

Recent benthonic foraminifera from the Western Antarctic Ocean

R. W. JONES¹ & C. A. PUDSEY²

¹BP Exploration (Frontier & International), 5 Long Walk, Stockley Park, Uxbridge, Middlesex UB11 1BP, UK.

²British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, UK.

ABSTRACT - Approximately 60 species of benthonic foraminifera are recorded from 14 samples collected by the RRS *Discovery* from water depths of 200–4200 m on the Antarctic Peninsula Shelf and Slope and adjacent areas of the Western Antarctic Ocean. Discussion focuses firstly on benthonic foraminiferal abundance, diversity and assemblage composition and the effects of calcite dissolution and, secondly, on the characteristic assemblages of the study area and their relationships to water-masses. *J. Micropalaeontol.* 13(1): 17–23, September 1994.

INTRODUCTION

Previous studies

In contrast to the Arctic, the Antarctic or Southern Ocean (i.e. the area between Antarctica and the Subtropical Convergence at about 40–50°S) received scant attention from foraminiferologists in the last century.

The earliest account of the Recent benthonic foraminifera from the area is that of Brady (1884), who described the material collected from around Heard Island and Kerguelen Island during the cruise of HMS *Challenger* (1872–6).

Most of the pioneering work was done in the early part of this century by, among others, Heron-Allen & Earland (1922, 1929, 1932) and Earland (1933, 1934, 1936) (foraminifera collected on the various *Discovery I* and *II*, *Scotia*, *Terra Nova* and *William Scoresby* Expeditions of the 1920s), Wiesner (1931) (German South Polar Expedition of 1901–3), Parr (1950) (BANZ Antarctic Research Expedition of 1929–31) and Shchedrina (1979) (Soviet Antarctic Expedition of 1955–66). The trochamminacean foraminifera described by Heron-Allen and Earland have recently been comprehensively revised by Brönnimann & Whittaker (1988).

Subsequent work has been undertaken by, among others, Saidova (1961), Bandy & Echols (1964) and Theyer (1971) (general); McKnight (1962), Pflum (1966), Kennett (1967, 1968), Echols & Kennett (1973), Fillon (1974), Kellogg *et al.* (1979), Osterman & Kellogg (1979), Milam & Anderson (1981), Nomura (1983, 1984) (surface and shallow subsurface sediments); Quilty (1985) and Schroder-Adams (1990) (Eastern Antarctica) (Lutzow-Holm Bay, Prydz Bay, Adelie-George V Land and Ross Sea); Pflum (1966), Echols (1971), Herb (1971), Anderson (1975), Lena (1975, 1980), Pudsey *et al.* (1987) (surface and shallow subsurface sediments); Mackensen *et al.* (1990) (Western Antarctica) (South Sandwich, Scotia Sea, South Orkneys, Drake Passage, Weddell Sea, Antarctic Peninsula, Bellingshausen Sea and Amundsen Sea); and Lindenberg & Auras (1984) (Kerguelen Plateau).

The most recent reference to hand is that of Murray (1991), which provides a concise and extremely useful synthesis of ecological information on nearshore and shelf to

deep sea areas (with specific reference to the Weddell Sea, Prydz Bay, McMurdo Sound and the Ross Sea, the Amundsen and Bellingshausen Seas, and the Drake Passage and Scotia Seas).

The high-resolution diatom stratigraphy of the Quaternary of the Scotia Sea is discussed by Jordan & Pudsey (1992).

The geology of Antarctica is discussed by, among others, St John (1990).

Present study

The present study focuses on samples collected in the Western Antarctic Ocean on RRS *Discovery* Cruises 154 (January–April 1985) and 172 (December 1987–March 1988) (Fig. 1).

The studied surface samples comprised seven from the Antarctic Peninsula Shelf, two from South Sandwich (one of which could, in fact, be of Latest Pliocene–Early Pleistocene rather than Holocene age), two from the Drake Passage, two from the Scotia Sea, and one from the Antarctic Peninsula Slope. Full location, depth and lithological details are given on Table 1.

