



Monothalamous foraminifera from Admiralty Bay, King George Island, West Antarctica

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Abstract: During the late 2007 austral summer, 20 sediment samples were collected in Admiralty Bay (King George Island, South Shetlands, West Antarctica) from 8 down to 254 m water-depth (mwd). The samples yielded abundant assemblage of monothalamous benthic foraminifera, belonging to at least 40 morphospecies. They constituted the first such collection from Antarctic Peninsula fjords and provided a new insight into this group's diversity and distribution. Among organic-walled taxa, *Psammophaga* sp., *Allogromia* cf. *crystallifera*, and three morphotypes of *Gloioquillina* were especially abundant. Agglutinated forms were dominated by *Hippocrepinella hirudinea*, *Psammospaera* spp., *Lagenammia* spp., and various mudballs. Although, the majority of the morphotypes were known from other high-latitude locations, some were reported for the first time. Our quantitative data (>125 µm) showed the greatest differences between monothalamous foraminifera assemblages at shallowest water depths above 50 mwd. The deepest assemblages from between 179 and 254 mwd, were most similar, suggesting uniform near-bottom conditions at ~200 mwd throughout the Admiralty Bay.

Key words: Antarctica, South Shetlands, Foraminifera, Recent.

Introduction

For decades, foraminifera have been used for reconstructing past environments and contributed a great deal to our knowledge of ecological changes. These studies focused, however, on robust, multilocular testate forms, which could be preserved in fossil record. Very little is known about the diversity of unilocular (monothalamous) benthic foraminifera, despite the fact that they are particularly abundant in high latitude settings (Gooday 2002). This group is characterized by

single-chambered organic-walled or agglutinated tests and has been traditionally split into the orders Allogromiida and Astrorhizida (Sen Gupta 1999). However, the wall-structure-based distinction between these two orders has not been confirmed by molecular studies (Pawlowski *et al.* 2003). These studies suggest that the higher-level phylogenetic relations within this group are quite complex (Pawlowski *et al.* 2002b) and the diversity is largely underestimated (Pawlowski *et al.* 2002a).

Antarctic monothalamous foraminifera are known mainly from a few older studies (Pearcey 1914; Heron-Allen and Earland 1922, 1932; Wiesner 1931; Earland 1933, 1934) and some recent reports (Ward 1984; Violanti 1996). However, these authors did not describe the organic-walled species, poorly preserved in alcohol-fixed or dried samples. Recently, a growing interest in the diversity and ecology of Antarctic foraminifera led to more detailed description of both organic-walled and agglutinated monothalamous species from McMurdo Sound (Gooday *et al.* 1996) and Weddell Sea (Cornelius and Gooday 2004). Several new morphospecies have been described from these localities (Gooday *et al.* 1995, 2004; Bowser *et al.* 2002; Delaca *et al.* 2002; Gooday and Pawlowski 2004; Sabbatini *et al.* 2004). Molecular studies, based on analyses of isolated specimens and environmental DNA samples from the same localities, show that many more species remain to be described and that their genetic diversity at different taxonomic levels by far exceeds what could be expected from morphological studies (Pawlowski *et al.* 2002a, 2005; Habura *et al.* 2004).

The major goal of this research was to collect material for investigation of the morphological and molecular diversity of monothalamous foraminifera in Admiralty Bay. To our knowledge, this is the first attempt to study systematically this group of foraminifera in West Antarctic shallow-water environments. Below, we illustrate the morphospecies of monothalamous foraminifera found in Admiralty Bay and we present the first quantitative data set of such fauna from a West Antarctic fjord.

Study area

We carried out our investigations in Admiralty Bay, which is the largest fjord-like bay in the South Shetland Islands with a total area of ~120 km² (Fig. 1). It is composed of a >500 m deep main channel, which opens into Bransfield Strait, and splits into three major inlets with water depths down to 100–200 m (see Battke 1990). Less than half of this fjord shore-line is occupied by water-tide glaciers and ice falls, that have been retreating for at least the last few decades (Braun and Gossmann 2002).

Admiralty Bay is typical for the South Shetland Islands. A brief review of its hydrography, is presented in Majewski (2005). It is characterized by a well

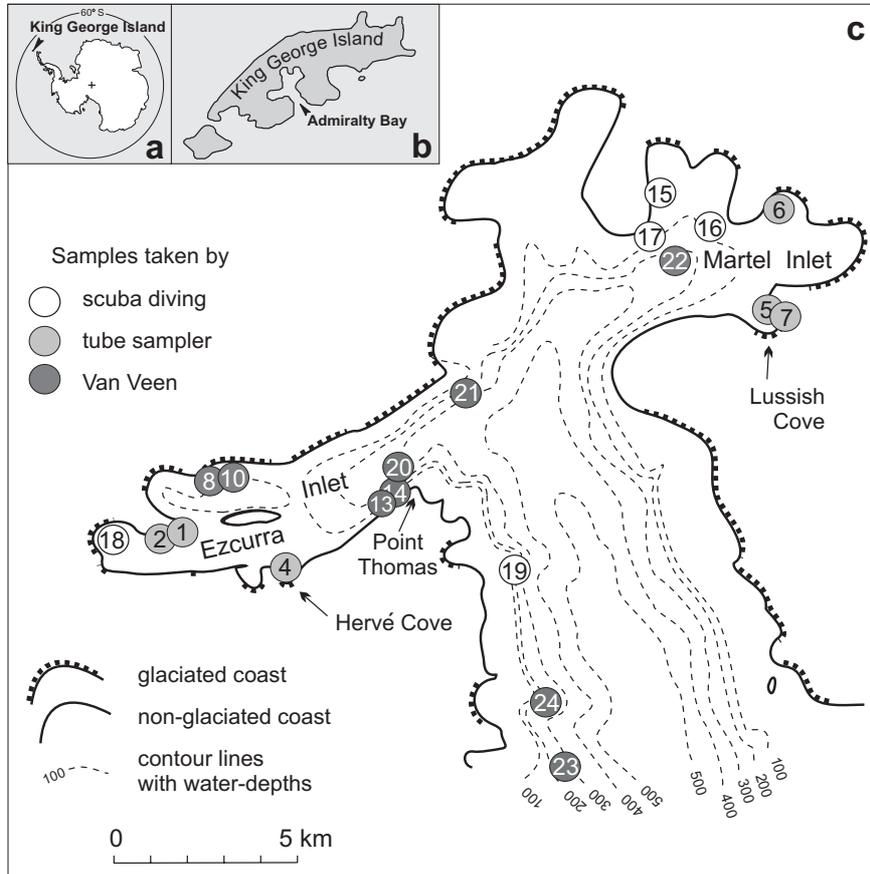


Fig. 1. The location of King George Island **a**, Admiralty Bay **b**, and sampling stations **c**. Note three shades of grey indicating different methods of sampling at particular stations KG1 to KG24, indicated by numbers 1 through 24.

mixed, rather uniform, and well ventilated water column (Lipski 1987). The bay is frequently frozen during winter (Kruszewski 2002) and significantly freshened during the summer melting-season in the upper 15–35 m water-layer (Sarukhanyan and Tokarczyk 1988). Prevailing winds from WSW and NWN, together with tides, drive water circulation. They push surface waters out to the sea and intensify inflow of open-sea water predominantly along the SW shore (Pruszek 1980; Robakiewicz and Rakusa-Suszczewski 1999). A significant structural upwelling takes place over the submarine escarpment, intersecting Ezcurre Inlet near Point Thomas (Rakusa-Suszczewski 1980).

Admiralty Bay has attracted considerable scientific attention from various nations over several decades. Despite broad ecological and biological studies (see Rakusa-Suszczewski 1993 for review), foraminiferal research in this area focused only on robust, testate taxa (Ishman and Domack 1994; Gaździcki and Majewski

2003; Majewski 2005), which did not include a majority of the monothalamous, allogromiid foraminifera. The present study fills this gap.

