1996) mentioned that "......it (*Classopollis*) does not become frequent in Argentinean successions until the Jurassic". In the assemblages from the Ferrar Group at Section Peak of the Rennick Glacier region and at Carapace Nunatak of Transantarctic Mountains, both of Early Jurassic age (Norris 1965, Tasch & Lammons 1978), *Classopollis* is an overwhelmingly dominant genus. It is believed that the MBF assemblage should be older than the Ferrar Group but can not be older than Norian and is possibly Norian–Rhaetian in age.

Regional correlation

Compared with those of the MBF assemblage, occurrences of some identical or comparable taxa from the Triassic, especially Upper Triassic in Antarctica, Australia and New Zealand are listed in Table I.

Fig. 5. (see opposite) **1.** Form 1 of abietoid- araucaroid transitional type, A97D129(8), 40.0/96.5, 142 x 38µm; **2.** Form 1 of araucaroid type. ARS2 (2), 28.2/101.5; 87 x 24µm; **3.** Form 2 of araucaroid type. ARS2 (1), 32.5/104.1, 95 X 38 µm; **4.** Tracheid with spiral thickenings- Form 1. A97D078 (8), 41.0/97.0, 32 x 21 µm; **5.** Form 3 of araucaroid type. A97D129 (9), 39.2/108.7, 120 x 48µm; **6.** Form 4 of araucaroid type. A97D129 (7), 33.0/102.0, 97 x 42 µm; **7, 12, 13.** Form 3 of abietoid type, **7.** A97D021-1 (2), 39.0/108.7, 74 x 35 µm; **12.** ARS2 (2), 30.0/103.0, 38 x 46 µm; **13.** A97D021-2 (27), 36.0/98.0; 76 x 47 µm; **8.** Tracheid with spiral thickenings-Form 2, A97D021-2 (18), 31.0/100.0, 57.5 x 24 µm; **9, 10.** Form 1 of abietoid type, **9.** A97D021-2 (28), 31.2/106.0, 120 x 57 µm; **10.** A97D021-2 (24), 37.0/96.5, 90 x 39 µm; **11.** Form 1 of gymnosperm unknown affiliation, A97D129 (14), 43.6/101.1, 82 x 55 µm; **14.** Tracheid with scalariform thickenings, A97D021-2 (30), 40.0/104.8, 110 x 83 µm; **15.** Form 2 of abietoid type, A97D021-2 (27), 39.1/108.0, 62 x 25 µm; **16.** Form 2 of abietoid -araucaroid transitional type, A97D246 (1), 33.0/109.0, 96 x 12.5 µm; **17.** Cuticle Form B of unknown affinity, A97D021-2 (32), 33.0/104.8, 178 x 135 µm (partly shown); **18, 19.** Cuticle Form A of possibly Bennettitales, **18.** A97D078 (6), 43.0/108, 75 x 70 µm; **19.** A97D078 (7), 39.8/103.8, 80 x 54 µm.


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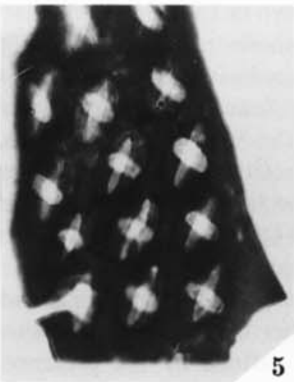
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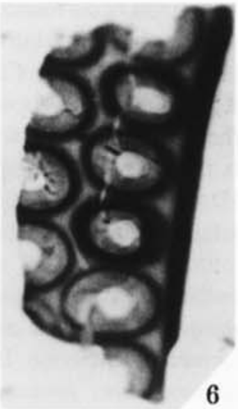
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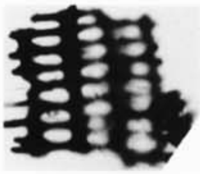
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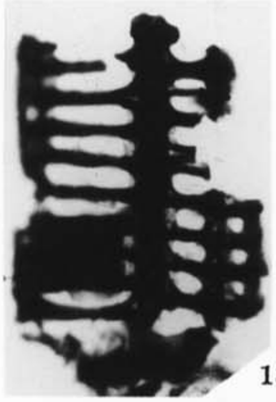
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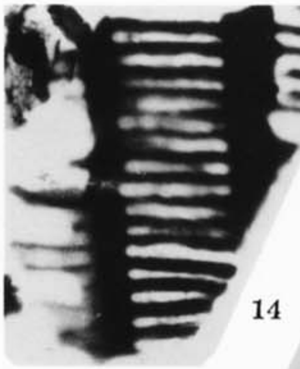
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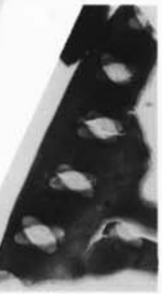
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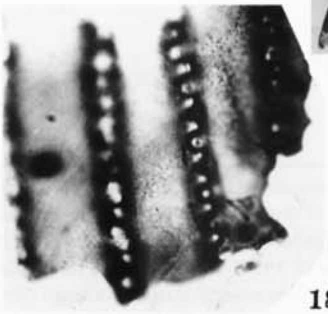
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Discussion of Table I