Full suites of oceanographic data pertaining to the study sites are held by the British Antarctic Survey (BAS) in Cambridge. The bottom temperature and current velocity data documented in the succeeding section are extracted from the BAS database.

The hydrographic regime of the study area is discussed by Gordon (1971), Deacon (1979), Kilworth (1983), Patterson & Sievers (1980), Foster & Middleton (1984), Sievers & Nowlin (1984), Nowlin & Zenk (1988), Pudsey *et al.* (1988) and Jordan & Pudsey (1992) (and references therein). The palaeohydrographic regime is discussed by Barker *et al.* (1988).

There are two deep water-masses in the study area at the present time, namely Circumpolar Deep Water (CPDW) and Antarctic Bottom Water (AABW). CPDW (with bottom potential temperature $\theta = 0.0$ – 1.0°C and salinity $S = 34.70$ – 34.73 ppt; Sievers & Nowlin, 1984) flows eastward through the Drake Passage and the Scotia Sea as the Antarctic Circumpolar Current. This current is approximately coincident with the Polar Front (Fig. 1), and passes

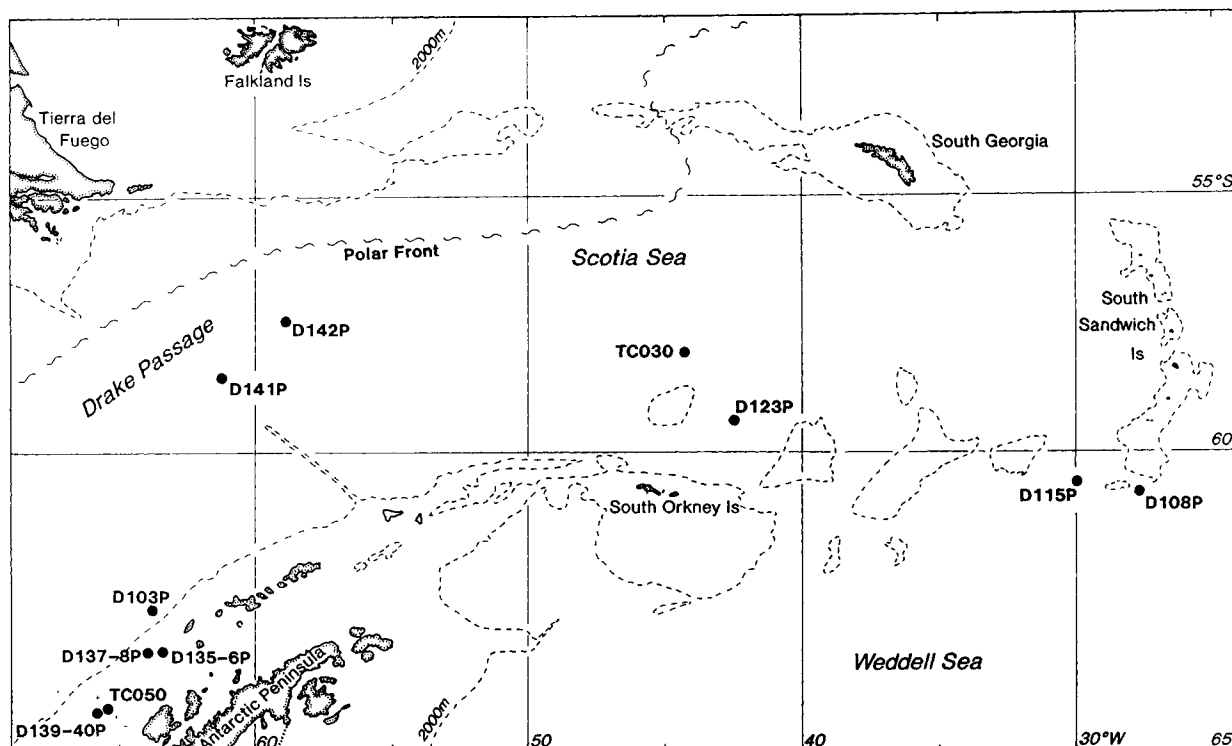


Fig. 1. Location map.