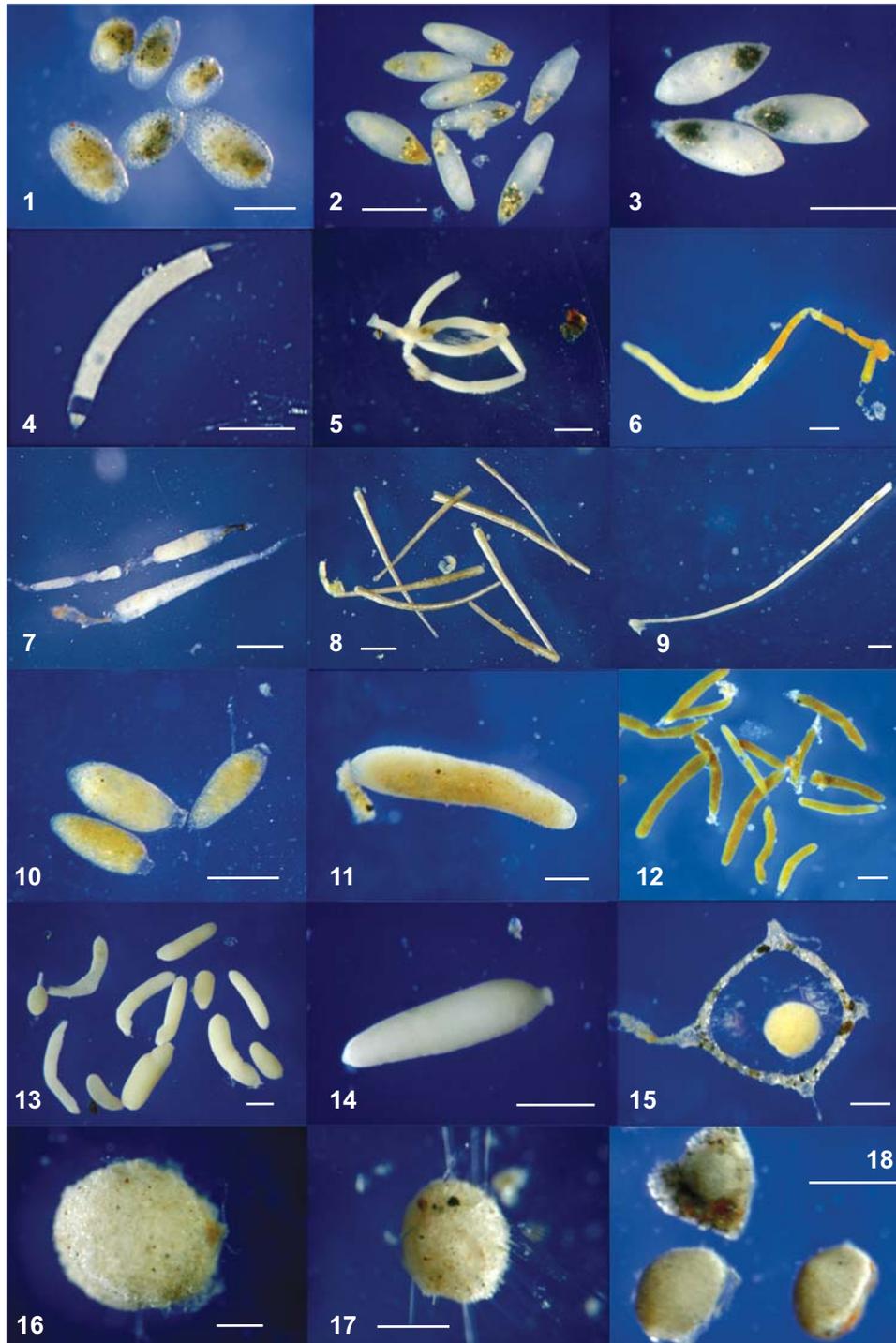
Methods

Sample collection and processing. — The fieldwork was conducted during the authors' stay at *Arctowski* Station between March 23rd and April 7th 2007. We sampled at water depths between 8 and 254 mwd, using a Van Veen sampler operated from the *M/S Polar Pioneer*, tube sampler, and using scuba divers (Fig. 1). The specimens were isolated from the upper 3 cm of surface sediments. In this layer, Majewski (unpublished results) found over 80% of “living” (Rose Bengal stained) foraminiferal population during his fieldwork in 2002/2003. None of the “living” taxa exhibited a typical deep-infaunal distribution.

Immediately after recovery, all samples were gently washed over a set of sieves with cold sea-water and stored at ~2° C temperature. During the next few days, >125 µm residues were scanned for living foraminifera. Soft-walled, fresh-looking individuals, as well as robust agglutinated specimens, containing cytoplasm when broken, were regarded as living, photographed (Figs 2–4), and preserved in guanidine-based DNA extraction buffer. The residues were preserved with 70% ethanol diluted in sea water, and shipped home for further study. In our Polish laboratory, all monothalamous (organic or soft-agglutinated) foraminifera were picked from 15 samples. From five faunally-rich samples over 300 specimens were picked and placed by taxa in separate vials. At this stage, we did not attempt to distinguish the living specimens, and picked all specimens recognised. The final quantitative dataset presented in this paper combines the data obtained at the field station and later in preserved samples.

Limitations of the dataset. — The preserved samples showed only minor degree of deterioration. Ethanol had a certain effect on tests of *Psammophaga*, but in general foraminifera were well preserved. Nevertheless, some percentages, particularly those of fragile, organic-walled species (*Micrometula* sp. *Nemogullmia* sp.), may be slightly underestimated. On the other hand, species of the robustly agglutinated genus *Lagenammia* may represent mixed subfossil and Recent populations and its percentages may be rather overestimated.

Fig. 2. **1.** *Allogromia* cf. *crystallifera*, KG5 (# 406–408). **2.** *Psammophaga* sp., KG8 (# 209–212). →
3. *Psammophaga* sp., KG5 (# 356). **4.** *Tinogullmia* sp., KG19 (# 652). **5.** *Nemogullmia* sp., KG14 (# 582). **6.** *Nemogullmia* sp. KG14 (# 597). **7.** *Micrometula* sp., KG13 (# 397). **8.** *Bathysiphon* cf. *argenteus*, KG13 (# 405). **9.** *Bathysiphon* cf. *flexilis*, KG23 (# 640). **10.** *Gloiogullmia* sp. 1, KG13 (# 388). **11.** *Gloiogullmia* sp. 2, KG20 (# 608). **12.** *Gloiogullmia*-like, KG13 (# 380–384). **13.** *Hippocrepinella alba*, KG14 (# 401–404). **14.** *Hippocrepinella alba* KG14 (# 367). **15.** *Vanhoeffenella gausi*, KG23 (# 611). **16.** *Crithionina* cf. *granum*, KG1 (# 151). **17.** *Crithionina* sp., KG24 (# 683).
18. Undetermined attached 1, KG 14 (Et 21). Scale bars = 0.25 mm.

