Cretaceous Research 26 (2005) 906–919

CRETACEOUS RESEARCH

www.elsevier.com/locate/CretRes

Provenance of recycled palynomorph assemblages recovered from surficial glaciomarine sediments in Bransfield Strait, offshore Antarctic Peninsula

Sangheon Yi [a,*], David J. Batten [b], Seong Joo Lee [c]

[a] *Quaternary Environmental Research Group, Geological and Environmental Hazards Division,*
Korea Institute of Geoscience and Mineral Resources, 30 Gajeong-dong,
Yuseong-gu, Daejeon 305-350, South Korea
[b] *School of Earth, Atmospheric and Environmental Sciences, University of Manchester, Oxford Road,*
Manchester M13 9PL, and Institute of Geography and Earth Sciences, University of Wales, Aberystwyth SY23 3DB, UK
[c] *Department of Geology, Kyungpook National University, Daegu 702-701, South Korea*

Received 2 July 2004; accepted in revised form 15 June 2005
Available online 21 November 2005

Abstract

Glaciomarine surficial sediments in cores taken from Bransfield Strait, adjacent to the Antarctic Peninsula, have yielded abundant recycled and contemporaneous (Pleistocene–Holocene) palynomorphs. The former are derived principally from Late Cretaceous–Palaeogene sediments and provide information on glaciomarine depositional conditions and sediment source areas. The composition of the assemblages suggests that they reflect vegetation that was endemic to the Weddellian Biogeographic Province, which includes what is now Seymour Island, James Ross Island and other parts of the Antarctic Peninsula region. The sediments concerned are considered to have accumulated as a result of ice-rafting and discharge of subglacial meltwater.

Keywords: Palynofloras; Recycling; Bransfield Strait; Antarctic Peninsula

1. Introduction

The glaciomarine sediments that cover the sea-floor around the Antarctic Peninsula are rich in Recent and recycled marine and non-marine organic- and inorganic-walled microfossils, e.g., spores, pollen grains and dinoflagellate cysts, and diatoms and silicoflagellates respectively. These microfossils derive from sedimentary rocks that crop out either on the peninsula and neighbouring islands, where they are commonly hidden by thick ice, or at submarine locations on the continental shelf. They accumulated as a result of glacial and/or submarine processes.

The occurrence of fossil palynofloras (organic-walled microfossils) in essentially modern glacial marine muds close to Antarctica has been reported previously on a number of occasions (e.g., Truswell, 1983; Truswell and Drewry, 1984; Byun et al., 1996). The specimens recovered have been used for determining the ages of rocks hidden beneath the ice around Antarctica (Kemp, 1972; Truswell, 1982, 1983, 1990; Truswell and Drewry, 1984) and suggesting the general composition of the vegetation that once clothed the continent. Cretaceous and Palaeogene palynomorphs are known from the eastern side of the Antarctic Peninsula, where outcrop successions on James Ross and Vega islands (Askin, 1983), Seymour Island (Askin, 1988a,b, 1989, 1990a,b, 1997), and

---

* Corresponding author.
E-mail addresses: shyi@kigam.re.kr (S. Yi), david.batten@manchester.ac.uk (D.J. Batten).

0195-6671/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cretres.2005.06.004

in the James Ross Island Basin (Dettmann and Thomson, 1987) have been examined. Some of the Antarctic Cretaceous and Cenozoic spore and pollen (miospore) assemblages contain species that may have been produced by plant taxa that were endemic to the region, and some of the species are thought to have their earliest occurrences in the Antarctica, both implying that the parent plants originated in the region (Askin, 1989). In this paper we concentrate on the occurrence of recycled miospores and dinoflagellate cysts in the sea-floor sediments of the Bransfield Strait and their likely provenance.

2. Physiography and vegetation of the Antarctic Peninsula

The Bransfield Strait is a semi-enclosed sea about 300 km long and 100 km wide located between the South Shetland archipelago and the north-eastern tip of the Antarctic Peninsula (i.e., ca. 61–64°S; Fig. 1). This strait is a narrow, deep (up to >2000 m), volcanic, rifted basin (the Bransfield Basin) that has been actively spreading during the past 4 myr in response to subduction in the South Shetland Trench (Barker, 1982; González-Ferrán, 1985; Gamboa and Maldonado, 1990). The north-eastern part of the strait opens out into the Scotia and Weddell seas. The south-western part is connected to the eastern Bellingshausen Sea via the Gerlache Strait.

The north-east–south-west-orientated Bransfield Basin is divided into three subbasins: Western, Central and Eastern. These are separated from each other by sills at depths in the region of 500 m and progressively deepen north-eastward (Fig. 1A). The Western Subbasin, in which Core S7 was drilled, is irregular in shape, and flanked by shelves 20–50 km wide. The Central Subbasin, from which Cores S4 and AB2 were taken (the latter on its western margin), is more regular in shape with a relatively wide continental margin (ca. 100 km) on the Antarctic Peninsula side and, in contrast, a narrow shelf (<20 km) and steep slope (5–10°) on the margin of the South Shetland Islands (Prieto et al., 1997; Yoon, S. et al., 2002). The depth of the sea-floor in this subbasin increases gradually towards the north-east up to a little over 2000 m. The width of southern continental shelf is wider than that of the north owing to the north–south asymmetry of the Bransfield Basin. The Eastern Subbasin, which also extends north-eastward, has relatively wide continental margins (50–125 km), and reaches a depth of 2500 m.

Surface water circulation in the Bransfield Basin is controlled by the interaction of two different inflows: cold, saline Weddell Sea water on the Antarctic Peninsula side, and relatively warmer, less saline Bellingshausen Sea water on the South Shetland Islands side (López et al., 1999). Circulation at depth is mainly linked to the entrance of dense Weddell shelf waters around the north-east tip of Joinville Island, which then sinks over the shelf and down the slope into the basin (Whitworth et al., 1994; López et al., 1999).

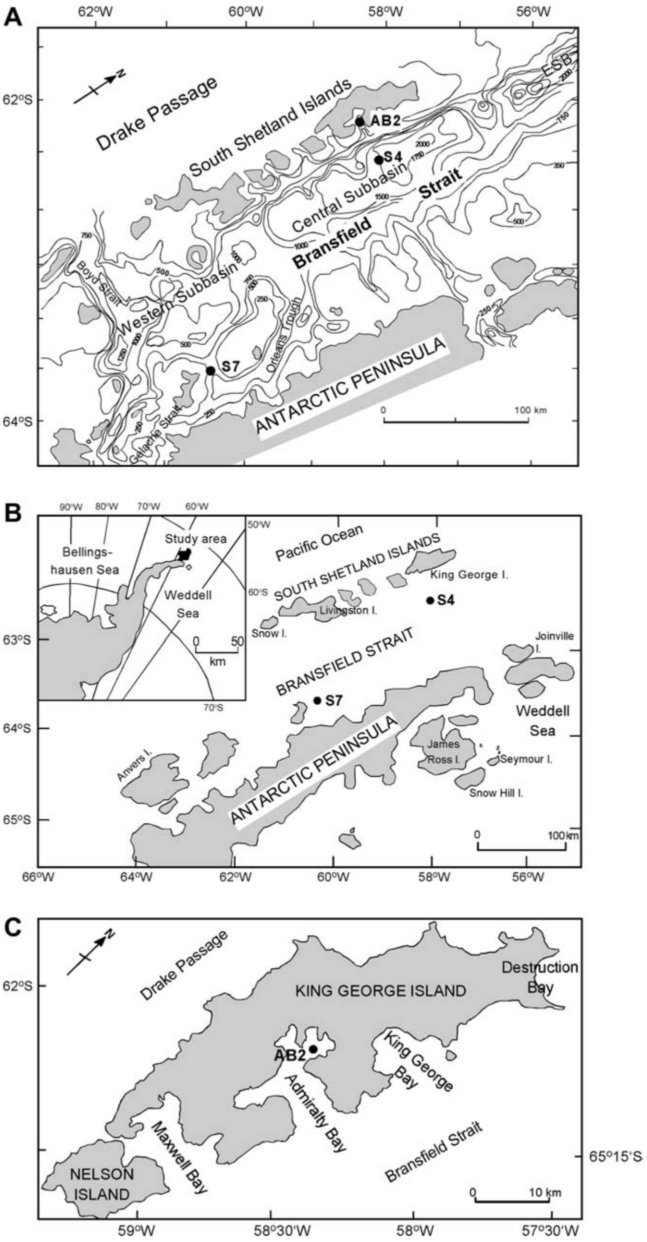


Fig. 1. A, bathymetric map of Bransfield Strait (from Jeffers and Anderson, 1991) with the location of cores; contours in metres; ESB, Eastern Subbasin. B, map showing the location of the study area (inset) and islands mentioned in the text. C, outline map of King George Island and neighbouring Nelson Island with the location of Core AB2 indicated.

The surficial sediments of the basin are composed mainly of sandy silt (4–6Φ) and silty clay (>6Φ). The latter is distributed over the deepest parts of the basin, whereas sandy silt deposits occur on the continental shelf and slope (Yoon, 1995).

Today vegetation on the Antarctic Peninsula is sparse, dominated by non-vascular plants, and mostly near the coast (Bliss, 1979). At least 200 species of lichens and 85 species of mosses together with many species of algae have been recorded from Antarctica (Walton and Bonner, 1985). Commonly colonizing rock surfaces, with some herbs on the soils, all have to tolerate the harsh tundra environment. Representatives of only two flowering plant families, a pearlwort and a grass species, have been reported (Bliss, 1979; Longton, 1985), both of which are confined to the maritime zone.

3. Material and methods

During the 1991/92 survey season, the Korea Ocean Research and Development Institute (KORDI) operated a "Korean Antarctic Research Program" and drilled several piston cores in the Bransfield Basin, three of which were intended for palynological analysis. Sixty-eight samples were taken from these cores at intervals of 10–20 cm: 10 from Core S7, 31 from Core S4, and 27 from Core AB2.

