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A new Antarctic foraminiferal species for detecting climate change in sub-Recent glacier-proximal sediments

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Abstract: *Cribroelphidium webbi* sp. nov. is the only adequately described sub-Recent elphidiid foraminifer from Antarctica. In Admiralty Bay (King George Island, South Shetland Islands), it is found at several locations within inner fiord setting at water depths between 33 and 165 m, but most commonly shallower than 100 m. In outer basins this foraminifer is absent. In the cores analysed, *C. webbi* sp. nov. is present in well-constrained sub-Recent horizons that are clearly related to climate warming and deglaciation. These horizons represent a diachronous facies marker rather than a single stratigraphic layer. *Cribroelphidium webbi* sp. nov. shows clear association with retreating tidewater glaciers, therefore it is an important sensitive glacier-proximal indicator. It appears that it shares similar ecologic affinities with *Cribroelphidium excavatum clavatum*, which is widely distributed throughout the Arctic.

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Introduction

For over a century, the Antarctic foraminifera have captured the attention of numerous investigators (see Mikhalevich 2004 for details) but our knowledge, especially of the shallow water fauna is still far from being complete. The fjords of the South Shetland Islands received considerable attention over the past decades since it was thought that they may provide some of the most complete and detailed sedimentary records of palaeoclimatic Holocene changes in the region (e.g. Straten 1996, Yoon *et al*. 2000, Khim & Yoon 2003). Some foraminiferal ecological studies were carried out in this region (Finger & Lipps 1981, Ishman & Domack 1994, Chang & Yoon 1995, Mayer 2000, Gray *et al*. 2003) and Admiralty Bay (King George Island) was researched in considerable detail for benthic foraminifera. The research focused not only on robust, testate taxa (Ishman & Domack 1994, Gaździcki & Majewski 2003, Majewski 2005) but also included monothalamous, allogromiid foraminifera (Majewski *et al*. 2007, Sinniger *et al*. 2008).

Among some 105 testate species of benthic foraminifera catalogued from Admiralty Bay (Majewski 2005) the single member of the *Elphidiidae* family stands out. Firstly, it is the only easily recognized modern elphidiid known to date from a Southern Hemisphere polar setting (south of 60°S), despite the fact that its relatives are broadly distributed throughout a wide variety of Arctic habitats. Secondly, it is a species of very strictly defined distribution, which carries a precise ecological implication for palaeoenvironmental research.

Study area

Admiralty Bay is the largest fjord in the South Shetland Islands with total area of 120 km^2 (Fig. 1). It is formed of a $>$ 500 m deep main channel, which is open to Bransfield Strait, and splits into three major inlets with water depths down to 100–200 m. The hydrography of Admiralty Bay is typical for the South Shetland Islands (see Majewski 2005 for a brief review). It is characterized by a well-mixed, rather uniform (except in the coastal zone) and well-ventilated water column (Lipski 1987). The upper 15–35 m water layer is significantly freshened during the summer by meltwater and contains mineral suspension (Sarukhanyan & Tokarczyk 1988). Prevailing strong winds from WSW and NWN direction together with tides drive the water circulation. They push surface waters out to sea and intensify inflow of open seawater predominantly along the south-west shore (Robakiewicz & Rakusa-Suszczewski 1999).

Almost half of the Admiralty Bay shoreline is occupied by tidewater glaciers and icefalls that have been retreating for at least the last few decades (Braun & Gossmann 2002, Pudełko 2008). The bay's glaciological setting is characterized by elevated equilibrium lines at ~150 m above sea level (Domack & Ishman 1993). Sediment is ~70 m thick in the northern part of the bay (Griffith & Anderson 1989). Sedimentation is affected by meltwater processes, an abundance of volcanoclastic detritus, which is dispersed by estuarine circulation, and, periodically, strong bottom water currents (Domack & Ishman 1993). In some areas gravity flows are a common phenomenon (Straten 1996).