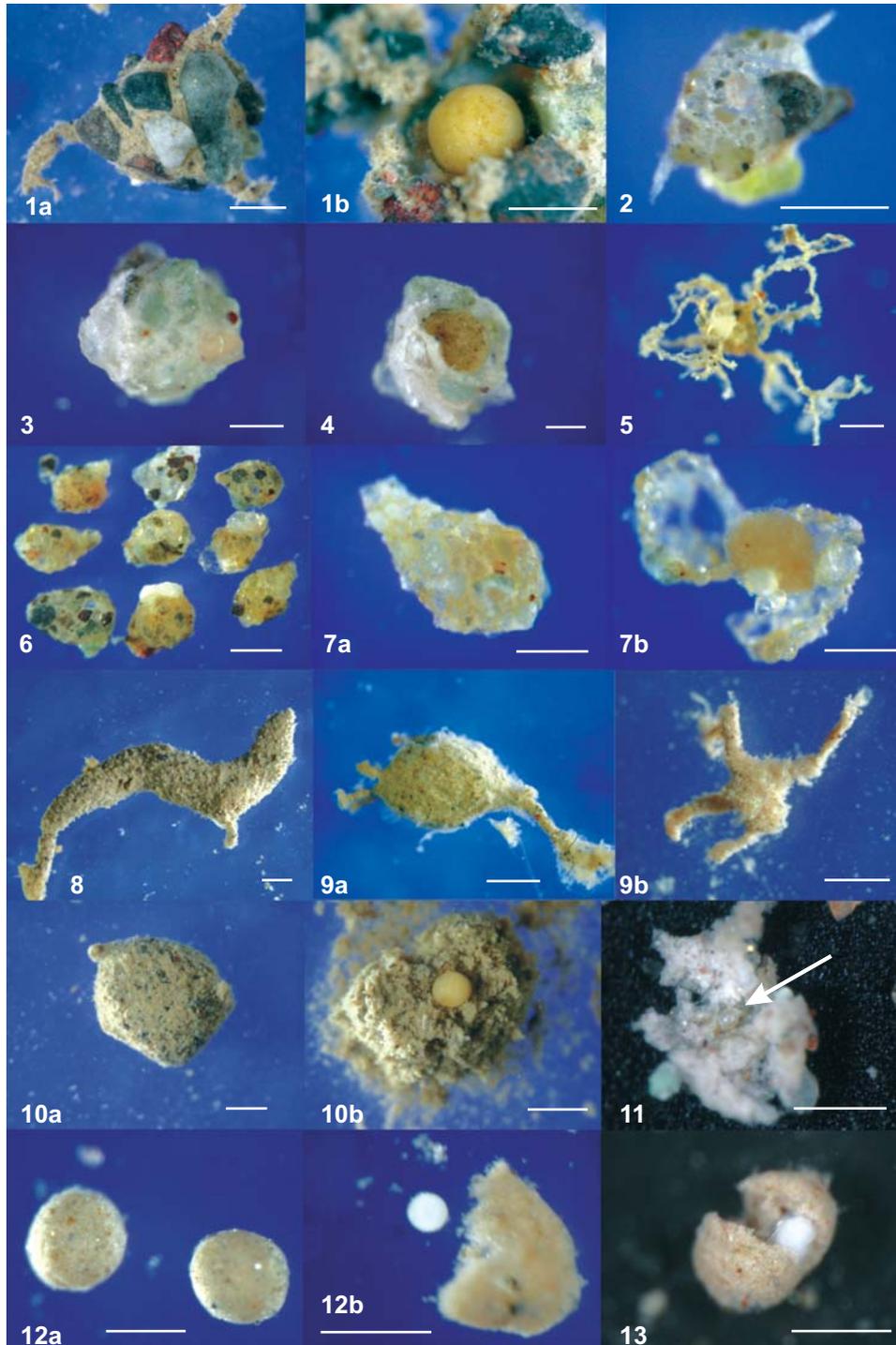


The abundances of total assemblages should be treated with caution. The split-fractions of the residues were only estimated and the absolute abundance data of rich samples are therefore approximations. Moreover, during scuba diving, the area of sea-floor sampled was not determined. Total abundances at these

Table 1
List of sampling stations indicating site location, method of sampling and area of sea-floor sampled

Station	Water-depth (mwd)	Distance from open-sea (km)	GPS location	Method	Surface area (cm ²)
KG1	17.5–25	17.1	S 62°10.998' W 58°37.306'	tube-sampler	~ 70
KG2	17.5	17.6	S 62°11.216' W 58°37.492'	tube-sampler	~ 70
KG4	17	15.0	S 62°10.688' W 58°32.115'	tube-sampler	~ 70
KG5	35	16.0	S 62°06.247' W 58°19.777'	tube-sampler	~ 70
KG6	47.5	17.3	S 62°04.416' W 58°19.932'	tube-sampler	~ 70
KG7	30	16.5	S 62°06.220' W 58°19.676'	tube-sampler	~ 70
KG8	119	16.2	S 62°09.650' W 58°34.774'	Van Veen	~ 800
KG10	107	15.7	S 62°09.584' W 58°34.287'	Van Veen	~ 800
KG13	108	12.0	S 62°09.461' W 58°29.737'	Van Veen	~ 800
KG14	100	11.5	S 62°09.290' W 58°29.439'	Van Veen	~ 600
KG15	16.3	15.3	S 62°05.123' W 58°23.471'	diving	–
KG16	29–31.4	15.5	S 62°04.760' W 58°21.495'	diving	–
KG17	20.8	14.0	S 62°05.319' W 58°23.777'	diving	–
KG18	8.0–12.0	19.9	Goulden Cove, ~150 m from ice-edge	diving	–
KG19	40	4.5	S slopes of Napier Rock	diving	–
KG20	249	11.2	S 62°09.053' W 58°30.435'	Van Veen	~ 800
KG21	254	10.9	S 62°07.488' W 58°27.545'	Van Veen	~ 800
KG22	233	14.0	S 62°05.610' W 58°22.944'	Van Veen	~ 800
KG23	223	–1.1	S 62°13.361' W 58°22.892'	Van Veen	~ 800
KG24	179	0.8	S 62°12.057' W 58°23.666'	Van Veen	~ 600

Fig. 3. **1.** *Astrammia rara* before (a) and after opening of the test (b), showing spherical cell-body, KG24 (# 667). **2.** *Armorella cf. sphaerica*, KG13. **3.** *Psammosphaera* sp., KG1 (# 155). **4.** *Psammosphaera* sp. with opened test, showing spherical cell-body, KG1 (# 152). **5.** *Armorella*-like, KG20 (Et33). **6.** *Lagenammia* spp. (more globular type), KG20. **7.** *Lagenammia* sp., more transparent type before (a) and after opening of the test (b), showing spherical cell-body, KG8, (# 213). **8.** *Pelosina didera*, KG24 (Et 32). **9.** *Pelosina* aff. *sphaeriloculum* before (a) and after removing the mud covering the flexible arms and central part (b), KG24 (# 669). **10.** Mudball before (a) and after removing the muddy covering (b), showing spherical cell-body, KG23. **11.** Opened mudball with minute silver cell-body inside, shown by an arrow, KG2 (# 145). **12.** Spherical mudballs before (a) and after opening (b) with minute, spherical cell-body inside, KG21. **13.** Opened mudball with irregular cytoplasm inside, KG23. Scale bars = 0.25 mm, except figures 1, 2, 5, 6, 8–11, in which scale bars = 1 mm. →



sites may still be roughly estimated by taking into account number of individuals collected and sediment split used during picking. Accordingly, it is clear that samples KG18 and KG15 were extremely poor in soft-wall foraminifera, KG17 and KG19 were somewhat richer, while sample KG16 was especially rich (see also Table 2).

Results and discussion

Table 2 presents our quantitative dataset, including 4462 specimens of monothalamous soft-walled benthic foraminifera. During the initial investigation at *Arctowski* Station, 1583 specimens were isolated and processed for DNA extraction. Of these, 552 were incorporated into our quantitative dataset of Table 2. Moreover, 3910 specimens were picked later from the preserved samples. The recognized foraminifera belong to 25 morphospecies identified at generic and specific level and a large number of unidentified morphotypes of various ranks (Figs 2–4). The geographic and bathymetric distributions of some key taxa is presented on Figs 5 and 6. Morphospecies, which closely resemble those originally described from northern hemisphere, but representing most likely different molecular species, were noted as “closely comparable” (cf.).

Monothalamous foraminiferan taxa. — The most common morphospecies present in almost all samples were *Psammophaga* sp. and the related species *Allogromia* cf. *crystallifera* (Fig. 5). The species differ in the shape of the test, which is fusiform in *Psammophaga* sp. and ovoid to spherical in *A. cf. crystallifera*. They are characterized by the presence of mineral particles inside the test. The particles were usually located near the aperture in *Psammophaga* sp. and more or less loosely distributed in *A. cf. crystallifera*. At some localities, the majority of specimens contains black particles, while at others they appear to be brighter in colour. A majority of the particles exhibit magnetic properties and they were recognized under SEM (backscattered mode) as titaniferous magnetite silt grains. Both morphospecies resemble closely the specimens collected in McMurdo

Fig. 4. **1.** *Hippocrepinella hirudinea*, KG10 (# 261–262, # Et 3). **2.** Three-branched individuals of *Hippocrepinella hirudinea*, KG16 (# Et 25). **3.** *Phainogullmia* cf. *aurata*, KG12 (# 335). **4.** *Hippocrepina* cf. *crassa*, KG14 (# 434–440). **5.** *Hippocrepina* cf. *crassa*, KG13 (# 423). **6.** Sausage-like undetermined allogromiid, KG23 (# F 23). **7.** Sausage-like undetermined allogromiid, KG10 (# 266). **8.** Undetermined, yellow ovoid allogromiid, KG19 (# 655). **9.** Undetermined, white, spherical allogromiid, KG13 (# 412–413). **10.** Egg-shaped, ovoid saccamminid, KG13 (# F36). **11.** Egg-shaped, ovoid saccamminid, KG10 (# 293). **12.** Undetermined allogromiid, KG10 (# Et 4). **13.** Undetermined allogromiid, KG10 (# 260), **14.** Undetermined allogromiid KG8 (# 214). **15.** Undetermined dark fusiform saccamminid, KG13 (# F23). **16.** Undetermined elongate saccamminid, KG14 (# 508). **17.** Ovoid gromiids, KG13 (# 432). **18.** Elongate gromiid, KG10 (# 267). Scale bars = 0.25 mm, except figures 1 and 2, in which scale bars = 1 mm. →