from the Scotia Sea to the Southwest Atlantic at about 45°W. AABW ($\theta = <0.0^\circ\text{C}$; $S = 34.65\text{--}34.67$ ppt) flows eastwards in the northern limb of the cyclonic Weddell Gyre in the Northern Weddell Sea (Deacon, 1979). Some AABW flows into the southern Scotia Sea (Gordon, 1971; Jordan & Pudsey, 1992 (and references therein)). Indeed, cold deep water of Weddell Sea type has been detected as far west as the South Shetlands (Nowlin & Zenk, 1988). CPDW and AABW meet at the so-called Weddell–Scotia Confluence (Patterson & Sievers, 1980), which widens and becomes more diffuse east of the South Orkneys (Foster & Middleton, 1984).

Comparatively little is known of the shallow water-masses of the study area. However, unpublished expendable bathythermograph (XBT) measurements show bottom temperatures to be around 1.3°C . This suggests that the Antarctic Peninsula Shelf, unlike other shelf areas around the Antarctic, is not a reservoir of cold, dense water (Kilworth, 1983).

Material. Fourteen surface samples were made available for foraminiferal analysis through the good offices of the British Antarctic Survey, together with another ten shallow subsurface samples (which were ignored other than for systematic purposes as they were too few in

Sample	Latitude	Longitude	Area	Depth (m)	Lithology
D103P	62°42'S	63°49'W	Antarctic Peninsula Slope	4200	Silty mud
D108P	60°44'S	27°37'W	South Sandwich	3000–3200	Ashy mud
D115P	60°31'S	29°56'W	South Sandwich	2425–2700	Ashy mud* 1
D123P	59°23'S	42°28'W	Scotia Sea	2900	Silty ooze
D135P	63°25'S	63°25'W	Antarctic Peninsula Shelf	340–550	Ashy mud
D136P	63°25'S	63°28'W	Antarctic Peninsula Shelf	500	Silty mud
D137P	63°25'S	64°02'W	Antarctic Peninsula Shelf	200	Crystal–vitric ash
D138P	63°23'S	64°06'W	Antarctic Peninsula Shelf	280	Vitric ash
D139P	64°24'S	65°47'W	Antarctic Peninsula Shelf	500	Sandy mud
D140P	64°24'S	65°46'W	Antarctic Peninsula Shelf	390–480	Sandy mud
D141P	58°35'S	61°13'W	Drake Passage	1960–2700	Sandy mud
D142P	57°29'S	58°54'W	Drake Passage	2550–3000	Sandy mud
878TC030 05 cm	58°06'S	44°17'W	Scotia Sea	2730	Mud-bearing ooze
878TC050 CC* 2	64°19'S	65°27'W	Antarctic Peninsula Shelf	575	Muddy ooze

Table 1. Sample database. *1 Diatom evidence indicates that this sample might be latest Pliocene to Early Pleistocene, rather than Holocene, in age; *2 from core catcher (within 20 cm of sediment surface).

number to provide any meaningful regional stratigraphic or palaeoenvironmental information).

Two of the samples (878TC030 0–5 cm and 878TC050 CC) were from trigger cores. The remaining twelve (prefixed D) were obtained opportunistically using a pipe dredge rigged beneath a rock dredge being dragged up slope in order to sample hard rocks (basalts, metasediments, etc.) in connection with various tectonic studies. A pipe dredge deployed like this (see also Kidd *et al.* (1990)) can collect a large quantity (up to 30–40 l) of soft sediment, of which 1–2 l is normally retained for study. It probably fills up almost immediately on striking the sea-floor rather than gradually over a range of depths. However, it can sink into soft sediment under its own weight and retrieve sediment from the shallow subsurface rather than from the surface. As noted below, the sample from Station D115P could be of Latest Pliocene–Early Pleistocene, rather than Holocene, age.

Methods. 10 cm³ splits of the study samples, stained for live protoplasm (using Rose Bengal), were disaggregated using standard micropalaeontological techniques. The dried disaggregated material was then passed through a nest of sieves (the finest one of which has a 75 µm mesh), and the benthonic foraminifera from each sieve fraction were picked, sorted and identified.