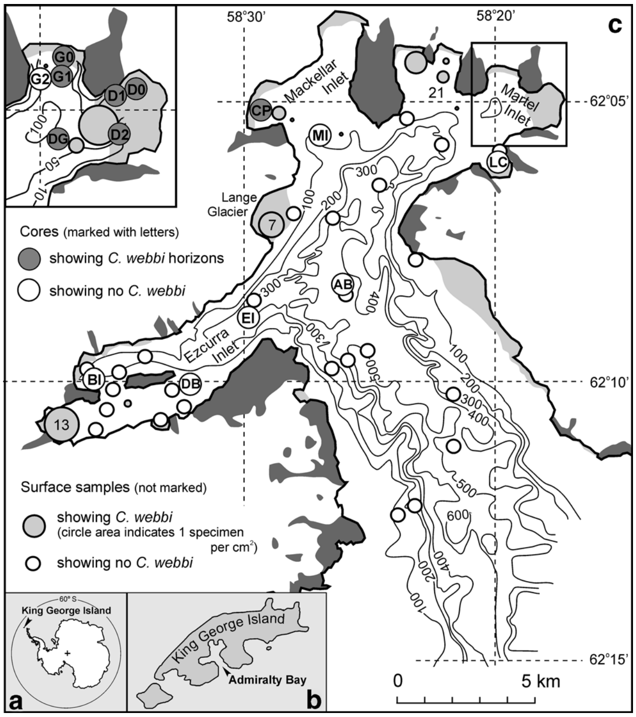

Fig. 1. The location of **a.** King George Island, **b.** Admiralty Bay**,** and **c.** sampling stations. Dark grey indicates inland glacier-free areas (Battke 1990), light grey within the fjord indicates areas freed by the retreating tidewater glacier since AD 1956 (Braun & Gossmann 2002). The bathymetric contour lines in metres after Straten (1996). Cores marked by names, surface samples not marked except sites 7, 13, and 21 where holotype, paratypes, and "living" specimens of *C. webbi* were found.

Table I. Core discussed in this study. See Fig. 1 for core locations.

Site	Water depth (m)	Core depth (cm)	Depth of the *C. webbi* horizon (cm)
BI	128	80	
MC	12	65	
AB	475	38	
CP	88	38	8–16
MI	101	50	
LC	35	84	
EI	291	52	
DB	64	71	
D0	82	16	8–10
D1	33	24	8–12
D2	46	52	6–18
G0	67	40	8–26
G1	81	34	14–20
G2	78	28	
DG	68	54	8–15

Methods

During the 2002/2003 summer, 38 surface-sediment samples (0–10 cm) were collected throughout Admiralty Bay from 8 to 520 m water depth, (see Fig. 1 for sampling locations and Majewski (2005) for more details). The surface samples were stained with Rose Bengal (1 g l^{-1}) and 70% ethanol diluted in seawater, and picked for "living", meaning Rose Bengal stained, and "dead" foraminifera. Moreover, 14 undisturbed sediment cores of up to 82 cm in length were collected using a tube-sampler from water depths ranging from 12–475 m (Fig. 1, Table I). The sediment cores were sliced into 2 cm thick sections.

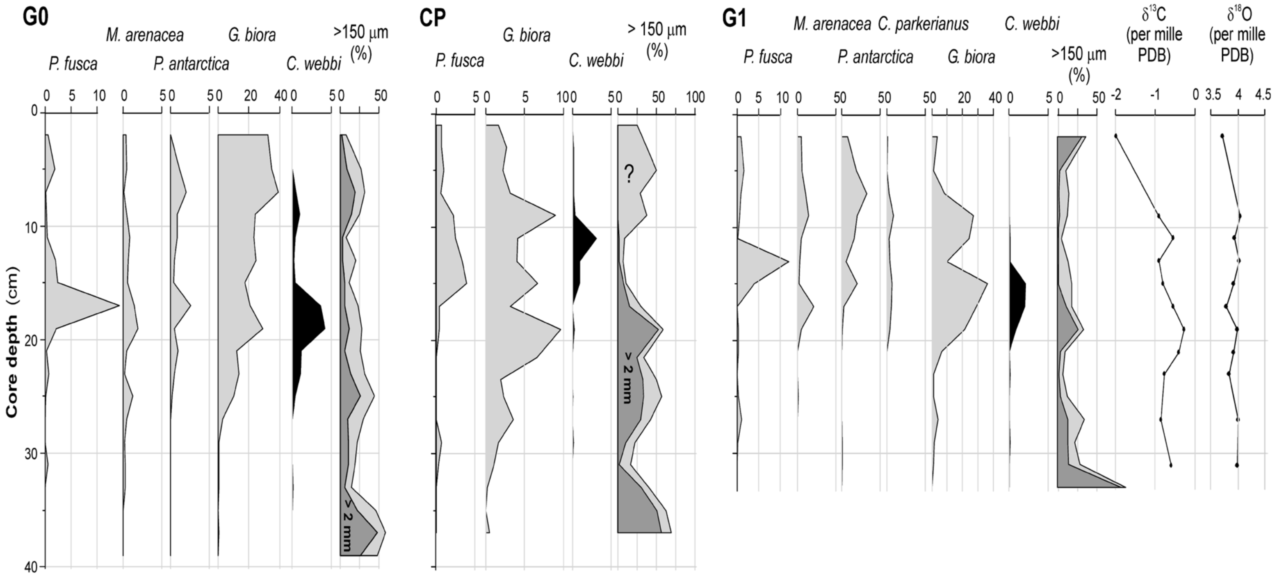

Fig. 2. Foraminiferal frequencies (specimens per gram of dry sediment), granulometric data (% > 150 µm and > 2 mm fraction, the later marked in darker grey), and stable isotopic data, from selected cores. Note *Cribroelphidium webbi* frequencies marked in black. For full names of foraminiferal species, refer to Appendix B.