The common occurrences shown in Table I indicate that the MBF assemblage is relatively similar to the ULY, ICM, TCM and NGT assemblages. Compared with subzones A, B, C and D of Kyle's (1977) *Alisporites* Zone for the Triassic interval of the Victoria Group from the Murlock–Mackay Glacier area, the MBF assemblage is relatively closer to subzones C and D and the Timber Peak assemblage which Kyle considered to be equivalent to her subzone C. Subzone A (Early Triassic) is characterized by various trilete cavate spores (*Lundbladispora*+*Densoisporites*) and common or abundant *Aratrisporites* as well as other taxa such as *Grebespora concentrica*. Subzone B is defined by the presence of *Cadagarsporites senectus*, ?*Kraeuselisporites verrucifer*, *Retusotriletes junior*, *Tigrisporites playfordii*, *Equisetosporites steevesi* and *Duplexisporites problematicus*. These taxa have not been observed in our assemblage except the common presence of *Aratrisporites* and *Vitreisporites pallidus*. If "the lower Lashly assemblage" assigned to subzone B as Kyle did, although some common or similar elements occur in the MBF assemblage as shown in the Table I, the absence of *Protohaploxypinus* and especially the diagnostic zonal species *Cadargasporites senectus* defies correlation between the MBF assemblage and subzone B. The MBF may be temporarily correlated with the upper part of the Ipswich Coal Measures and the Bundamba Group, and seems to be younger than the lower part of the Ipswich Coal Measures because in the latter *Aratrisporites* is rather diverse. The occurrence of *Craterisporites rotundus* and bisaccate Striatiti in the Falla Formation suggests a little older age than the MBF. Among the four assemblages recorded from New Zealand (Zhang & Grant-Mackie 1997), the MBF assemblage bears greater resemblance with the assemblages I and II (Norian–Rhaetian), although some index forms have not been observed in the MBF assemblage, such as *Polycingulatisporites crenulatus*, *Annulispora microannulata* and *Foveosporites moretonensis*. On the other hand, the assemblages III and IV (Early Jurassic) differ from the MBF assemblage in having some diagnostic Jurassic forms, such as *Toripustulatisporites hokonuiensis*, *Antulsporites varigranulatus*, *Kyrtomisporites elsenndoonii*, *Cibotium juncta*, *Lycopodiumsporites austroclavatidites*, *Perinopollenites elatoides* and abundant *Classopollis* (assemblage IV). The MBF assemblage is also correlatable with those from the upper *Polycingulatisporites crenulatus* Zone and the *Foveosporites moretonensis* Zone (the Warepan and Otapirian Stages) of New Zealand, viz. to the more securely dated late Norian and Rhaetian (De Jersey & Raine

Table I. Regional correlation of Triassic taxa.