RESULTS

The semiquantitative distribution of benthonic foraminiferal species in the studied samples is shown in Table 2. Note that all of the species were only recorded 'dead' (unstained by Rose Bengal).

Antarctic Peninsula Shelf

The seven samples from the Antarctic Peninsula Shelf are from water depths of 200–575 m (Table 1). At the sampling stations, lithologies vary from oozes and silty and sandy muds to ashy muds and crystal and/or vitric volcanic ashes (some are situated on the flanks of volcanoes) (Table 1). At D140P, the bottom temperature is 1.3°C, and the current velocity up to 25 cm s⁻¹.

The Antarctic Peninsula Shelf samples are generally characterized by low benthonic foraminiferal abundance and diversity. One (D139P) is barren. Agglutinating and calcareous benthonic foraminifera occur in equal proportions. Rare planktonic foraminifera (*Neogloboquadrina pachyderma*) and locally abundant siliceous plankton (diatoms) also occur.

Abundance and diversity are highest in D140P (480 m) and D135P (550 m), which are situated on topographic 'highs' on the deeper parts of the shelf. Conspicuous benthonic foraminiferal taxa, common or abundant in one or other of these samples, include Hormosininae div. spp., *Quinqueloculina* spp. and *Trifarina angulosa*.

Drake Passage

The two samples from the Drake Passage are from water depths of 2700–3000 m. At both the sampling stations, the lithologies are 'sandy muds', the bottom temperature 0 to –0.5°C, and the current 'strong'. The samples are characterized by moderate benthonic foraminiferal abundance

and diversity. Agglutinating and calcareous benthonic foraminifera occur in equal proportions. The most conspicuous species are *Martinottiella communis*, *Pyrgo murrhina*, *Uvigerina* sp. and *Cibicides* ex gr. *lobatulus*. Abundant planktonic foraminifera (*Globigerina bulloides*, *Globorotalia* spp., *Neogloboquadrina pachyderma*) also occur.

South Sandwich

The two samples from South Sandwich are from water depths of 2700–3200 m. At both the sampling stations, lithologies are 'diatom-bearing ashy muds'. At D108P, the bottom temperature is 0 to –0.5°C, and the current velocity 4–5 cm s⁻¹.

The sample from D108P is characterized by low to moderate benthonic foraminiferal abundance and diversity. Agglutinating foraminifera predominate, and indeterminate astrophorids are common. Planktonic foraminifera (*Neogloboquadrina pachyderma*) and diatoms also occur.

The sample from D115P is also characterized by low to moderate benthonic foraminiferal abundance and diversity, with agglutinating foraminifera predominant. Planktonic foraminifera (*Neogloboquadrina pachyderma*) and diatoms also occur. The diatoms include *Actinocyclus ingens*, *Coscinodiscus elliptopora* and ?reworked *Denticulopsis* sp., indicating that this sample could be of Latest Pliocene–Early Pleistocene, rather than Holocene, age.

Scotia Sea

The two samples from the Scotia Sea are from water depths of 2730–2900 m. At D123P, the lithology is a 'silty ooze', and the bottom temperature is 0 to –0.3°C. At 878TC030, the lithology is a 'mud-bearing ooze'. The samples are characterized by low benthonic foraminiferal abundance and diversity. Only agglutinating species are found. *Cribratommoides subglobosus* and *Martinottiella communis* are common in D123P (2900 m). Diatoms are abundant in both D123P and 878TC030.

Antarctic Peninsula Slope

The sample from the Antarctic Peninsula Slope is from a water depth of 4200 m. The lithology at the sampling station is a 'silty mud'. The bottom temperature is 0.2–0.4°C, and the current velocity up to 10 cm s⁻¹. The sample is characterized by low benthonic foraminiferal abundance and diversity. Agglutinating foraminifera predominate. The only calcareous foraminifera found are a single indeterminate benthonic species, and a single reworked Cretaceous planktonic species (*Globigerinelloides* sp.). Indeterminate astrophorids, *Cribratommoides subglobosus* and *Martinottiella communis* are all common. Diatoms are again abundant.