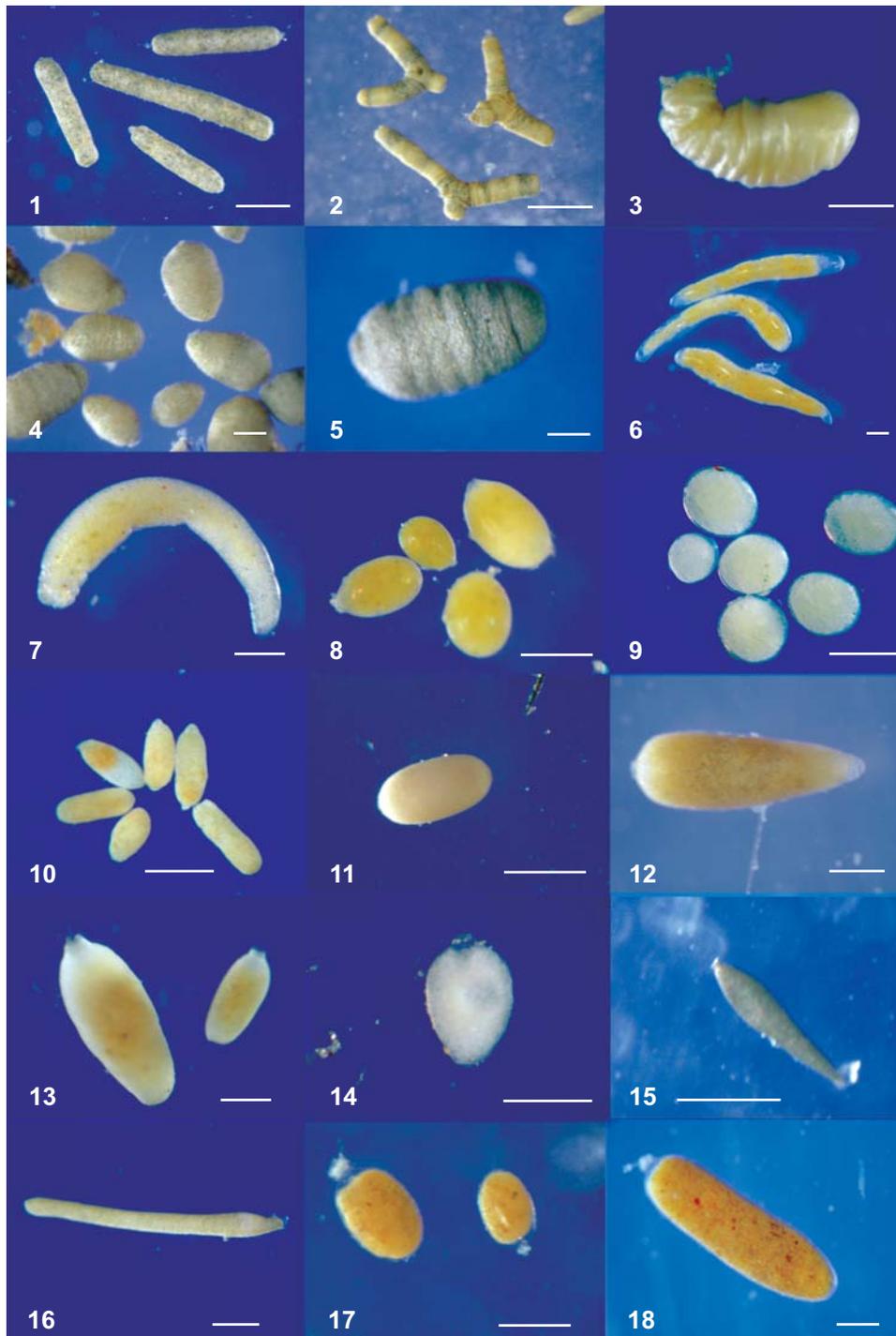


Table 2

The occurrence of monothalamous foraminifera in Admiralty Bay. Stations are arranged with increasing water-depth. Foraminiferal abundances are expressed in percentages of total monothalamous assemblage. Gromiid abundances, marked with *, are expressed as numbers of individuals, and were not used for calculating population parameters. Shannon diversity index was calculated according to equation $H = -\sum(n_i/n) \ln(n_i/n)$ and Dominance $D = \sum(n_i/n)^2$, where n_i indicates number of individuals of taxon i , and n indicates the total number of individuals.

Station	KG 18	KG 15	KG 4	KG 2	KG 1	KG 17	KG 7	KG 16	KG 5	KG 19	KG 6	KG 14	KG 10	KG 13	KG 8	KG 24	KG 23	KG 22	KG 20	KG 21	
Water-depth (mwd)	10	16.3	17	17.5	20	20.8	30	30	35	40	47.5	100	107	108	119	179	223	233	249	254	
<i>Allogromia</i> cf. <i>crystallifera</i>		12.3			27.3	15.5	10.2	42.1	19.2		4.8	2.2	0.0	3.9							
<i>Armorella</i> cf. <i>sphaerica</i>					5.5										1.6	2.3	4.6	11.2	7.3	3.9	
<i>Armorella</i> -like						26.3		0.3									0.3				
<i>Astrammina</i> <i>rara</i>																4.6					
<i>Astrammina</i> <i>triangularis</i>																	0.3				
<i>Astrorhiza</i> sp.															0.3						
<i>Bathysiphon</i> cf. <i>argenteus</i>			0.5	1.6		1.9		0.6		14.6		12.6	3.0	14.5	1.6	2.0	6.5	2.1	0.9	5.0	
<i>Bathysiphon</i> cf. <i>flexilis</i>														0.5		2.6	1.6		0.9	1.1	
<i>Crithionina</i> cf. <i>granum</i>		3.5			12.7										3.2		0.5			0.6	
<i>Crithionina</i> sp.																1.0		0.7	1.4	0.6	
<i>Gloiogullmia</i> sp. 1							16.2	0.3	3.3	17.8		2.5		2.6		0.3				1.1	
<i>Gloiogullmia</i> sp. 2										6.7					0.8		2.4	4.9	10.9	2.8	
<i>Gloiogullmia</i> -like					0.5	3.5				1.2	61.2	58.4	3.2	11.1	0.5	7.7				13.3	
<i>Hippocrepina</i> cf. <i>crassa</i>								0.6		9.4	8.1		3.2						5.0	1.1	
<i>Hippocrepinella</i> <i>alba</i>		5.3									12.6	4.5		3.9		23.5		9.8	7.7	6.6	
<i>Hippocrepinella</i> <i>hirudinea</i>				45.3	12.7	0.9		38.9		24.0		0.6	4.0	0.8	6.4	2.9	10.3		15.5	0.6	
<i>Lagenammina</i> spp.													54.2	0.3	59.2	14.7	16.8	22.4	5.9	10.5	
<i>Micrometula</i> sp.														0.5			2.7	0.7	2.3		
<i>Nemogullmia</i> spp.										0.9		0.8	1.0	0.5	2.4	1.0	0.5	0.7	1.4		
<i>Pelosina</i> <i>didera</i>																0.3		0.7	0.5		
<i>Pelosina</i> aff. <i>sphaeriloculum</i>																0.3					

Table 2 – continued.