Core S7 (Latitude 63°30′05″S, Longitude 60°26′06″W; Fig. 2) was drilled in water 675 m deep on the southern slope of the Western Subbasin. It is 523 cm long and consists of clay, silt, sand and gravel. Samples were not taken from the lower part of the section because of the high sand and gravel content, which is unsuitable for the preservation of palynomorphs. Core S4 (62°30′58″S, 58°05′58″W; Fig. 3), drilled in water 1846 m deep in the central part of the Central Subbasin, is 537 cm long and composed mainly of clay and silt, with a small amount of sand. Core AB2 (62°05′09″S, 58°23′06″W; Fig. 4), drilled in water 261 m deep in Admiralty Bay, King George Island, is 256 cm long and consists largely of mud (Park et al., 1992).

About 30 g of each of the dried samples were processed for palynological analysis using standard procedures (Moore et al., 1991) involving HCl (30%) and HF (45%) for the removal of calcareous and siliceous minerals. The organic matter recovered was oxidized with $NaClO_2$ (3%) to remove fine humic matter, and then sieved through screens of 10 μm mesh. The sieved residue was strew mounted on glass slides in glycerine jelly. Raw data were converted into percentages using TILIA v2.0 (Grimm, 1993). TILIAGRAPH v1.25 (Grimm, 1991) was used to generate the 'pollen' diagrams. The percentages of recycled and contemporaneous spores and pollen grains were calculated from the total palynomorph sum (Figs. 2–4).

4. Results

All of the palynological assemblages examined contain Pleistocene–Holocene and recycled miospores. Selected examples of both are shown in Figs. 5–7. The younger taxa consist of cryptogam spores (*Cyathea* and Polypodiaceae) and pollen grains of herbs (Chenopodiaceae, Compositae, Ericaceae and Poaceae; Fig. 5). Among the recycled miospores are: the spores *Baculatisporites comaumensis*, *Ceratosporites equalis*, *Clavifera triplex*, *Cyatheacidites annulatus*, *Osmundacidites wellmanii* and *Retitriletes eminulus*; the gymnosperm pollen *Dacrycarpites australiensis*, *Lygistepollenites florinii*, *Microcachryidites antarcticus*, *Phyllocladidites mawsonii* and *Podocarpidites marwickii*; and the

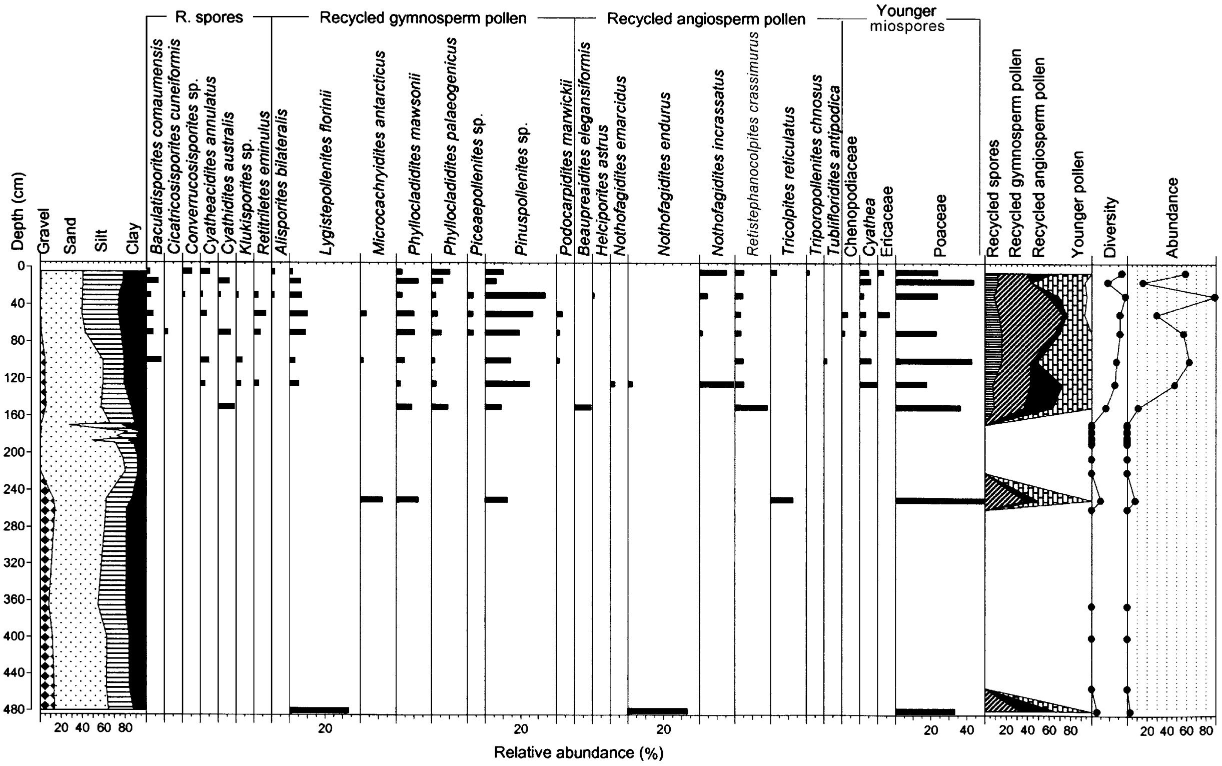


Fig. 2. 'Pollen diagram' of S7 core from Bransfield Strait showing most of the taxa recorded. Grain texture analysis is from Park et al. (1992).

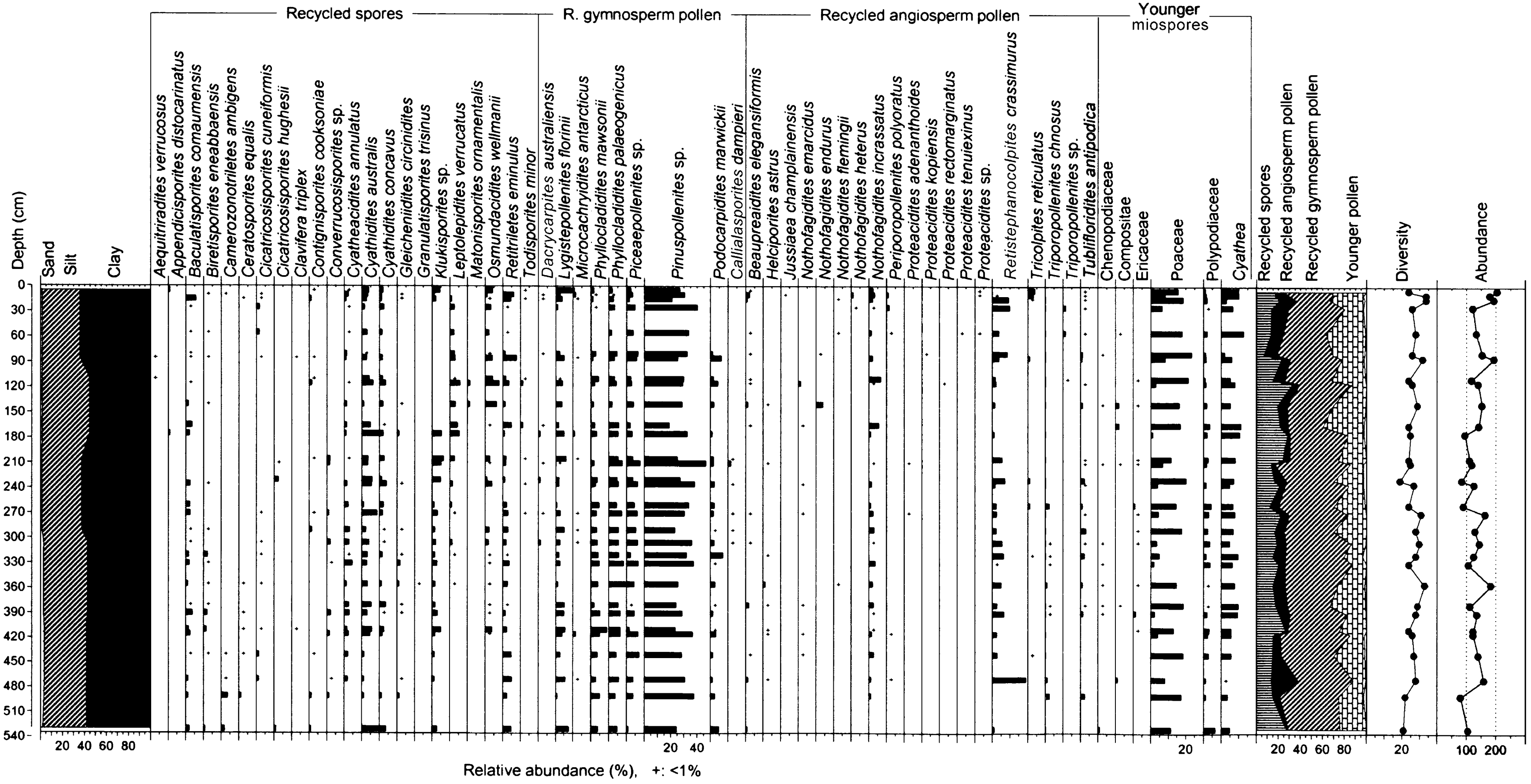


Fig. 3. 'Pollen diagram' of S4 core from Bransfield Strait showing most of the taxa recorded. Grain texture analysis is from the Park et al. (1992).