DISCUSSION

Abundance, diversity and assemblage composition, and the effects of calcite dissolution

To summarize the results given above, the study samples as a whole are characterized by low to moderate benthonic foraminiferal abundance and diversity (which may be at least in part attributable to the small sample size). The highest values are associated with mid-shelf topographic

Table 2. Distribution of foraminiferal species. Samples arranged in order of increasing depth: APSH = Antarctic Peninsula Shelf, DP = Drake Passage, SSa = South Sandwich, Sc = Scotia Sea, APSL = Antarctic Peninsula Slope; *P. fusca* = *Psammospaera fusca*, *B. hirudinea* = *Bathysiphon hirudinea*, *M. elongata* = *Marsipella elongata*, *R. discreta* = *Rhabdammina discreta*, *S. ramosa* = *Saccorhiza ramosa*, *A. clavata* = *Ammolagena clavata*, *U. charoides* = *Uzbekistania charoides*, *R. gaussicus* = *Reophax gaussicus*, *R. cf. pilulifer* = *Reophax cf. pilulifer*, *C. pauciloculata* = *Cystammina pauciloculata*, *L. scitula* = *Labrospira scitula*, *R. contortus* = *Recurvirox contortus*, *C. pusilla* = *Cyclammina pusilla*, *C. rotundidorsata* = *Cyclammina rotundidorsata*, *M. communis* = *Martinotiella communis*, *E. bradyi* = *Esgerella bradyi*, *P. murrhina* = *Pyrgo murrhina*, *P. rotalaria* = *Pyrgo rotalaria*, *P. venusta* = *Quinqueloculina venusta*, *E. exculpta* = *Excultina exculpta*, *F. abeolata* = *Fissurina abeolata*, *P. ex gr. lateralis* = *Parafissurina ex gr. lateralis*, *P. dorbignyana* = *Pseudofissurina dorbignyana* (syn. *p. mcullochae*), *B. elongata* = *Bulimina elongata*, *T. angulosa* = *Trifarina angulosa*, *C. porrectus* = *Cassidulinoides porrectus*, *G. subglobosa* = *Globocassidulina pacifica*, *G. subglobosa* = *Globocassidulina subglobosa*, *H. elegans* = *Hoeglundina elegans*, *L. pauperata* = *Laticarinina pauperata*, *G. soldanii* = *Gyroidinoides soldanii*, *O. weddellensis* = *Alabaminella weddellensis*, *O. umbonatus* = *Oridorsalis umbonatus*, *O. umbonifera* = *Osangulariella umbonifera*, *C. ex. gr. lobatulus* = *Cibicides ex gr. lobatulus*, *C. refugens* = *Cibicides refugens*, *P. bulloides* = *Pullenia bulloides*, *P. subcarinata* = *Pullenia subcarinata*, *M. affinis* = *Melonis affinis*, *M. pompilioides* = *Melonis pompilioides*, *1 from core catcher (within 20 cm of sediment surface); *2 diatom evidence indicates that this sample might be latest Pliocene to Early Pleistocene, rather than Holocene, in age; *3 subsurface only.

P = present (1–4 specimens/sample); C = common (5–19 specimens/sample); A = abundant (>20 specimens/sample).

'highs' on the Antarctic Peninsula Shelf (480–550 m), and in the Drake Passage (2700–3000 m). Values are low by comparison with those obtained from bathyal and abyssal samples from low to moderate latitudes, but closely comparable with those obtained from bathyal and abyssal samples from high latitudes in the northern hemisphere (Jones, 1984).

Agglutinating and calcareous benthonic species occur in equal proportions in the study samples on the Antarctic Peninsula Shelf (200–575 m), while agglutinating species generally predominate on the Antarctic Peninsula Slope and in South Sandwich, the Drake Passage and the Scotia Sea (2700–4200 m). This is probably at least partly explicable in terms of local inhibition of secretion (and/or preservation) of calcareous tests in corrosive, carbon dioxide-enriched bottom water. Note, however, that the relation between the preservation and partial or total dissolution of calcareous foraminifera is dependent less on depth than on water-mass association (see Murray, 1991; see also below).