MBF	ULY	LLY	BST	FLA	ICM	BDB	WOS	TCM	NGT
Deltoidospora directa			+	+	+		+	sp.	+
Dictyophyllidites harrisii	+	+	+	+	+	+	+	+	+
Punctatisporites sp.	+	+		+			+		+
Granulatisporites sp.					+	+		+	
Osmundacidites sp.	+	+	+	+	+	+	+	+	+
Converrucosisporites sp.	+	+	+		+		+	+	+
Uvaesporites verrucosus	+				+	+	+	+	+
Acanthotriletes sp.			+	+	+	+	+	+	+
Lophotriletes novicus	+				sp.	sp.	sp.		
Duplexisporites? sp.	+				+				
Cingulatisporites sp.					+				
Densosporites sp.	+				+	+			
Nevesisporites sp.	+	+							
Aratrisporites sp.	+	+			+	+	+	+	+
Alisporites spp.	+	+	?		+		+	+	+
Alisporites parvus	+			+	+				
Alisporites cf. *australis*	+				+		+		
Vitreisporites pallidus	+	+	+	+	+	+	+		
Vitreisporites subtilis					+				
Pityosporites sp.				+					
Platysaccus queenslandi	+			+	+	+	+	sp.	sp.
Pteruchipollenites sp.			+	+					
Araucariacites australis			+				+		sp.
Classopollis sp.						+	+		+
Cycadopites spp.	+	+	+		+	+	+	+	+

MBF = Miers Bluff Formation, the present assemblage; ULY = upper Lashly Formation (subzones C+D of the *Alisporites* Zone), Late Triassic, South Victoria Land, Antarctica (Kyle 1977); LLY = "lower Lashly Formation", Ladinian?, Mount Feather, South Victoria Land (Helby & McElroy 1969); BST = "Beacon Sandstone", Late Triassic, Timber Peak, northern Victoria Land (Gair *et al.* 1965, Norris 1965); FLA = Falla Formation, Carnian–Norian, Central Transantarctic Mountains (Farabee *et al.* 1989); ICM = Ipswich Coal Measures, Carnian, Australia (De Jersey 1962, 1971); BDB = Bundamba Group, Aberdale Conglomerate and Raceview Formation, Rhaetian, Australia (De Jersey 1970b, 1973); WOS = Warepan Stage (late Norian) and Otapirian Stage (Norian–Rhaetian) of the Murihiki Supergroup, New Zealand (De Jersey & Raine 1990); TCM = Trechmann Siltstone, Assemblage I, Norian; NGT = Ngutunui Formation and Neucastle Group, Assemblage II, Rhaetian, New Zealand (Zhang & Grant-Mackie 1997).

1990).

To sum up, the MBF assemblage is comparable to those of the C+D subzones of Kyle's *Alisporites* Zone of Victoria Land and the upper *Craterisporites rotundus* Zone and lower *Polycingulatisporites crenulatus* Zone of Australia as well as the *Polycingulatisporites crenulatus* Zone and *Foveosporites moretonensis* Zone of New Zealand, suggesting a Late Triassic (possibly Norian-Rhaetian) age. The absence of Striatiti and the sporadic occurrence of *Aratrisporites* and *Classopollis* lent support to the above dating. In addition, it is interesting to note the presence of a few possibly bennettitalean cuticles in the MBF: Bennettitaleans were represented by a number of taxa only up to Late Triassic in the Northern Hemisphere.

Conclusions

1)The deposits of the MBF contain various and diverse plant microfossils although they are poorly preserved due to thermal alteration of the rocks. The plant microfossils include a total of about 45 species (forms) assigned to 37 genera of miospores, viz. spores of 18 species/17 genera, pollen of 22 species/15 genera in addition to acritarchs of 5 species /5 genera; wood fragments of 13 forms and cuticles of two types.

2)The palynoflora is quantitatively dominated by bisaccate gymnosperm pollen, but with pteridophyte spores and gymnosperm pollen equally diverse. Phytogeographically, it belongs to the Ipswich type.

3)The palynoflora is comparable to subzones C+D of Kyle's (1977) Triassic *Alisporites* Zone from southern Victoria Land of Transantarctica and the upper *Craterisporites rotundus* Zone and *Polycingulatisporites crenulatus* Zone from Queensland (viz. the upper part of the Ipswich Coal Measures and Bundamba Group), indicating a Late Triassic (possibly Norian–Rhaetian) age.

4)The Late Triassic dating of the MBF lends support correlation with the Potranca Formation in southern Chile, the Greywacke Shale Formation in the South Orkney Islands, and the Cape Legoupil Formation, as well as probably the Paradise Harbour and Hope Bay Formations in the Antarctic Peninsula. All these formations might have been contemporaneously deposited under similar tectonic conditions just prior to the breakup of Gondwana in Early to early Middle Jurassic times.

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