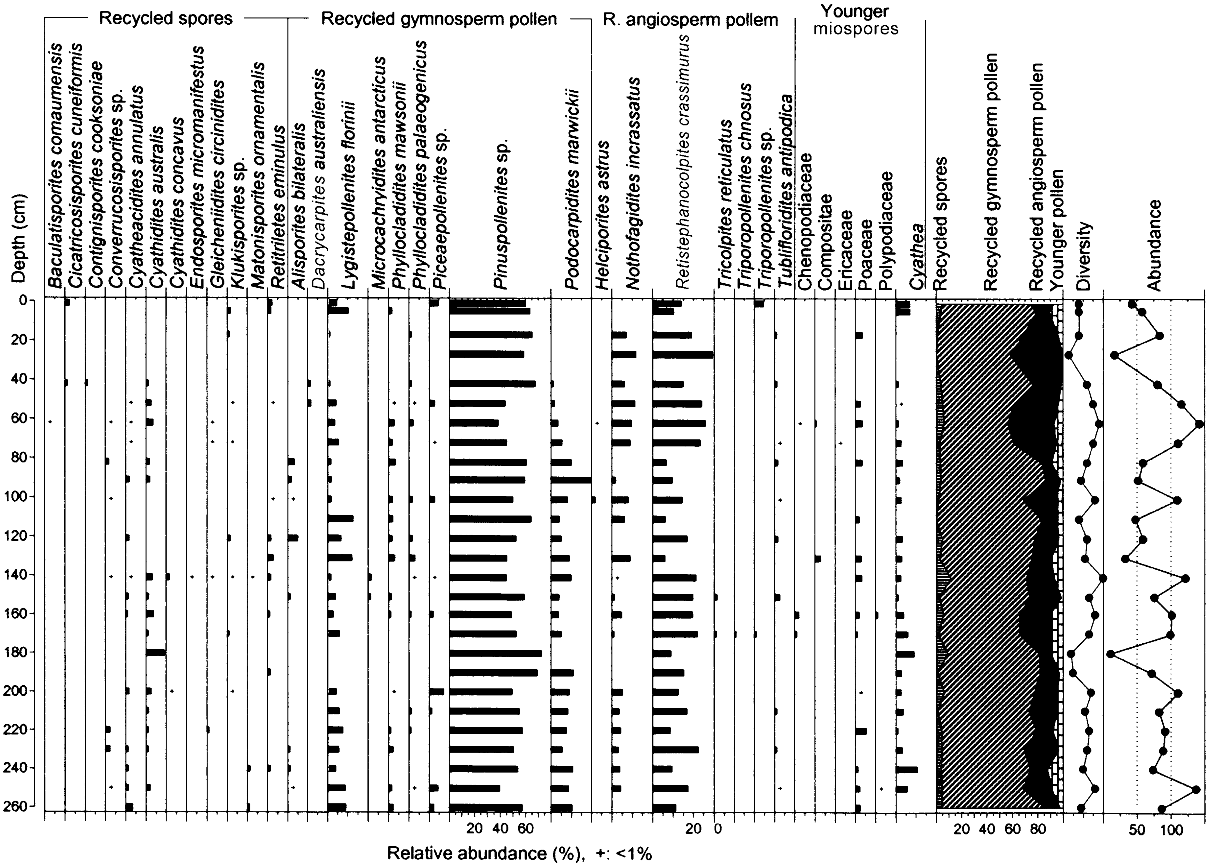


Fig. 4. 'Pollen diagram' of AB2 core from Bransfield Strait showing most of the taxa recorded. Grain texture analysis is from Park et al. (1992).

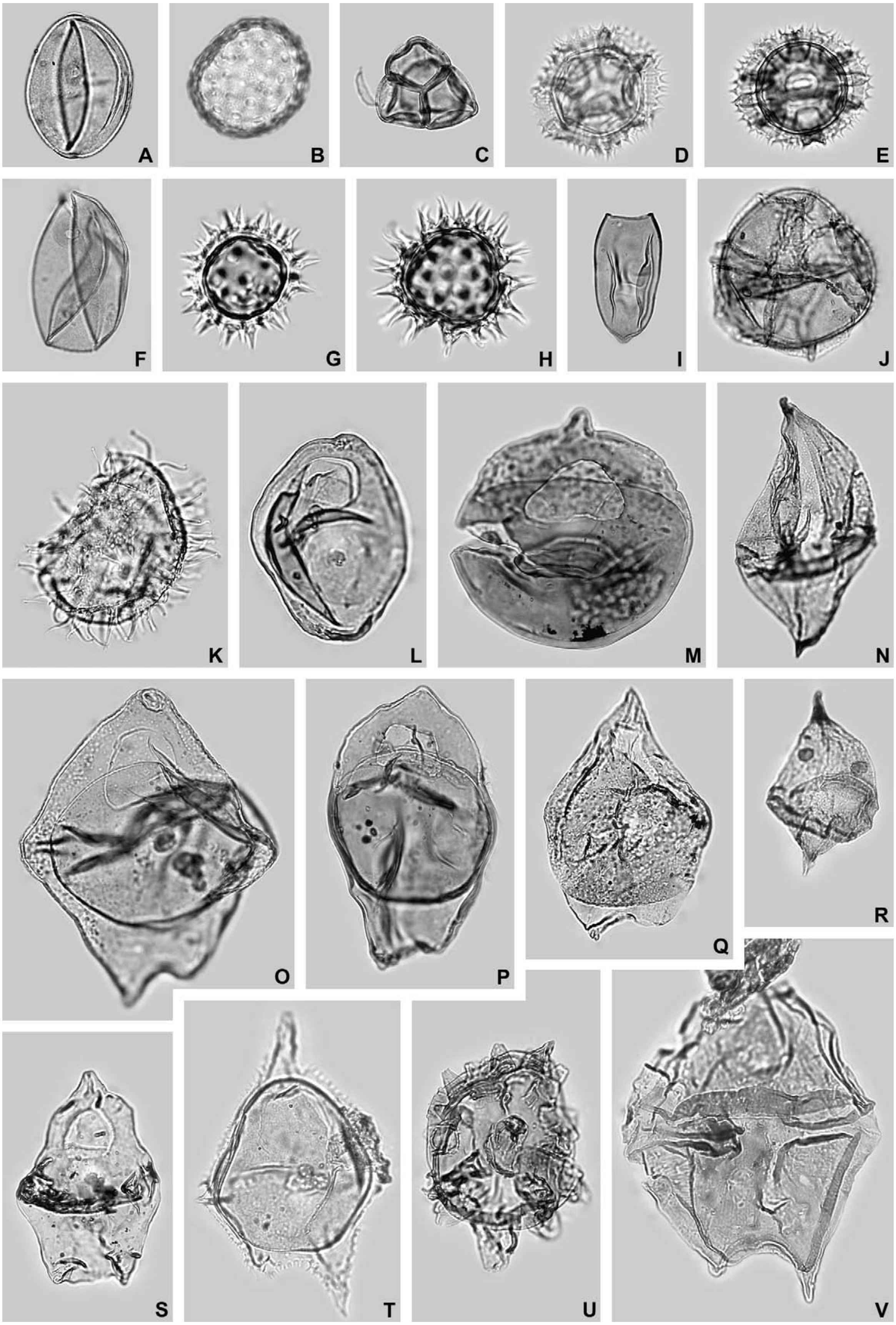
angiosperm pollen *Beaupreaidites elegansiformis*, *Nothofagidites endurus*, *N. flemingii*, *N. incrassatus*, *Periporopollenites polyoratus*, *Proteacidites adenanthoides*, *P. kopiensis*, *P. rectomarginatus*, *P. tenuiexinus*, *Tricolpites reticulatus*, *Triporopollenites chnosus* and *Tubulifloridites antipodica* (Figs. 6, 7, Table 1).

In Core S7, recycled gymnosperm pollen grains *Lygistepollenites florinii*, *Phyllocladidites mawsonii*, *P. palaeogenicus* and *Pinuspollenites* sp. are especially common along with reworked angiosperm pollen referable to *Retistephanocolpites crassimurus*. Contemporaneous products include abundant (ca. >20%) representatives of the Poaceae and common spores attributable to *Cyathea*. Other common, or intermittently numerous, taxa include recycled *Baculatisporites comaumensis*, *Cyathidites australis* and *Nothofagidites incrassatus* (Fig. 2).

In Core S4, the palynological assemblages are dominated (ca. 5–40%) by recycled gymnosperm pollen (*Pinuspollenites* sp.) and younger angiosperm pollen (Poaceae), in combination with common (ca. <5%) recycled *Cyathidites australis*, *Osmundacidites wellmanii* and *Retitriletes eminulus* and contemporaneous spores of *Cyathea*. Also common are recycled *Lygistepollenites florinii*, *Nothofagidites incrassatus*, *Phyllocladidites mawsonii*, *P. palaeogenicus*, *Piceaepollenites* sp. and *Retistephanocolpites crassimurus* (Fig. 3).

In Core AB2, recycled *Pinuspollenites* sp. and *Retistephanocolpites crassimurus* dominate (ca. 20–60%) throughout the section. Among the common taxa, reworked *Lygistepollenites florinii*, *Nothofagidites incrassatus* and *Podocarpidites marwickii* are especially abundant along with comparatively numerous spores of *Cyathea* and representatives of the Poaceae (Fig. 4).

Fig. 5. Examples of contemporaneous (Pleistocene–Holocene) angiosperm pollen grains (A–H), acritarch (I), and dinoflagellate cysts (J, K), and recycled dinoflagellate cysts (L–V) in the core samples from Bransfield Strait examined. The specimens are identified by core, sample depth (cm) and England Finder reference. A, Poaceae, Core S4, 55–60, F27/3 + 4. B, Chenopodiaceae, Core S4, 210–220, F17/3 + 4. C, Ericaceae, Core S4, 270–280, E20/3. D, E, Compositae: D, Core S7, 30–35, B42/2; E, Core S4, 320–325, F44/4. F, Poaceae, Core S4, 55–60, F27/3 + 4. G, H, Compositae: G, Core S4, 320–325, G17/2; H, Core S4, 55–60, N37/1 + 3. I, *Beringiella fritilla*, Core AB2, 52–57, E45/4. J, *Impagidinium patulum*, Core AB2, 141–146, V27. K, *Operculodinium centrocarpum*, Core S4, 140–145, U37. L, *Manumiella*? *cretacea*, Core S4, 55–60, L26. M, *Nelsoniella tuberculata*, Core S4, 290–295, Q24/1. N, *Diconodinium cristatum*, Core S4, 390–400, G28/1 + 3. O, *Manumiella seelandica* (Lange, 1969) Bujak and Davies, 1983, emend. Firth, 1987, Core S4, 115–125, C38/1. P, *Isabelidinium* sp., Core S4, 330–340, T19/3 + 4. Q, *Isabelidinium pellucidum*, Core S4, 85–95, C30/3 + 4. R, *Laciniadinium arcticum*, Core S4, 320–325, L20/1 + 3. S, *Chatangiella* sp., Core S4, 205–210, T20/3. T, *Senegalinium* sp., Core S4, 115–125, Y14/2. U, *Cassidinium fragile*, Core S4, 305–315, W25/1. V, *Paleoperidinium pyrophorum*, Core S4, 85–95, D14/1 + 2. A–H, ×900; I–V, ×400.