Planktonic foraminifera (calcareous) and diatoms (siliceous) are widespread and locally abundant in the study samples. Planktonic foraminifera are most common in the Drake Passage (2700–2900 m), where they occur to the total exclusion of diatoms. Diatoms are most common in the Scotia Sea (2730–2900 m), and on the Antarctic Peninsula Slope (4200 m), where they occur to the total exclusion of planktonic foraminifera (possibly because of dissolution effects at or near the local calcite compensation depth (CCD)).

Characteristic assemblages and their relationships to water-masses

Conspicuous benthonic foraminiferal taxa, common or abundant in one or more samples, include Hormosininae div. spp., *Quinqueloculina* spp. and *Trifarina angulosa* (Antarctic Peninsula Shelf, 480–550 m), *Pyrgo murrhina*, *Uvigerina* sp. and *Cibicides* ex gr. *lobatulus* (Drake Passage, 2700–3000 m), *Martinottiella communis* (Drake Passage, 2700–3000 m, Scotia Sea, 2900 m, and Antarctic Peninsula Slope, 4200 m), *Cribr stomoides subglobosus* (Scotia Sea, 2900 m, and Antarctic Peninsula Slope, 4200 m), and indeterminate astrorhizids (South Sandwich, 3200 m, and Antarctic Peninsula Slope, 4200 m).

The Antarctic Peninsula Shelf assemblages locally characterized by Hormosininae div. spp., *Quinqueloculina* spp., and *Trifarina angulosa* (200–575 m) are similar to those of the 'Fresh Shelf Water Facies' of Anderson (1975), the '*Trifarina angulosa* Assemblage' of Mackensen *et al.* (1990), and the '*Trifarina angulosa/earlandi* Association' of Murray (1991) (which are typically similarly dominated by calcareous foraminifera, though locally affected by partial dissolution). Mackensen *et al.* (1990) recorded their *Trifarina angulosa* Assemblage 'live' and 'dead' at the shelf break and on the uppermost continental slope, and in predominantly sandy sediments (in areas of strong bottom currents) (in the Eastern Weddell Sea). Murray (1991) recorded his *Trifarina angulosa/earlandi* Association in water depths of 0–2100 m (348–713 m in the Weddell Sea), in muddy sandy lithologies, and in bottom temperatures of

–1.9 to 0.6°C. He inferred a correlation with Fresh Shelf Water, a variant of Antarctic Surface Water occurring in ice-free areas in the Weddell Sea.

The Drake Passage assemblages characterized by *Pyrgo murrhina*, *Uvigerina* sp. and *Cibicides* ex gr. *lobatulus* (2700–3000 m) are similar to those of the 'Deep Water Calcareous–Arenaceous Facies' of Anderson (1975) and the '*Cassidulina crassa* Association of Murray (1991) (which are dominated by calcareous foraminifera). Murray (1991) recorded his *Cassidulina crassa* Association in water depths of 50–4008 m (104–4008 m in the Drake Passage and Scotia Sea), in fine sandy lithologies, and in bottom temperatures of –1.9 to 0.6°C and salinities of 33.96–35.19 ppt. These temperature and salinity ranges embrace those of both CPDW and AABW.

The South Sandwich assemblage, characterized by indeterminate astrorhizids (3200 m), and the Antarctic Peninsula Slope assemblage, characterized by indeterminate astrorhizids, *Cribr stomoides subglobosus* and *Martinottiella communis* (4200 m), are similar to the 'Abyssal Facies' of Anderson (1975), the '*Cribr stomoides subglobosus* Assemblage' of Mackensen *et al.* (1990) and the '*Cribr stomoides subglobosum* Association' of Murray (which are dominated by agglutinating foraminifera). Mackensen *et al.* (1990) recorded their *Cribr stomoides subglobosus* Assemblage 'live' on the continental terrace and abyssal plain between 2500–3000 m (in the Eastern Weddell Sea). Interestingly, they noted that '... because of rapid disintegration of the empty tests of this ... species [*Cribr stomoides subglobosus*] a predominantly calcareous fauna characterised by *Oridorsalis umbonatus* ... comprises the dead assemblage ...'. The poor preservation potential of some agglutinating species is also alluded to by Jones (1984) (Eastern North Atlantic) and Schroder (1986) (Western North Atlantic). Murray (1991) recorded his '*Cribr stomoides subglobosum* Association' in water depths of 3022–5587 m (3022–4099 m in the Drake Passage and Scotia Sea and 3737 m in the Weddell Sea). From the data of both Mackensen *et al.* and Murray, there appears to be a positive correlation with AABW.