Station	KG 18	KG 15	KG 4	KG 2	KG 1	KG 17	KG 7	KG 16	KG 5	KG 19	KG 6	KG 14	KG 10	KG 13	KG 8	KG 24	KG 23	KG 22	KG 20	KG 21	
Water-depth (mwd)	10	16.3	17	17.5	20	20.8	30	30	35	40	47.5	100	107	108	119	179	223	233	249	254	
<i>Phainogullmia</i> cf. <i>aurata</i>																4.9	0.5	0.7	1.8		
<i>Psammophaga</i> sp.		3.5	95.7		10.9	14.6	63.7	14.8	74.3	0.3	14.3	2.2	17.9	3.7	6.4	13.7	25.7	17.5	20.9	35.9	
<i>Psammospaera</i> spp.		5.3	1.3		27.3	30.0		0.3	1.0	1.5	4.8		5.0	0.5	6.4	3.3	4.1	1.4	0.9	1.7	
<i>Tinogullmia</i> sp.										0.3											
<i>Vanhoeffenella</i> <i>gaussi</i>																0.7	1.6	1.4	0.5		
mudballs	100	56.1	1.3	48.4		7.0	1.1	1.0	1.4	2.3	57.1	1.1	0.5	0.5	4.0	3.9	11.7	2.1	2.3	4.4	
silver saccamminids				3.1						0.6		0.3					1.9		0.9		
undet. attached 1		1.8			1.8	0.9						0.3		0.5					3.5		
undet. attached 2																0.3	1.1	1.4		1.1	
undet. sausage-like												0.3	6.5		2.4			1.4	4.2	0.9	0.6
egg-shaped saccamminid													0.5			0.3		1.4		2.2	
undet. dark fusiform														0.3		0.3	0.3				
undet. white sperical														1.8			0.5	0.7			
undet. yellow ovoid										2.0					0.3		0.3	2.8	0.5		
undet. strongly elongate												0.8								0.6	
undet. ovoid allogromiid		8.8	0.3	1.6		0.9	1.4		0.2	1.2	14.3	1.1	1.5	2.9	0.8	2.6	2.7	1.4	9.5	2.2	
other undet. allogromiids		3.5	1.0		1.8	1.4	3.9	1.0	0.5	4.7	4.8	1.1	5.5	0.8	1.6	3.3	0.8	0.7	2.3	4.4	
elongate gromiids*										1			2						6		
ovoid gromiids*			1		1					24			1	3		5	1	4		2	
# of taxa	1	9	6	5	8	11	7	10	7	16	6	16	12	19	14	23	25	23	22	21	
# of individuals	18	57	394	64	55	213	284	311	421	342	21	356	201	380	125	307	368	143	220	181	
Dominance	1.00	0.35	0.92	0.44	0.20	0.21	0.45	0.35	0.59	0.14	0.37	0.40	0.34	0.37	0.37	0.12	0.13	0.12	0.11	0.17	
Shannon index	0.00	1.53	0.24	0.95	1.78	1.76	1.17	1.22	0.80	2.18	1.31	1.48	1.55	1.61	1.64	2.48	2.43	2.51	2.52	2.28	
Fraction of sample investigated	1	1	1/20	1	1	1	1	1/15	1/3	1	1	1/10	1	1/4	1	1	1	1	1	1	
Total abundance (specimens per cm ²)	very low	very low	113	0.91	0.79	inter.	4.06	high	18.0	inter.	0.30	5.90	0.25	1.90	0.16	0.51	0.46	0.18	0.28	0.23	

Sound, to which they seem to be closely related according to the preliminary molecular analyses (unpublished data). A morphologically similar *Psammophaga* sp. was also present in Svalbard, but the Admiralty Bay specimens possessed organic test while those from Svalbard seemed to be more or less finely agglutinated (Majewski *et al.* 2005; Gooday *et al.* 2005). *Psammophaga* and *Allogromia crystallifera* also occur together on an intertidal mudflat near Southampton, south coast of UK (Larkin and Gooday 2004).

Another characteristic monothalamous foraminifer from Admiralty Bay was *Hippocrepinella hirudinea*. This species was previously reported from several locations around Antarctica. It was first described from South Georgia by Heron-Allen and Earland (1932). It was present at several locations around the Ross Sea (Gooday *et al.* 1996; Volanti 1996), as well as in the South Shetland Islands (Finger and Lipps 1981; Mayer 2000). It was also reported from Admiralty Bay (Majewski 2005). Interestingly, the recent distribution of *H. hirudinea* appears to be broader than in the 2002/2003 summer season. Majewski (2005) found this species to be abundant only in the inner part of Ezcurra Inlet, while in 2007 we found it to be abundant (39%) also at KG16 in Martel Inlet and in samples taken along the western slopes of the Admiralty Bay's main channel (Fig. 5).

The majority of *H. hirudinea* specimens found during the present study, had a typical stick-like form, ranging in length from 1 to 2 mm. However, we observed also several morphological variants within this species. Some specimens were much shorter measuring less than 0.5 mm. At KG16, few specimens have been found with three branching arms (Fig. 4.2) or with an anomalously thicker central part. It is doubtful that these particular specimens represent different species, but interestingly we have not found such variants in other localities in Arctic and Antarctic where this species was particularly common.

Besides *H. hirudinea*, the hippocrepinids were represented in Admiralty Bay by *Hippocrepinella alba*, *Hippocrepina* cf. *crassa*, and some other undescribed morphospecies. *Hippocrepinella alba* was quite common at depths greater than 40 m. It had a characteristic white test and was represented by a large variety of forms, as observed by Nyholm (1955). The species was originally described by Heron-Allen and Earland (1932) from South Georgia and the Admiralty Bay specimens are probably closely related to the type specimens. Like Nyholm (1955), we did not observe the secondary posterior aperture mentioned in the original description of the genus *Hippocrepinella* (Heron-Allen and Earland 1932). As the similar specimens of *H. alba* from Scandinavia do not branch with *H. hirudinea* in molecular phylogenies (Pawlowski *et al.* 2002c), we suggest that the generic affiliation of this species should be changed. Among other hippocrepinids, mostly at intermediate water-depths, we found typical *H.* cf. *crassa*, with a barrel-like wrinkled theca, but also many similar forms with a much smoother and thinner wall. Whether these forms are related or not is unknown. We found also a few large *Phainogullmia*, with characteristic silver tests (Fig. 4.3) in the samples from

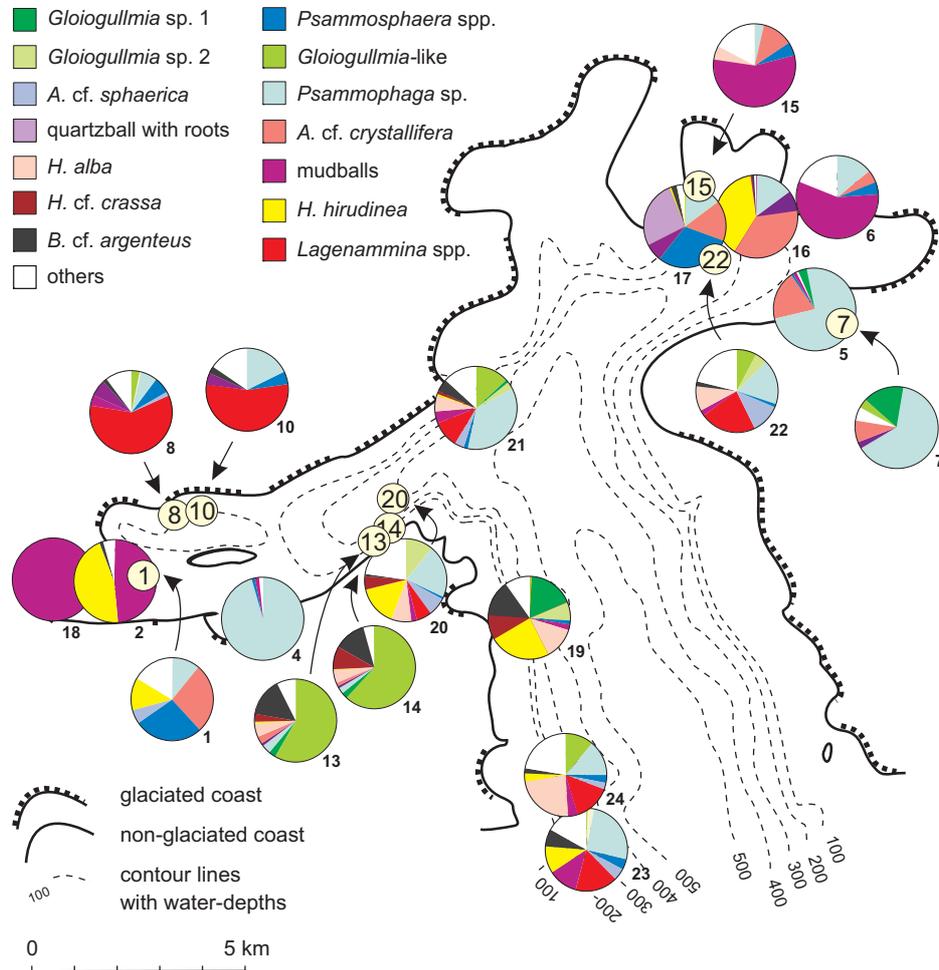


Fig. 5. Distribution map of 14 most prominent monothalamous taxa throughout Admiralty Bay. Station numbers KG1 to KG24 are indicated by numbers 1 through 24.

179 mwd and deeper. Curiously, we encountered only a few of the small silver saccamminids that usually are quite abundant in similar settings.