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V

5. Discussion

5.1. Age of recycled and contemporaneous palynofloras

The ages represented by the contemporaneous terrestrial palynofloras cannot be determined precisely because most of the components have biostratigraphic ranges that extend from the Oligocene to the present day (e.g., Cookson, 1947; Germeraad et al., 1968). However, it is possible to draw some conclusions by taking account of their associations with microplankton that have been recorded from the same cores as well as with the results of studies on these and other cores taken for different purposes (micropalaeontology: Yi et al., 1995; Byun et al., 1996; Lee, 1996; Shin et al., 2001; sedimentology: Yoon, H. et al., 2000; Yoon, S. et al., 2002; Bahk et al., 2003; organic geochemistry: Khim et al., 2002).

The diatoms, silicoflagellates and dinoflagellate cysts indicate that the surficial sediments were deposited from the beginning of the Pleistocene onwards. The silicoflagellate assemblages recovered from Cores S7 and S4 compare well with those of the Pleistocene–Holocene *Distephanus speculum speculum* Zone (Yi et al., 1995). Lee (1996) identified two diatom zones, a *Thalassiosira lentiginosa* Partial Range Zone and an *Actinocyclus ingens* Partial Range Zone, in all three of the cores examined for their microfossil content, and concluded that they also indicate an age-range of Pleistocene–Holocene. This determination is further supported by the occurrence of the acritarch *Beringiella fritilla* and the dinoflagellate cyst species *Impagidinium pallidum* and *I. patulum* in the same cores (Byun et al., 1996) (Fig. 5). Other authors have also regarded the S7 and S4 successions as having accumulated during the Quaternary period (Yoon, H. et al., 2000; Khim et al., 2002; Yoon, S. et al., 2002; Bahk et al., 2003). As a result, all of the younger palynofloras recorded from the S7, S4 and AB2 cores can be dated as Pleistocene–Holocene.

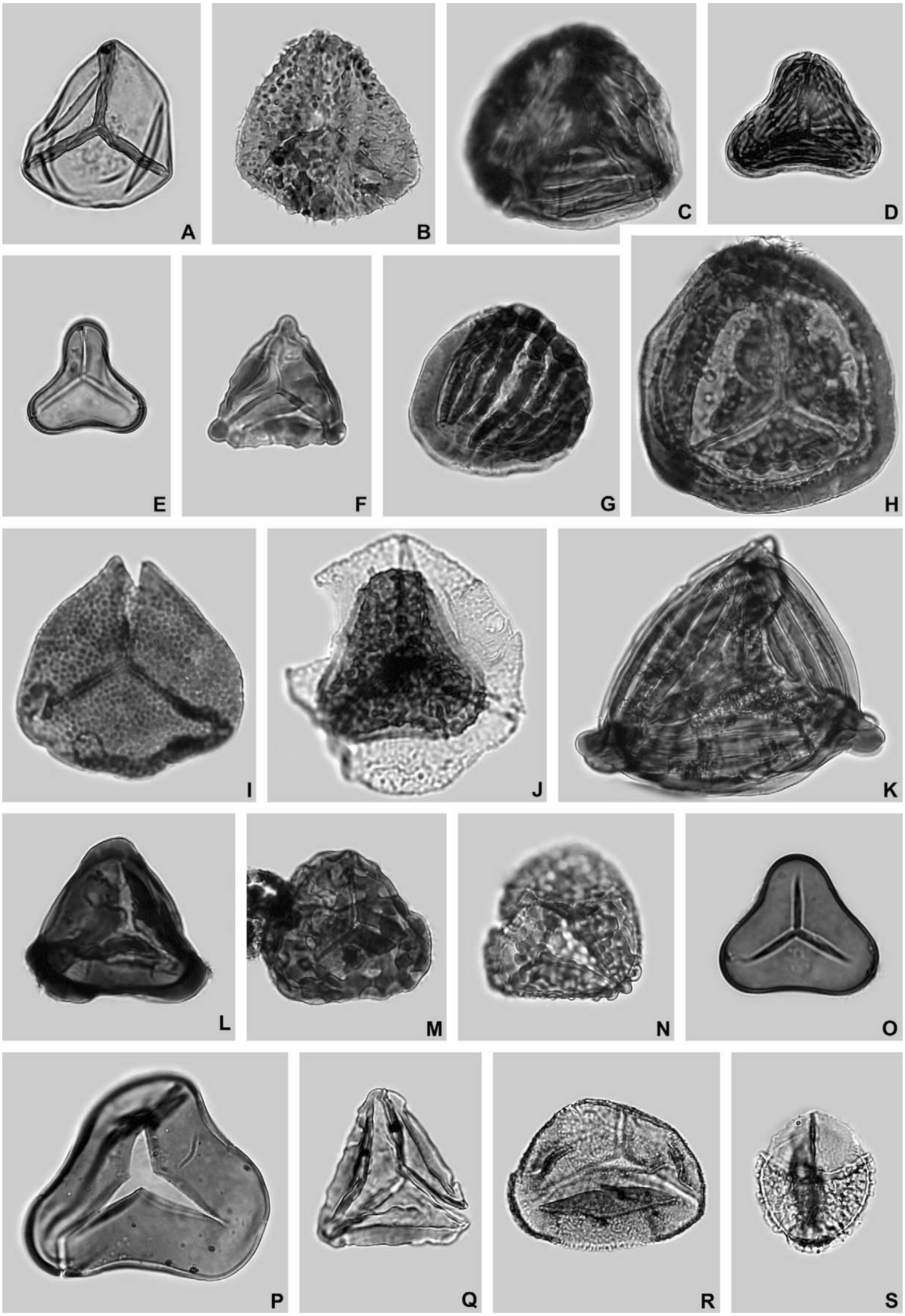
Although there is evidence of a small Palaeozoic contribution, the age-range of the dominant components of the recycled palynofloral assemblages recovered can be ascertained by comparison with the composition of the Late Cretaceous–Palaeogene assemblages and zonations of Dettmann and Thomson (1987), Askin (1988a,b, 1990a,b), Dettmann and Jarzen (1988), Dettmann (1989) and others. A variety of cryptogam spores, araucarian pollen grains, the gymnospermous *Microcachryidites* and *Podocarpidites*, and angiospermous *Beaupreaidites*, *Nothofagidites*, *Proteacidites*, *Tricolpites* and *Tubulifloridites* are common in Campanian–Maastrichtian sediments of the Antarctic Peninsula. Various proteaceous plant taxa were well-established in the Antarctic Peninsula area by the Late Campanian (Askin, 1983, 1989; Dettmann and Thomson, 1987; Dettmann and Jarzen, 1988; Dettmann, 1989). The Australasian-Antarctic region has been suggested as the place of origin of '*Beauprea*-type' proteaceous plants during the Campanian (Dettmann and Jarzen, 1988; Pocknall and Crosbie, 1988). Angiosperm diversification reached a peak during the Campanian–Maastrichtian when a mixed conifer (podocarp-type and araucarian)-Proteaceae-*Nothofagus* rain forest clothed the Antarctic Peninsula (Askin, 1992). This vegetation formed part of the Late Cretaceous–Early Cenozoic Weddellian Biogeographic Province (Case, 1988; Fig. 8).

The spores and pollen grains recorded from the Bransfield Strait cores are common to the palynofloras of the Upper Campanian–Maastrichtian–Lower Danian Lopez de Bertodano Formation on Seymour Island (Askin, 1990a) and Maastrichtian deposits on Vega Island (Dettmann and Thomson, 1987). The recycled dinoflagellates that have been recorded from the cores (Fig. 5) have been dated as Late Cretaceous–early Tertiary (Palaeogene) by Byun et al. (1996). Accordingly, the reworked spores and pollen grains recorded in this study are considered to range in age between Late Campanian and early Palaeogene.

5.2. Potential provenance of recycled palynofloras

During the Cretaceous and Palaeogene the northern tip of the Antarctic Peninsula was situated at about 59–62°S (Lawver et al., 1985; Case, 1988) (Fig. 8). Throughout the Late Cretaceous, the peninsula area apparently underwent general uplift and was periodically part of an active volcanic arc adjacent to a subduction zone. Exposures of Late Cretaceous marine deposits are confined today to the north-eastern side of the peninsula (Elliot, 1985). During this period the exposed regions were forested, as indicated by the remains of in situ trees (Francis and Poole, 2002). To the east of the peninsula Cretaceous–Palaeogene sediments were deposited in the James Ross Basin, with sediment supply from the active magmatic arc to the west-north-west, now represented by the Antarctic Peninsula land mass (Pirrie et al., 1991, 1997). Plant debris from the vegetation that clothed the peninsula was washed into this basin and preserved in marine sediments (Francis, 1986).