The Scotia Sea assemblage, characterized by *Martinottiella communis* and *Cribr stomoides subglobosus* (2900 m), is intermediate in character between the 'Deep Water Calcareous–Arenaceous' and 'Abyssal' Facies of Anderson (1975) or the '*Cassidulina crassa*' and '*Cribr stomoides subglobosum*' Associations of Murray (1991) (see above). Murray (1991) inferred no correlation between foraminiferal associations and water-masses in the Scotia Arc area, commenting that there '... the distribution of water masses is complex and poorly understood ...'.

CONCLUSIONS

The study samples, from water depths of 200–4200 m on the Antarctic Peninsula Shelf and Slope and adjacent areas of the Western Antarctic Ocean, are characterized by generally low to moderate benthonic foraminiferal abundance and diversity (which may be at least in part attributable to the small sample size). Agglutinating and calcareous benthonic species occur in equal proportions in the study samples from

200–575 m, while agglutinating species generally predominate in the samples from 2700–4200 m. The low abundance and diversity values and shallow threshold to agglutinate-dominated assemblages may both be related to inhibition of secretion (and/or preservation) of calcareous tests in corrosive bottom waters.

Antarctic Peninsula Shelf assemblages, locally characterized by Hormosininae div. spp., *Quinqueloculina* spp., and *Trifarina angulosa* (200–575 m), are similar to those of the 'Fresh Shelf Water Facies' of Anderson (1975), the '*Trifarina angulosa* Assemblage' of Mackensen *et al.* (1990), and the '*Trifarina angulosa/earlandi* Association' of Murray (1991), which may be correlated with Fresh Shelf Water (a variant of Antarctic Surface Water occurring in ice-free areas in the Weddell Sea).

Drake Passage assemblages, characterized by *Pyrgo murrhina*, *Uvigerina* sp. and *Cibicides* ex gr. *lobatulus* (2700–3000 m), are similar to those of the 'Deep Water Calcareous–Arenaceous Facies' of Anderson (1975) and the '*Cassidulina crassa* Association' of Murray (1991), which can be correlated with either CPDW or AABW.

The South Sandwich assemblage, characterized by indeterminate astrorhizids (3200 m), and the Antarctic Peninsula Slope assemblage, characterized by indeterminate astrorhizids, *Cribr stomoides subglobosus* and *Martinottiella communis* (4200 m), are similar to the 'Abyssal Facies' of Anderson (1975), the '*Cribr stomoides subglobosus* Assemblage' of Mackensen *et al.* (1990), and the '*Cribr stomoides subglobosum* Association' of Murray (1991), which appear to be correlated with AABW.

The Scotia Sea assemblage, characterized by *Martinottiella communis* and *Cribr stomoides subglobosus* (2900 m), is intermediate in character between the 'Deep Water Calcareous–Arenaceous' and 'Abyssal' Facies of Anderson (1975) or the '*Cassidulina crassa*' and '*Cribr stomoides subglobosum*' Associations of Murray (1991).

ACKNOWLEDGEMENTS

Grateful thanks are due to the British Antarctic Survey for providing the study samples, to BAS and the British Petroleum Company PLC for granting permission to publish (and for providing preparation facilities), and to Mairead Rutherford of BP, who produced the tables. The constructive criticism of Prof. F. T. Banner is also gratefully acknowledged.

Manuscript received August 1992

Manuscript accepted June 1993

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