Among the organic-walled allogromiids common in high latitude regions, the most abundant in Admiralty Bay was the genus *Gloiogullmia* represented by various morphotypes. Some of them had ovoid (Fig. 2.10) to elongate (Fig. 2.11) form (sp. 1 and sp. 2) similar to the specimens from McMurdo Sound and Svalbard. Others have unusual elongate, finer, slightly curved form (Fig. 2.12) and have been called here *Gloiogullmia*-like. These three morphotypes were found sometimes in great numbers (up to 61%) practically throughout sampling localities except water depths shallower than 20 m (Figs 5 and 6). We also have found a few *Micrometula* and *Nemogullmia* in samples deeper than 100 and 40 mwd, respec-

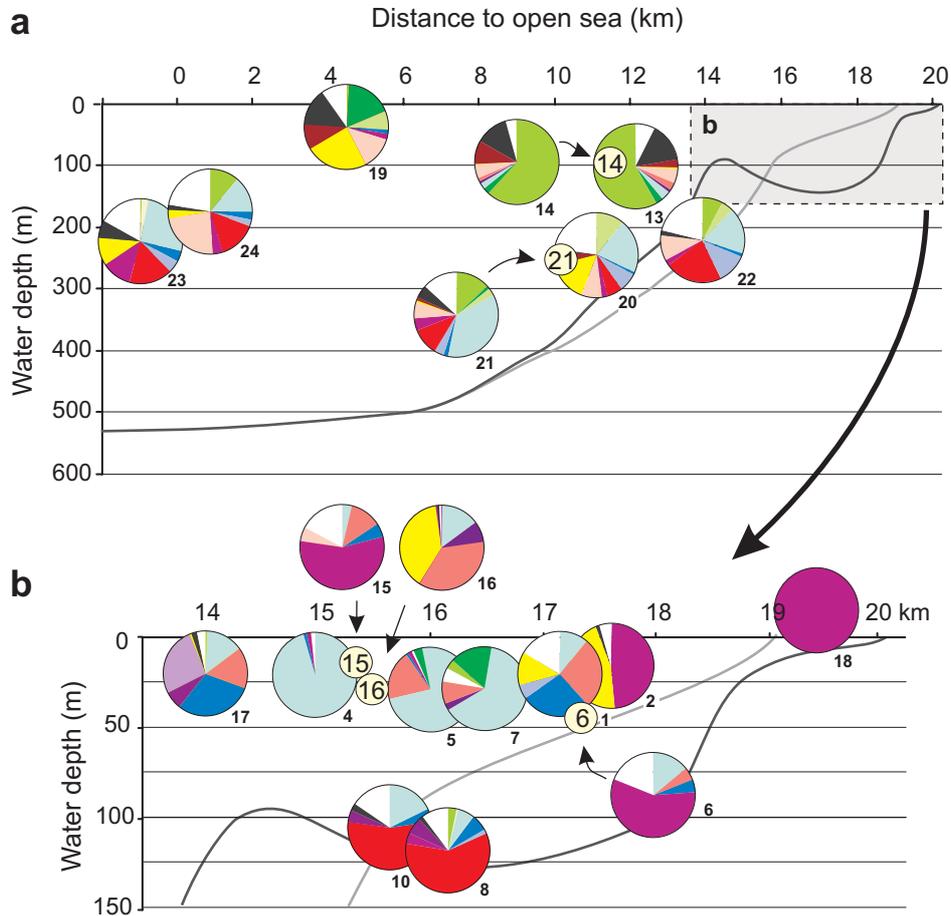


Fig. 6. The 14 most prominent taxa *versus* water depth and distance to open sea. Gray lines show bathymetrical profiles along the fjord main axes, dark gray for the main channel and Ezcurra Inlet, bright gray for Martel Inlet. For colors assigned to different taxa, see Fig. 5.

tively. *Micrometula* had a typical elongated conical form with long bendy posterior part. Most of *Nemogullmia* were atypically short and many contained yellow cytoplasm. Only a single specimen of typical *Tinogullmia* was found at 40 mwd (KG19).

Among coarsely agglutinated astrorhizids with hard tests, only *Psammosphaera* was common in shallow and deeper samples (Fig. 6). They resembled *Psammosphaera fusca*, which was originally described from Norwegian Sea by Schulze (1875) and represent probably a different species than our forms from Admiralty Bay. Some *Psammosphaera* specimens contained a large ovoid cell body. Many were empty and some were extremely fragile. It seems that they represented at least two species that differ in the degree of cementation of the mineral grains, but we did not attempt to discriminate between them.

More than one morphospecies was also suspected in the genus *Lagenammina*. They were very common in the samples from deeper than 100 mwd (Fig. 6). Some specimens of *Lagenammina* (Fig. 3.6) had larger, more globular tests, composed of darker mineral. They were especially abundant in samples KG20 and KG24. The other form incorporated quartz grains, which made their tests more transparent (Fig. 3.7). Both types of tests were rather robust. In some individuals, we found large cell bodies entirely filling the test (e.g. Fig. 3.7b).

A few large (>1 mm) specimens of *Astrammmina rara*, *Astrammmina triangularis* and *Astrorhiza* sp. were found at one of two stations situated closest to the open sea. Specimens of *A. rara* from Admiralty Bay resemble those from McMurdo Sound but seem to have broader spaces between the grains and a less regular shape (Fig. 3.1). The single specimen of *A. triangularis* had four arms and a typical flat test composed of transparent coarse grains (Fig. 7.2). We found also a single specimen of an undetermined *Astrorhiza*, which resembles *Astrorhiza polygona* (Earland 1934) but has more circular outline and as many as 11 arms (Fig. 7.1).

Armorella cf. *sphaerica* was more common than *Astrammmina* and *Astrorhiza* (Table 2). This species was reported from both the southern (e.g. Earland 1934; Mayer 2000) and northern (Höglund 1947; Gabel 1971) hemispheres. We found several typical specimens (Fig. 3.2) in deeper-water samples. Although DeLaca (1986) suggested its synonymy with *A. rara*, our specimens differed from this species in having delicate, agglutinated tests composed of a single layer of mainly quartz grains cemented by transparent silty cement. We found also an interesting, smaller *Armorella*-like morphotype with long bifurcated flexible arms (Fig. 3.5). Its central spherical capsule measured 150–200 µm in diameter. The test was composed of small transparent quartz grains and occasionally diatom skeletons (Fig. 7.3). The arms were also agglutinated but they fell apart when specimens were dried. Some specimens contained organic walled spherical yellowish cell body. Interestingly, this species was very common only in one sample KG17.

Among other monothalamids, we found representatives of following genera: *Vanhoeffenella*, *Bathysiphon*, *Crithionina* and *Pelosina*. *Vanhoeffenella gaussi* has been reported throughout Southern Ocean (e.g. Heron-Allen and Earland 1922; Earland 1933; Ishman and Domack 1994; Volanti, 1996). It was originally described by Rhumbler (1905) from the Southern Ocean and is therefore probably identical to the species that we collected at four ~200 mwd sites (Table 2). *Bathysiphon* cf. *argenteus* (Fig. 2.8) was relatively common and present in samples from all water depths, while *Bathysiphon* cf. *flexilis* (Figs 2.9 and 7.5) was found only deeper than 100 mwd. Among the few species of *Crithionina* with free test, the most characteristic was *Crithionina* sp., which incorporates numerous long sponge spicules into finely agglutinated test (Fig. 2.17). It resembles *C. cf. granum*, also represented in the samples (Fig. 2.16), in having a test wall composed of fine quartz silt, rather than *C. hispida*, which has wall composed of sponge spicules arranged nearly perpendicular to the test surface (Flint 1899).