Fig. 6. Examples of recycled spores, and one contemporaneous spore (O), in the core samples from Bransfield Strait examined. The specimens are identified by core, sample depth (cm) and England Finder reference. A, *Biretisporites eneabbaensis*, Core S4, 290–295, E43/3. B, *Ceratosporites* sp., Core S4, 355–360, D14. C, *Cicatricosisporites hughesii*, Core S4, 210–220, D20/1. D, *Cicatricosisporites cuneiformis*, Core S4, 55–60, X18/4. E, *Cyathidites concavus*, Core S4, 115–125, Q30/4. F, *Clavifera triplex*, Core S4, 410–415, N18/1 + 3. G, *Contignisporites cooksoniae*, Core S4, 5–10, X50/3 + 4 (distal view). H, *Cyatheacidites annulatus*, Core S4, 165–170, V40/3 + 4. I, *Granulatisporites trisinus*, Core S4, 355–360, V30/1. J, *Aequitriradites* sp. cf. *A. verrucosus*, Core S4, 530–537, O48/3. K, *Appendicisporites distocarinatus*, Core S4, 175–185, X43/3. L, *Matonisporites agatonensis*, Core AB2, 240–245, E43/4. M, *Klukisporites* sp., Core AB2, 17–22, L41/1 + 3. N, *Leptolepidites verrucatus*, Core S4, 55–60, P19/3. O, *Cyathea*, Core S4, 230–235, Q26/2. P, *Cyathidites australis*, Core S4, 175–185, S38. Q, *Gleicheniidites circinidites*, Core S4, 140–145, Y27/3 + 4. R, *Osmundacidites* sp. cf. *O. wellmanii*, Core S4, 115–125, Q21/2 + 4. S, *Retitriletes eminulus*, Core S4, 10–15, E14/4 (lateral view). All × 900.


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S

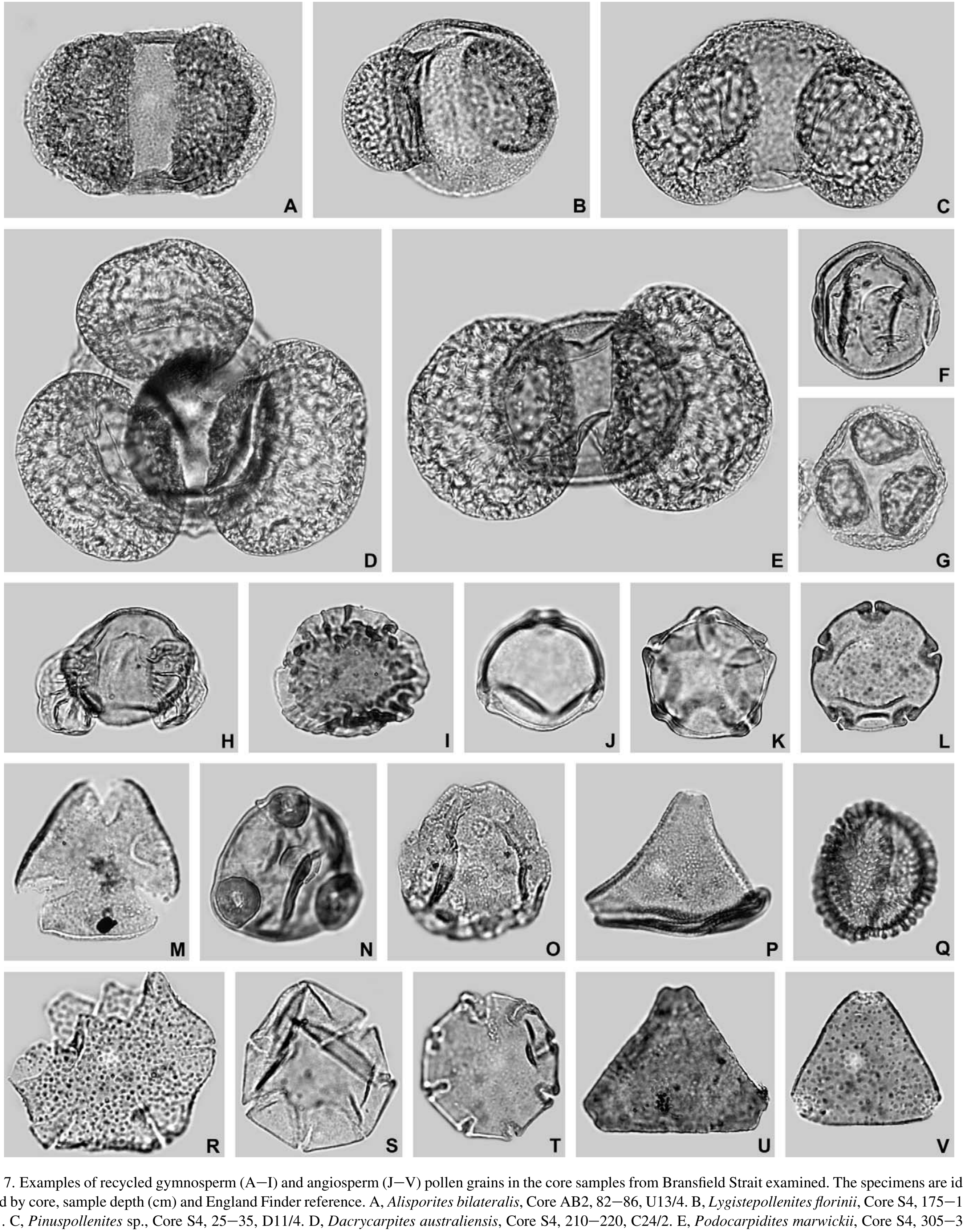


Fig. 7. Examples of recycled gymnosperm (A–I) and angiosperm (J–V) pollen grains in the core samples from Bransfield Strait examined. The specimens are identified by core, sample depth (cm) and England Finder reference. A, *Alisporites bilateralis*, Core AB2, 82–86, U13/4. B, *Lygistepollenites florinii*, Core S4, 175–185, Q21. C, *Pinuspollenites* sp., Core S4, 25–35, D11/4. D, *Dacrycarpites australiensis*, Core S4, 210–220, C24/2. E, *Podocarpidites marwickii*, Core S4, 305–315, O29/1 + 2. F, *Phyllocladidites palaeogenicus*, Core S4, 110–115, H21/3. G, *Microcachryidites antarcticus*, Core S4, 5–10, D28/3. H, *Phyllocladidites mawsonii*, Core S4, 410–415, X34. I, *Callialasporites dampieri*, Core S4, 205–210, G21/2. J, *Triporopollenites chnosus*, Core S4, 55–60, F30/4. K, *Helciporites astrus*, Core AB2, 101–106, B26. L, *Nothofagidites flemingii*, Core AB2, 17–22, X13. M, *Beaupreaidites elegansiformis*, Core S4, 115–125, Y36/3. N, *Jussiaea champlainensis*, Core S4, 10–15, Q44/3. O, *Periporopollenites polyoratus*, Core S4, 25–35, X26/1. P, *Proteacidites adenanthoides*, Core S4, 210–220, C21/4. Q, *Tricolpites reticulatus*, Core S4, 320–325, D30/3. R, *Nothofagidites emarcidus*, Core S4, 55–60, O41/4. S, *Nothofagidites heterus*, Core S4, 380–385, W24/4. T, *Nothofagidites incrassatus*, Core S4, 140–145, G36. U, *Proteacidites rectomarginatus*, Core S4, 115–125, K33/1. V, *Proteacidites tenuiexinus*, Core S4, 55–60, W34/3. All × 900.

Table 1
Recycled spores and pollen grains recorded from the core samples examined, with author attributions and year of publication provided for the species; stratigraphic ranges based on data from Antarctica, Australia, and southern Argentina as reported in particular by Askin (1983, 1989, 1990a,b), Dettmann and Thomson (1987), Dettmann and Jarzen (1988), Dettmann (1989) and Baldoni and Askin (1993) (bibliographic details are in the publications concerned and not included here)

Spores
Aequitriradites verrucosus (Cookson and Dettmann) Cookson and Dettmann, 1961: Berriasian–Albian
Appendicisporites distocarinatus Dettmann and Playford, 1968: Cenomanian–Turonian
Baculatisporites comaumensis (Cookson) Potonié, 1956: Late Jurassic–Mid Oligocene
Biretisporites eneabbaensis Backhouse, 1978: Late Tithonian–Late Aptian
Camerozonotriletes ambigens (Fradkina) Playford, 1971: Late Campanian–Late Maastrichtian
Ceratosporites equalis Cookson and Dettmann, 1958: Late Jurassic–Danian
Cicatricosisporites cuneiformis Pocock, 1965: Late Albian–?Coniacian
Cicatricosisporites hughesii Dettmann, 1963: Aptian–?Cenomanian
Clavifera triplex (Bolchovitina) Bolchovitina, 1966: Campanian–Paleocene
Contignisporites cooksoniae (Balme) Dettmann, 1963: Jurassic
Converrucosisporites sp.
Cyatheacidites annulatus Cookson, 1947 ex Potonié, 1956: Neocomian–Miocene
Cyathidites australis Couper, 1953: Jurassic–Oligocene
Cyathidites concavus (Bolchovitina) Dettmann, 1963: Jurassic–Aptian
Endosporites micromanifestus Hacquebard, 1957: Late Fammenian–Visean
Gleicheniidites circinidites (Cookson) Dettmann, 1963: Late Jurassic–Eocene
Granulatisporites trisinus Balme and Hennelly, 1956: Permian
Klukisporites sp.
Leptolepidites verrucatus Couper, 1953: Late Jurassic–Albian
Matonisporites agatonensis Backhouse, 1978: Late Jurassic–Early Berriasian
Matonisporites ornamentalis (Cookson) Partridge, 1973: Eocene–Miocene
Osmundacidites wellmanii Couper, 1953: Jurassic–Early Oligocene
Retitriletes eminulus (Dettmann) Srivastava, 1977: Late Campanian–Early Oligocene
Todisporites minor Couper, 1958: Triassic–Palaeogene

Gymnosperm pollen grains
Alisporites bilateralis Rouse, 1959: Jurassic–Maastrichtian
Callialasporites dampieri (Balme, 1957) Sukh Dev, 1961: Neocomian–Albian
Dacrycarpites australiensis Cookson and Pike, 1953: Paleocene–Early Oligocene
Lygistepollenites florinii (Cookson and Pike) Stover and Evans, 1973: Santonian–Late Pliocene
Microcachryidites antarcticus Cookson, 1947: Campanian–Oligocene
Phyllocladidites mawsonii Cookson, 1947: Campanian–Oligocene
Phyllocladidites palaeogenicus (Cookson and Pike, 1954) Truswell, 1983: Paleocene–Pliocene
Piceaepollenites sp.
Pinuspollenites sp.
Podocarpidites marwickii Couper, 1953: Campanian–Early Oligocene

Angiosperm pollen grains
Beaupreaidites elegansiformis Cookson, 1950: Maastrichtian–Miocene
Helciporites astrus Partridge, 1973: Eocene
Jussiaea champlainensis Traverse, 1955: Eocene
Nothofagidites emarcidus (Cookson) Harris, 1965: Paleocene–Early Miocene
Nothofagidites endurus Stover and Evans, 1973: Maastrichtian–Early Eocene
Nothofagidites flemingii (Couper) Potonié, 1960: Late Campanian–Oligocene
Nothofagidites heterus (Cookson) Stover and Evans, 1973: Late Oligocene–Early Miocene
Nothofagidites incrassatus (Cookson) Dettmann, 1990: Eocene
Periporopollenites polyoratus (Couper) Stover, 1973: Maastrichtian–Early Eocene
Proteacidites adenanthoides Cookson, 1950: Campanian–Early Oligocene
Proteacidites kopiensis Harris, 1972: Campanian–Eocene

Table 1 (*continued*)

Proteacidites rectomarginatus Cookson, 1950: Maastrichtian–Late Miocene
Proteacidites tenuiexinus Stover, 1973: Maastrichtian–Early Oligocene
Proteacidites sp.
Retistephanocolpites crassimurus Rao and Ramanujam, 1982: Lower–Middle Miocene
Tricolpites reticulatus Cookson, 1947: Campanian–Paleocene
Triporopollenites chnosus Partridge, 1973: Late Eocene–Miocene
Triporopollenites sp.
Tubulifloridites antipodica Cookson, 1947: Campanian–Pliocene

Antarctic outcrops of Late Cretaceous and Palaeogene age are restricted to the peninsula region. Fossil plants and palynomorphs occur on various islands in the James Ross Basin; in the South Shetland Islands on Livingston, King George and adjacent small islands (Fig. 1B); and on Alexander, Adelaide, and Brabant islands. Terrigenous detritus from these regions is transported into the marine realm and onto the ocean floor in a number of ways, but principally by turbidity, surface and bottom currents, and ice.

Direct correlation of the resulting recycled assemblages to their source areas is difficult because most of the South Shetland Islands and Antarctic Peninsula are covered by glaciers, and igneous rocks are also widespread. Hence, stratigraphic knowledge is limited to comparatively small areas of sedimentary rocks that are free of ice cover. Most of the South Shetland Islands are composed of Late Jurassic–Cenozoic tholeiite and calc-alkaline rocks (e.g., Smellie et al., 1984). Much of King George Island consists of Late Jurassic and Palaeogene igneous rocks (Barton, 1965). The oldest of these are thick successions of andesite lavas that have been correlated with Late Jurassic volcanic accumulations on the Antarctic Peninsula. The Fildes Peninsula Group, which (as the name implies) is largely confined to the Fildes Peninsula, includes layers of andesite, agglomerate and tuff with

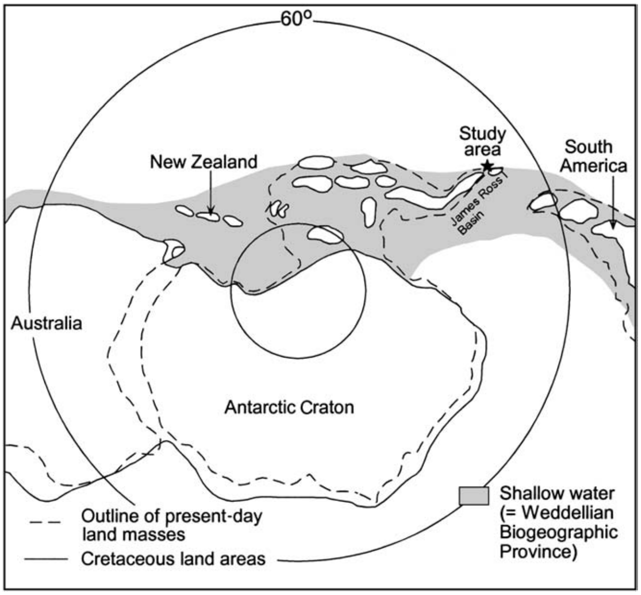


Fig. 8. Weddellian Biogeographic Province during the Late Cretaceous and Early Cenozoic (based on Case, 1988, fig. 6).

interbedded sedimentary rocks of Palaeogene age (Watts, 1982; Weaver et al., 1982). Late Cretaceous palynofloras have, however, been reported from the island (Dutra and Batten, 2000), and the limited deposits of this age may have contributed in a small way to the recycled assemblages of the AB2 core.

Deposition of the sediments that comprise the S7 and S4 cores took place on the continental slope mainly by mass flow and ice-rafting, and less often by water currents (Powell, 1984). Core S7 is divisible into two parts: an upper section rich in palynomorphs and a lower zone of impoverished assemblages; both contain Late Cretaceous and Palaeogene taxa (Fig. 2). The change from poor to rich assemblages suggests a change from shallow to deeper depositional conditions, the former reflecting a sea-level lowstand resulting from a cold period of glacial advance. This is supported by the presence of gravels in, and the absence of dinoflagellate cysts (Byun et al., 1996) from, the lower section.

The relatively diverse palynomorph assemblages and the abundance of recycled Late Cretaceous and Palaeogene palynomorphs in Core S4 (Fig. 3) could be taken to imply derivation from several areas and transport to the site of deposition by a variety of means. However, most of the sediment is considered to have been deposited by mass flows during a relatively short period because the core is from a steep (5–10°) marine slope to the south of the South Shetlands Islands (Prieto et al., 1997; Yoon, S. et al., 2002) (Fig. 1A).

On the western side of Admiralty Bay, King George Island, from which Core AB2 was obtained, the weathered Paleocene–Eocene basalts of the Fildes Peninsula Group crop out. On its eastern side Eocene–Oligocene fine-grained or glassy hypersthene-augite andesites of the Henequine Formation occur (Weaver et al., 1982). Overall, the taxonomically rich recycled palynomorph assemblages recorded from the core (Fig. 4) are closely comparable to the Campanian–Palaeogene assemblages that have been reported from James Ross (Askin, 1983) and Seymour islands (Askin, 1988a,b, 1989, 1990a,b), and from the exposures of Late Cretaceous deposits on King George Island itself (Dutra and Batten, 2000).

The Late Cretaceous (Campanian–Maastrichtian) dinoflagellate cyst assemblages, which include *Amphidiadema denticulata*, *Isabelidinium thomasii*, *Manumiella*? *cretacea*, *Odontochitina spinosa*, *Palaeoperidinium pyrophorum* and *Satyrodinium haumuriense* (Byun et al., 1996; nomenclature here according to Fensome and Williams, 2004; see Table 2), are comparable to those of the Santa Marta Formation on James Ross and Humps islands (Sumner, 1992; Wood and Askin, 1992), and the Palaeogene assemblages of *Areosphaeridium diktyoplokum*, *Cordosphaeridium fibrospinosum*, *Enneadocysta multicornuta*, *Isabelidinium pellucidum*, *Senegalinium*? *dilwynense*, *Vozzhennikovia apertura* and other taxa are similar to those of the Paleocene Sobral Formation on Seymour Island and Eocene La Meseta Formation on Snow Hill Island (Askin, 1988a).

Overall, the composition of both the marine and non-marine palynological assemblages suggests that the sediments examined came from the Weddell Sea rather than from the Bellingshausen Sea, mostly transported via ice-rafted debris or by discharge of subglacial meltwater (Fig. 9). The sedimentary formations that crop out on the eastern side of the Antarctic Peninsula, including those on James Ross, Seymour, Joinville and Snow Hill Islands, are considered to have been the main sources of the recycled material.

Table 2
Dinoflagellate cysts and an acritarch (asterisked) recorded from the core samples examined, with author attributions and year of publication; nomenclature according to Fensome and Williams (2004) in which details of the publications concerned are provided

Amphidiadema denticulata Cookson and Eisenack, 1960a
Areosphaeridium diktyoplokum (Klumpp, 1953) Eaton, 1971
Beringiella fritilla Bujak, 1984*
Cassidinium fragile (Harris, 1965) Drugg, 1967
Chatangiella sp.
Cordosphaeridium fibrospinosum Davey and Williams, 1966b, emend. Davey, 1969c
Diconodinium cristatum Cookson and Eisenack, 1974, emend. Morgan, 1977
Enneadocysta multicornuta (Eaton, 1971), Stover and Williams, 1995
Impagidinium pallidum Bujak, 1984
Impagidinium patulum (Wall, 1967) Stover and Evitt, 1978
Isabelidinium sp.
Isabelidinium pellucidum (Deflandre and Cookson, 1955) Lentin and Williams, 1977a
Isabelidinium thomasii (Cookson and Eisenack, 1961a) Lentin and Williams, 1977a
Laciniadinium arcticum (Manum and Cookson, 1964) Lentin and Williams, 1980
Operculodinium centrocarpum (Deflandre and Cookson, 1955) Wall, 1967
Manumiella? *cretacea* (Cookson, 1956) Bujak and Davies, 1983
Nelsoniella tuberculata Cookson and Eisenack 1960a
Manumiella seelandica (Lange, 1969) Bujak and Davies, 1983, emend. Firth, 1987
Nelsoniella tuberculata Cookson and Eisenack, 1960a
Odontochitina spinosa Wilson, 1984c
Operculodinium centrocarpum (Deflandre and Cookson, 1955) Wall, 1967
Paleoperidinium pyrophorum (Ehrenburg, 1838 ex Wetzel, 1933a) Sarjeant, 1967b
Satyrodinium haumuriense (Wilson, 1984c) Lentin and Manum, 1986
Senegalinium sp.
Senegalinium? *dilwynense* (Cookson and Eisenack, 1965c) Stover and Evitt, 1978
Vozzhennikovia apertura (Wilson, 1967a) Lentin and Williams, 1976

5.3. Evolution and migration of angiosperm pollen

It is clear from the palynological and plant megafossil record that during the Late Cretaceous and Palaeogene the vegetation of the Antarctic Peninsula was much richer and more varied than today, and that it became increasingly impoverished as the climate deteriorated from the Eocene onwards (Elliot, 1985; Truswell, 1991; Hansom and Gordon, 1998), although even during the mid Late Pliocene woody angiosperms still inhabited inland Antarctica, suggesting the overall presence of a complex and diverse vegetation (Hill, 1991) that was finally obliterated during the onset of the Pleistocene glaciation.