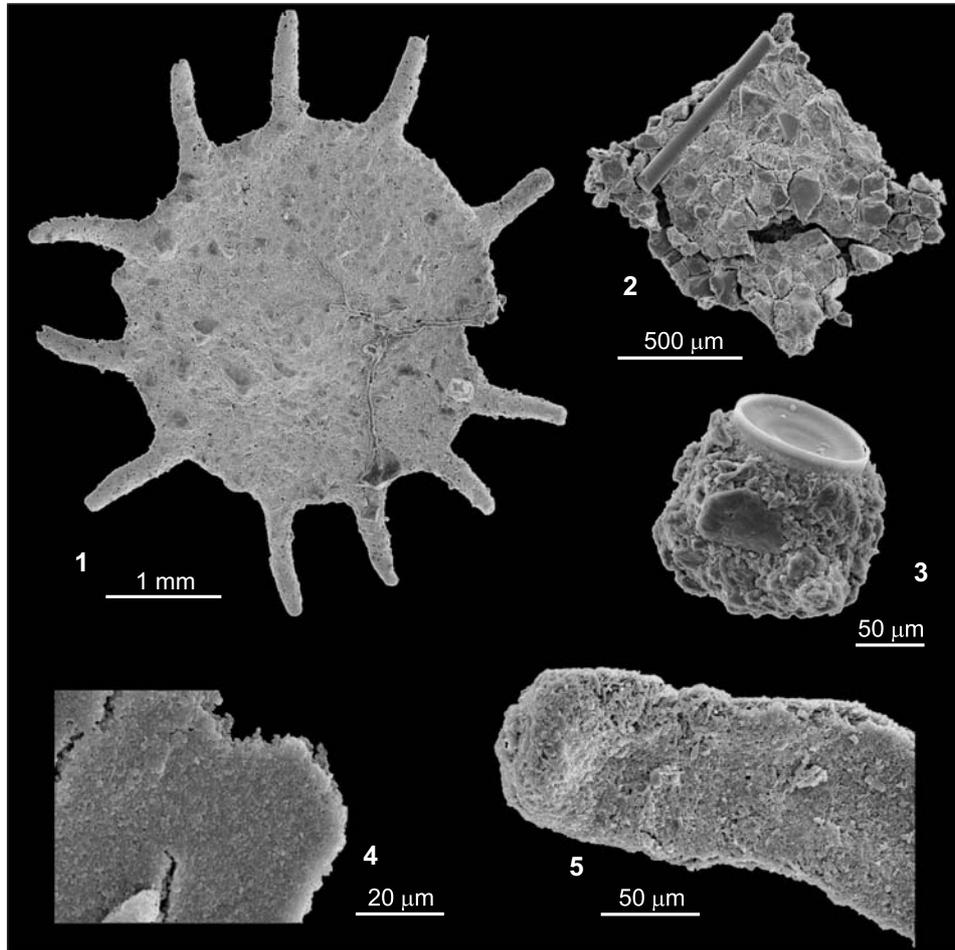


Fig. 7. 1. *Astrorhiza* sp., KG24. 2. *Astrammima triangularis*, KG23. 3. *Armorella*-like with detached long arms KG17. 4. Finely agglutinated wall of undetermined dark fusiform saccamminid, KG23. 5. Broader end of *Bathysiphon* cf. *flexilis* with visible aperture and agglutinated wall composed of thin plates, KG24.

Each sample, especially those obtained at shallow water-depths, contained also many mudballs of different form, wall composition, and size ranging from 0.2 to 1 mm. A few had elongate tests and resembled *Pelosina didera* (Fig. 3.8). Others had a much more globular outline and resembled *Pelosina sphaeriloculum* (Fig. 3.9). Among this latter morphotype, some specimens contained small spherical allogromid-like cell bodies while in others the arms were connected in the central flexible part (Fig. 3.9b), which was difficult to dissect. In some *Pelosina*-like mudballs, we found minute silver cell bodies (Fig. 3.11). Some deep-water samples also yielded a few spherical mudballs with smooth, fine-grained walls and containing a small, spherical allogromid (Fig. 3.12). The mudballs with irregular

cytoplasm filling the interior space were also found (Fig. 3.13). Molecular identification of these mudballs is in progress (Lecroq *et al.* in preparation).

Several putative new species have been found among organic-walled morphotypes. The most spectacular was a large (~1.5 mm) elongate, sausage-like morphotype (Fig. 4.6–7) found in most of the samples from depths greater than 100 mwd (Table 2). The species possesses a thick, glossy, transparent organic theca densely filled with white to brown cytoplasm. We did not observe any apertures. A similar morphotype was observed in samples from under Ross Ice Shelf (Pawlowski *et al.* 2005). Another morphotype with a thick, glossy theca and lacking aperture has been found at stations KG19, KG22 and KG24. The specimens of this type were easily distinguished by their ovoid or bean-shaped theca and intensely colored yellow to red cytoplasm (Fig. 4.8). A few specimens having spherical organic test and white cytoplasm were found in station KG13 (Fig. 4.9).

Another peculiar, putatively new species is illustrated on Fig. 4.15. This species has a dark gray, fusiform test with clearly visible slightly protruding rounded aperture. The test length is 500 μm and diameter is up to 70 μm . It reaches the largest diameter at about 1/3 distance from the apertural end. The wall is finely agglutinated (Fig. 7.4). Only few specimens of this type have been found in samples from below 100 mwd (Table 2).

The examples of other undetermined morphotypes are illustrated at Fig. 4.10–16. Some of them have a distinctive aperture and bottle-like form (Fig. 4.13–14). Some others lack clearly distinctive apertures and have a white, finely agglutinated egg-shaped test (Fig. 4.10–11). They resemble white unidentified saccamminids found in Svalbard. Two specimens had strongly elongate, agglutinated tests with a distinctive aperture at one end (Fig. 4.16). They closely resembled other undetermined forms from Svalbard fjords (Majewski *et al.* 2005). We also found some undetermined attached saccamminids. Some of them were attached to larger sediment grains (Fig. 2.18) (type 1). Their test structure resembled that of *Crithionina*. Another type had larger, more irregularly-shaped tests with a thin agglutinated wall and large test cavity. Unfortunately, we found only detached, empty specimens of this second type. Our samples contained also few gromiids, including the typical ovoid (Fig. 4.17) and more elongate types (Fig. 4.18).

Population structure and total abundances. — In general, samples from the shallowest water-depths (down to 50 mwd), exhibited the widest range of faunal parameters (Table 2). They showed both the highest (113 specimens *per cm*² at KG4) and the lowest (KG18) total abundances (Fig. 8). Shannon diversity index (H) showed low to intermediate values (0–1.78) (Fig. 9), while Dominance (D) was between 0.2 and 1. D reached the highest values of 1 and 0.92 at samples KG18 and KG4, which were from the most restricted environments close to glacier fronts at Golden and Hervé coves. Interestingly, sediment collected at Napier Rock

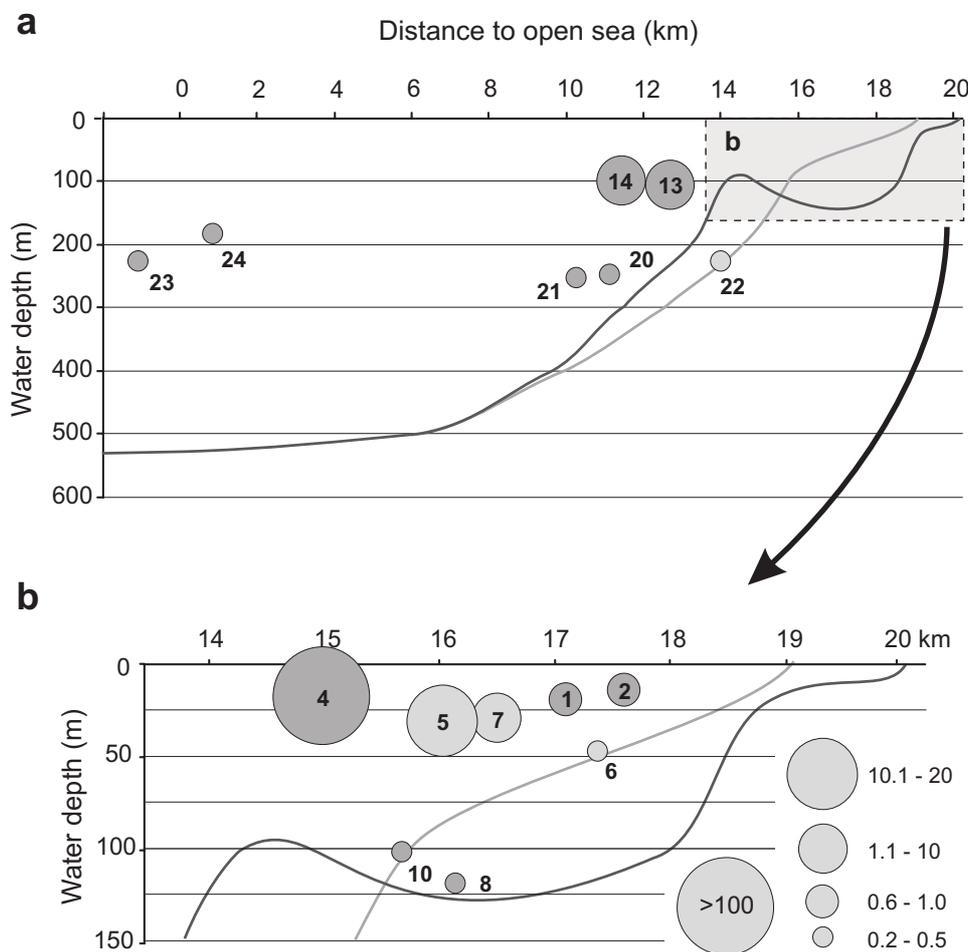


Fig. 8. Total abundances of the monothalamous assemblages expressed in number of specimens *per* cm² *versus* water depth and distance to open sea. Data only for the Van Veen and tube-sampler samples. Note non-linear bubble scale used and gray lines showing bathymetrical profiles along the fjord main axes, dark gray for the main channel and Ezcurra Inlet, bright gray for Martel Inlet.