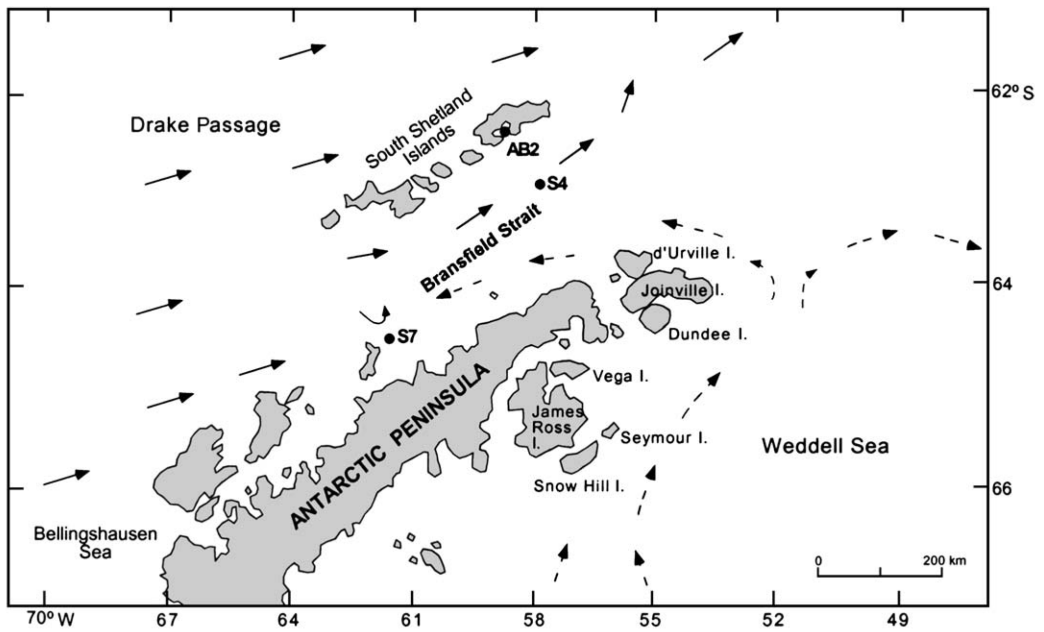


Fig. 9. Main surface currents in Bransfield Strait and vicinity. Dashed arrows indicate cold, saline Weddell Sea water; solid arrows indicate relatively warm and less saline water masses originating from the Bellingshausen Sea (cf. Byun et al., 1996, fig. 5, Bahk et al., 2003, fig. 1, and others). Arrows to the north of the South Shetland Islands indicate the Antarctic Circumpolar Current.

Angiosperms migrated into Antarctica from South America during the Cretaceous Period, and possibly also from southeast Asia via Australia (Dettmann and Jarzen, 1988; Askin, 1989; Truswell, 1990; Hill and Scriven, 1995). They speciated rapidly at these high latitudes, contributing to the development of the angiosperm vegetation that dominates the Southern Hemisphere today. The migration and evolution of early angiosperms in Gondwana was probably enhanced by the high level of disturbance caused primarily by the rifting of the supercontinent (Truswell, 1990; Hill and Scriven, 1995). The recycled palynofloras of the Bransfield Strait appear to be typical of the Weddellian Biogeographic Province. As the climate deteriorated during the Cenozoic, the angiosperm flora was reduced in biomass and diversity, finally being restricted to the remnants that are present today (Francis, 1991; Hill and Scriven, 1995).

Acknowledgements

We thank the Korea Ocean Research and Development Institute (KORDI) for providing the samples. This work was financially supported by Korea Research Foundation Grant KRF-2002-070-C00087, and in part by the project ''Earth Environmental Changes (KR-04-05)''.

References

Askin, R.A., 1983. Campanian palynomorphs from James Ross and Vega islands, Antarctic Peninsula. Antarctic Journal of United States 18, 63–64.

Askin, R.A., 1988a. Campanian to Paleocene palynological succession of Seymour and adjacent islands, northeastern Antarctic Peninsula. In: Feldmann, R.M., Woodburne, M.O. (Eds.), Geology and Paleontology of Seymour Island, Antarctic Peninsula. Geological Society of America, Memoir 169, 131–153.

Askin, R.A., 1988b. The palynological record across the Cretaceous/Tertiary transition on Seymour Island, Antarctica. In: Feldmann, R.M., Woodburne, M.O. (Eds.), Geology and Paleontology of Seymour Island, Antarctic Peninsula. Geological Society of America, Memoir 169, 155–162.

Askin, R.A., 1989. Endemism and heterochroneity in the Late Cretaceous (Campanian) to Paleocene palynofloras of Seymour Island, Antarctica: implications for origins, dispersal and paleoclimates of southern floras. In: Crame, J.A. (Ed.), Origins and Evolution of the Antarctic Biota. Geological Society, London, Special Publication 47, 107–119.

Askin, R.A., 1990a. Campanian to Paleocene spore and pollen assemblages of Seymour Island, Antarctica. Review of Palaeobotany and Palynology 65, 105–113.

Askin, R.A., 1990b. Cryptogam spores from the upper Campanian and Maastrichtian of Seymour Island, Antarctica. Micropaleontology 36, 141–156.

Askin, R.A., 1992. Late Cretaceous–early Tertiary Antarctic outcrop evidence for past vegetation and climates. In: The Antarctic Paleoenvironment: A Perspective on Global Change. Antarctic Research Series 56, 61–73.

Askin, R.A., 1997. Eocene–?earliest Oligocene terrestrial palynology of Seymour Island, Antarctica. In: Ricci, C.A. (Ed.), The Antarctic Region: Geological Evolution and Processes. Terra Antarctica Publication, Siena, 993–996.

Bahk, J.J., Yoon, H.I., Kim, Y.D., Kang, C.Y., Bae, S.H., 2003. Microfabric analysis of laminated diatom ooze (Holocene) from the eastern Bransfield Strait, Antarctic Peninsula. Geosciences Journal 7, 135–142.

Baldoni, A.M., Askin, R.A., 1993. Palynology of the lower Lefipán Formation (Upper Cretaceous) of Barranca de los Perros, Chubut Province, Argentina – Part II. Angiosperm pollen and discussion. Palynology 17, 241–264.

Barker, P.F., 1982. The Cenozoic subduction history of the Pacific margin of the Antarctic Peninsula: ridge crest–trench interactions. Journal of the Geological Society, London 139, 787–801.

Barton, C.M., 1965. The geology of the South Shetland Islands. British Antarctic Survey, Scientific Report 44, 33 pp.

Bliss, L.C., 1979. Vascular plant vegetation of the Southern Circumpolar Region in relation to Antarctic, alpine, and Arctic vegetation. Canadian Journal of Botany 57, 2167–2178.

Byun, H., Yun, H., Yi, S., Chang, S.-K., 1996. Reworked dinocysts from the Bransfield Strait, Antarctica. Journal of the Paleontological Society of Korea 12, 22–56.

Case, J.A., 1988. Paleogene floras from Seymour Island, Antarctic Peninsula. In: Feldmann, R.M., Woodburne, M.O. (Eds.), Geology and Paleontology of Seymour Island, Antarctic Peninsula. Geological Society of America, Memoir 169, 523–530.

Cookson, I.C., 1947. Plant microfossils from the lignites of Kerguelen archipelago. B.A.N.Z. Antarctic Research Expedition 1929–1931, Reports Series A 2 (8), 129–142, pls 13–17.

Dettmann, M.E., 1989. Antarctica: Cretaceous cradle of austral temperate rainforests? In: Crame, J.A. (Ed.), Origins and Evolution of the Antarctic Biota. Geological Society, London, Special Publication 47, 89–105.

Dettmann, M.E., Jarzen, D.M., 1988. Angiosperm pollen from uppermost Cretaceous strata of southeastern Australia and the Antarctic Peninsula. In: Jell, P.A., Playford, G. (Eds.), Palynological and Palaeobotanical Studies in Honour of Basil E. Balme. Association of Australasian Palaeontologists, Memoir 5, 217–237.

Dettmann, M.E., Thomson, M.R.A., 1987. Cretaceous palynomorphs from the James Ross Island area, Antarctica – a pilot study. British Antarctic Survey, Bulletin 77, 13–59.

Dutra, T.L., Batten, D.J., 2000. Upper Cretaceous floras of King George Island, West Antarctica, and their palaeoenvironmental and phytogeographic implications. Cretaceous Research 21, 181–209.

Elliot, D.H., 1985. Physical geography–geological evolution. In: Bonner, W.N., Walton, D.W.H. (Eds.), Key Environments. Antarctica. Pergamon Press, Oxford, 39–61.

Fensome, R.A., Williams, G.L., 2004. The Lentin and Williams index of fossil dinoflagellates, 2004 edition. American Association of Stratigraphic Palynologists, Contributions Series 42, 909 pp.

Francis, J.E., 1986. Growth rings in Cretaceous and Tertiary wood from Antarctica and their palaeoclimatic implications. Palaeontology 29, 665–684.

Francis, J.E., 1991. Paleoclimatic significance of Cretaceous–early Tertiary fossil forests of the Antarctic Peninsula. In: Thomson, M.R.A., Crame, J.A., Thomson, J.W. (Eds.), Geological Evolution of Antarctica. Cambridge University Press, Cambridge, 623–627.

Francis, J.E., Poole, I., 2002. Cretaceous and early Tertiary climates of Antarctica: evidence from fossil wood. Palaeogeography, Palaeoclimatology, Palaeoecology 182, 47–64.

Gamboa, L.A.P., Maldonado, P.R., 1990. Geophysical investigations in the Bransfield Strait and in the Bellingshausen Sea – Antarctica. In: St John, B. (Ed.), Antarctica as an Exploration Frontier: Hydrocarbon Potential, Geology and Hazards. American Association of Petroleum Geologists, Studies in Geology 31, 127–141.

Germeraad, J.H., Hopping, C.A., Muller, J., 1968. Palynology of Tertiary sediments from tropical areas. Review of Palaeobotany and Palynology 6, 189–348.

González-Ferrán, O., 1985. Volcanic and tectonic evolution of the northern Antarctic Peninsula – Late Cenozoic to Recent. In: Husebye, E.S., Johnson, G.L., Kristoffersen, Y. (Eds.), Geophysics of the Polar Regions. Tectonophysics 114, 389–409.

Grimm, E., 1991. TILIAGRAPH v1.25 (computer software) Illinois State Museum, Research and Collections Center, Springfield.

Grimm, E., 1993. TILIA v2.0 (computer software) Illinois State Museum, Research and Collections Center, Springfield.

Hansom, J.D., Gordon, J.E., 1998. Antarctic Environments and Resources: A Geographical Perspective. Longman, Essex, xiv + 402 pp.

Hill, R.S., 1991. Tertiary *Nothofagus* (Fagaceae) macrofossils from Tasmania and Antarctica and their bearing on the evolution of the genus. Botanical Journal of the Linnean Society 105, 73–112.

Hill, R.S., Scriven, L.J., 1995. The angiosperm-dominated woody vegetation of Antarctica: a review. Review of Palaeobotany and Palynology 86, 175–198.

Jeffers, J.D., Anderson, J.B., 1991. Sequence stratigraphy of the Bransfield Basin, Antarctica: implications for tectonic history and hydrocarbon potential. In: St John, B. (Ed.), Antarctica as an Exploration Frontier: Hydrocarbon Potential, Geology and Hazards. American Association of Petroleum Geologists, Studies in Geology 31, 13–30.

Kemp, E.M., 1972. Reworked palynomorphs from the West Ice Shelf area, East Antarctica, and their possible geological and palaeoclimatological significance. Marine Geology 13, 145–157.

Khim, B.-K., Yoon, H.I., Kang, C.Y., Bahk, J.J., 2002. Unstable climate oscillations during the Late Holocene in the eastern Bransfield Basin, Antarctic Peninsula. Quaternary Research 58, 234–245.

Lawver, L.A., Sclater, J.G., Meinke, L., 1985. Mesozoic and Cenozoic reconstructions of the South Atlantic. In: Husebye, E.S., Johnson, G.L., Kristoffersen, Y. (Eds.), Geophysics of the Polar Regions. Tectonophysics 114, 233–254.

Lee, Y.G., 1996. Micropaleontological (diatoms) study of the core sediments in the Bransfield Strait, Antarctica. Journal of the Paleontological Society of Korea 12, 1–21.

Longton, R.E., 1985. Terrestrial habitats – vegetation. In: Bonner, W.N., Walton, D.W.H. (Eds.), Key Environments. Antarctica. Pergamon Press, Oxford, 73–105.

López, O., Garćia, M.A., Gomis, D., Rojas, P., Sospedra, J., Sánchez-Arcilla, A., 1999. Hydrographic and hydrodynamic characteristics of the eastern basin of the Bransfield Strait (Antarctica). Deep-Sea Research, I 46, 1755–1778.

Moore, P.D., Webb, J.A., Collinson, M.E., 1991. Pollen Analysis, second ed. Blackwell Scientific Publications, Oxford, viii + 216 pp.

Park, B.K., Choi, M.Y., Chang, S.K., Cheong, D.K., Shin, D.H., Park, J.K., Ju, Y., Kang, C.Y., 1992. Sedimentological and engineering geological characteristics of cores drilled in the Bransfield Strait, Antarctic Peninsula. In: Antarctic Environments and Natural Resource Exploration. Report of Korea Ocean Research and Development Institute, Ansan, 89–135 (in Korean).

Pirrie, D., Crame, J.A., Riding, J.B., 1991. Late Cretaceous stratigraphy and sedimentology of Cape Lamb, Vega Island, Antarctica. Cretaceous Research 12, 227–258.

Pirrie, D., Crame, J.A., Lomas, S.A., Riding, J.B., 1997. Late Cretaceous stratigraphy of the Admiralty Sound region, James Ross Basin, Antarctica. Cretaceous Research 18, 109–137.

Pocknall, D.T., Crosbie, Y.M., 1988. Pollen morphology of *Beauprea* (Proteaceae): modern and fossil. Review of Palaeobotany and Palynology 53, 305–327.

Powell, R.D., 1984. Glacimarine processes and inductive lithofacies modelling of ice shelf and tidewater glacier sediments based on Quaternary examples. Marine Geology 57, 1–52.

Prieto, M.J., Gràcia, E., Canals, M., Ercilla, G., De Batist, M., 1997. Sedimentary history of the central Bransfield Basin (NW Antarctic Peninsula). In: Ricci, C.A. (Ed.), The Antarctic Region: Geological Evolution and Processes. Terra Antarctica Publication, Siena, pp. 711–717.

Shin, Y., Yoon, H.I., Kim, Y., Kang, C.Y., 2001. Diatom assemblages and its [sic] paleoceanography of the Holocene glaciomarine sediments from the western Antarctic Peninsula shelf, Antarctica. The Sea. Journal of the Korean Society of Oceanography 6, 152–163 (in Korean, English abstract).

Smellie, J.L., Pankhurst, R.J., Thomson, M.R.A., Davies, R.E.S., 1984. The Geology of the South Shetland Islands: VI. Stratigraphy, Geochemistry and Evolution. British Antarctic Survey, Scientific Report 87, 85 pp.

Sumner, P.W., 1992. Dinoflagellate cysts from the Rabot Member (Santa Marta Formation) of eastern James Ross Island. Antarctic Science 4, 305–310.

Truswell, E.M., 1982. Palynology of seafloor samples collected by the 1911–14 Australasian Antarctic expedition: implications for the geology of coastal East Antarctica. Journal of the Geological Society of Australia 29, 343–356.

Truswell, E.M., 1983. Recycled Cretaceous and Tertiary pollen and spores in Antarctic marine sediments: a catalogue. Palaeontographica Abteilung B 186, 121–174, 6 pls.

Truswell, E.M., 1990. Cretaceous and Tertiary vegetation of Antarctica: a palynological perspective. In: Taylor, T.N., Taylor, E.L. (Eds.), Antarctic Paleobiology. Its Role in the Reconstruction of Gondwana. Springer-Verlag, New York, 71–88.

Truswell, E.M., 1991. Antarctica: a history of terrestrial vegetation. In: Tingey, R.J. (Ed.), The Geology of Antarctica. Clarendon Press, Oxford, 499–537.

Truswell, E.M., Drewry, D.J., 1984. Distribution and provenance of recycled palynomorphs in surficial sediments of the Ross Sea, Antarctica. Marine Geology 59, 187–214.

Walton, D.W.H., Bonner, W.N., 1985. Terrestrial habitats. In: Bonner, W.N., Walton, D.W.H. (Eds.), Key Environments: Antarctica. Pergamon Press, Oxford, 71–72.

Watts, D.R., 1982. Potassium-argon ages and paleomagnetic results from King George Island, South Shetland Islands. In: Craddock, C. (Ed.), Antarctic Geoscience. University of Wisconsin Press, Madison, pp. 255–261.

Weaver, S.D., Saunders, A.D., Tarney, J., 1982. Mesozoic–Cenozoic volcanism on the South Shetland Islands and the Antarctic Peninsula: geochemical nature and plate tectonic significance. In: Craddock, C. (Ed.), Antarctic Geoscience. University of Wisconsin Press, Madison, pp. 263–273.

Whitworth III, T., Nowlin Jr., W.D., Orsi, A.H., Locarnini, R.A., Smith, S.G., 1994. Weddell Sea shelf water in the Bransfield Strait and Weddell–Scotia confluence. Deep-Sea Research, I 41, 629–641.

Wood, S.E., Askin, R.A., 1992. Dinoflagellate cysts from the Marambio Group (Upper Cretaceous) of Humps Island. Antarctic Science 4, 327–336.

Yi, S., Yun, H., Byun, H., Chang, S.-K., 1995. Quaternary silicoflagellates from the core sediments of the Bransfield Strait, Antarctica. Journal of the Paleontological Society of Korea 11, 61–78 (in Korean, English abstract and systematic section).

Yoon, H.I., 1995. Glaciomarine sedimentation patterns of Bransfield Strait and adjoining fjords in South Shetland Islands, Antarctica: implications for Late Quaternary glacial history. PhD thesis, Inha University, Incheon, Korea, 273 pp.

Yoon, H.I., Park, B.-K., Kim, Y., Kim, D., 2000. Glaciomarine sedimentation and its paleoceanographic implications along the fjord margins in the South Shetland Islands, Antarctica during the last 6000 years. Palaeogeography, Palaeoclimatology, Palaeoecology 157, 189–211.

Yoon, S.H., Yoon, H.I., Howe, J., 2002. High-resolution echo facies analysis of glacial-marine deposits in Bransfield Strait, Antarctica. Journal of the Geological Society of Korea 38, 537–550 (in Korean, English abstract).