(KG19) from 40 mwd yielded an unusually diverse monothalamous assemblage with $H = 2.18$ and D of only 0.14 (Table 2).

Samples taken from about 100 mwd showed similar intermediate values of H (1.48–1.64) and D (0.34–0.4) but strikingly different total abundances (Figs 8, 9). At sites KG8 and KG10, located within a sea-floor depression behind Dufayel Island, the abundances were very low (0.16 and 0.25 specimens *per* cm²), whereas they were fairly high at the KG13 and KG14 sites, located in outer Ezcurra Inlet, reaching 1.9 and 5.9 specimens *per* cm² respectively (Table 2; Fig. 8).

The deepest samples (KG20 to KG24), from between 179 and 254 mwd, showed the highest values of H (2.28–2.52) and the lowest D (0.11–0.17) regard-

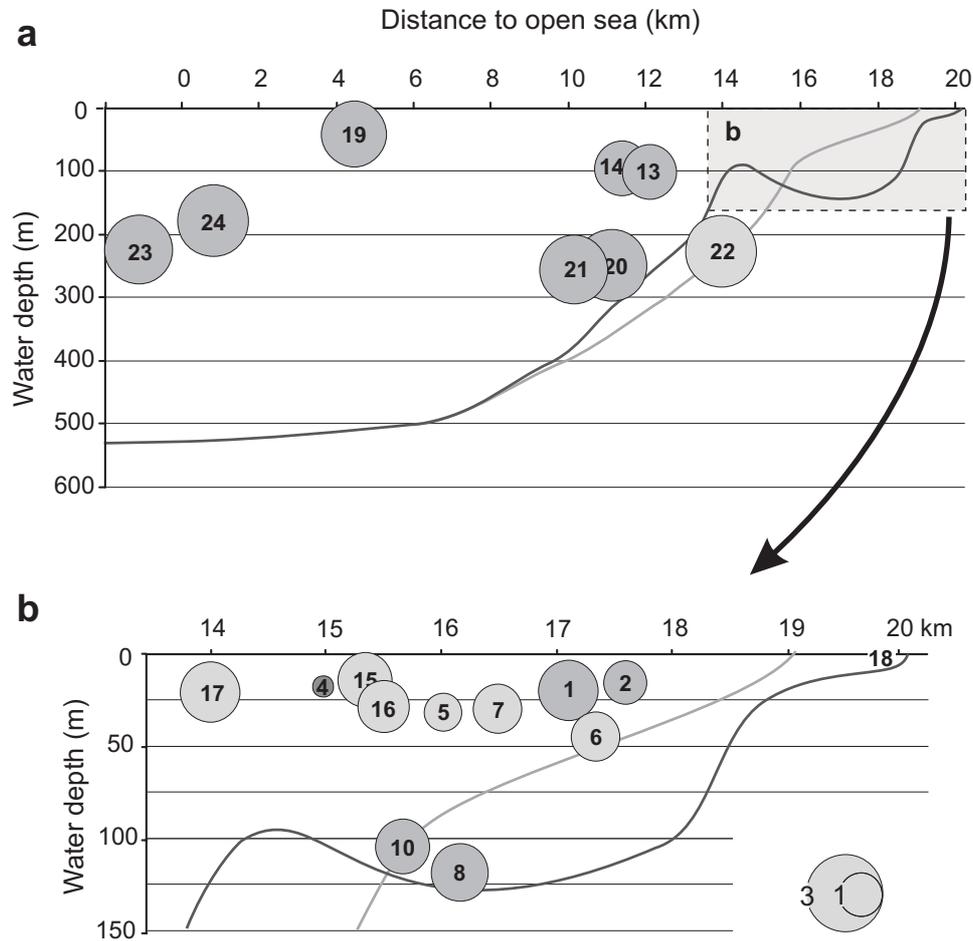


Fig. 9. Shannon diversity index $H = -\sum(n_i/n) \ln(n_i/n)$ calculated for all samples. Note bubble scale expressed by circle surface and gray lines showing bathymetrical profiles along the fjord main axes, dark gray for the main channel and Ezcurra Inlet, bright gray for Martel Inlet.

less their position throughout the Admiralty Bay (Table 2). Moreover, they all showed rather low total abundances (0.18–0.51 specimens *per* cm²) (Fig. 8).

Ecological interpretation. — It appears that both the taxonomic composition and population structure of monothalamous foraminifera in Admiralty Bay varied primarily with water-depth. This observation is not surprising, as such factor as food supply, melt water and atmosphere influence change drastically with bathymetry. However, it is proposed that the Southern Ocean coastal benthic species have relatively wide bathymetric ranges, due to the uniform temperature and periodic depth migration during glacial periods (Brey *et al.* 1996). In agreement with this theory, recent molecular analyses of the foraminifer *Epistominella vitrea*

showed that specimens from 20 m in McMurdo Sound and 1000 m in Weddell Sea were genetically almost identical (Pawlowski *et al.* in press). According to our unpublished molecular data, the same genotype of *E. vitrea* has been found also in Admiralty Bay at 40 and 100 m (KG19, KG14), suggesting panantarctic distribution of some foraminifera having wide bathymetric ranges.

The distribution of monothalamous foraminifera in Admiralty Bay can be compared to the fjords and shelf waters off western Svalbard in the European Arctic. Korsun and Hald (2000), Gooday *et al.* (2005), and Sabbatini *et al.* (2007) reported differences in the distribution of monothalamous foraminifera between the inner and outer parts of fjords, stressing the presence of the highest abundances close to the glacier head where the environment is under the strongest influence of meltwater. However, it is difficult to apply this approach to our data because Admiralty Bay has a much weaker and more diverse meltwater supply than the fjords of western Svalbard, up to a point that it is difficult to separate the influence of water depth and distance from meltwater source. Nevertheless, our data do show the highest abundances of monothalamous foraminifera in the shallowest, near-shore sites KG4, KG5, and KG16 (Table 2, Fig. 8).

The monothalamous communities from the shallowest stations (down to 50 mwd) showed the greatest variability in terms of taxonomic composition (Table 2, Fig. 6), species diversity and abundance (Table 2, Figs 8 and 9). It is not surprising, as they were under the greatest atmospheric and meltwater influence and subject to the strongest hydrographic isolation. The reason for the development of the particularly diverse monothalamous assemblage at site KG19 (Napier Rock) is probably due to very local conditions. This site is sheltered from westerly winds but also washed by open-sea waters entering the Admiralty Bay along its western shore. It is only 1 km away from two major penguin rookeries at Rakusa and Liano points (Battke 1990), which may supply additional nutrients. For the same reason, Napier Rock is well known among divers for having the most diverse and abundant macro-benthic communities within the entire Admiralty Bay.

The faunal difference between sites located at similar water depths (~100 mwd) in the inner part of the Ezcurra Inlet (KG8, KG10) and near its mouth (KG13, KG14) may be related to different hydrographical settings of those two locations. Sites KG8 and KG10 are located within a sea-floor depression behind Dufayel Island and are affected by a weaker open-sea water inflow. Being located in an isolated, inner-bay basin, they may be also subject to a larger sediment input and a stronger glacial influence than other sites. The benthic communities near the mouth of the inlet (KG13, KG14), on the other hand, may benefit from upwelling taking place over the submarine escarpment in the outer part of Ezcurra Inlet, as well as from easier access of open-sea communities.

The deepest samples (KG20 to KG24), from between 179 and 254 mwd, showed roughly similar faunal parameters and taxonomic composition, despite

their different location, which clearly indicates uniform sea-floor conditions at ~200 mwd throughout the Admiralty Bay. Majewski (2005) suggested that 200 mwd marked a major bathymetrical division between homogeneous deep-water communities and those influenced by the dynamic conditions in shallower water. Our recent results suggest that the monothalamous foraminifera assemblages become uniform somewhere between 120 and 180 mwd.

Conclusions

- Admiralty Bay is inhabited by rich communities of monothalamous benthic foraminifera, belonging to at least 40 morphospecies.
- The majority of these morphospecies are known from other Antarctic and Arctic locations, but a few are reported for the first time.
- The greatest abundance of monothalamous foraminifera >125 µm occurred at water depths shallower than 50 mwd.
- The highest diversity of monothalamous species occurred in samples between 179 and 254 mwd.
- The foraminiferal assemblages were much more homogenous at deeper sites, suggesting uniform sea-floor conditions at ~200 mwd throughout Admiralty Bay.

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