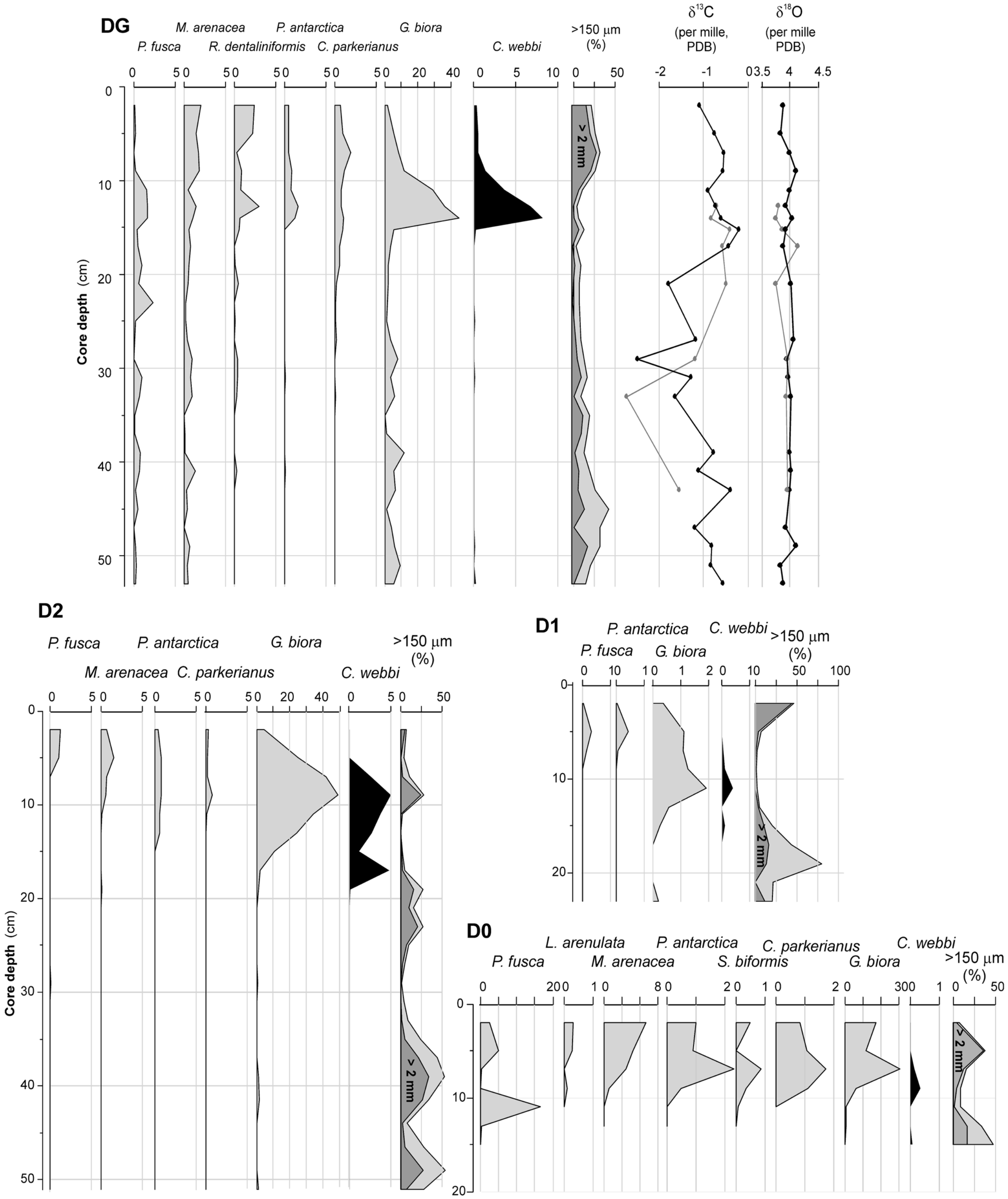

Fig. 3. Foraminiferal frequencies (specimens per gram of dry sediment), granulometric data (% > 150 µm and > 2 mm fraction, the later marked in darker grey), and stable isotopic data, from selected cores. Stable isotopic results on opaque and transparent *Globocassidulina biora* specimens mark in grey and black, respectively. Note *C. webbi* frequencies marked in black. For full names of foraminiferal species, refer to Appendix B.

Sediment was washed over a 150 µm sieve. The > 150 µm residue was weighted. Dried samples were picked for foraminifera. All specimens were arranged by taxa on micropalaeontological slides. The classification scheme of the Order Foraminiferida used is that of Loeblich & Tappan (1988).

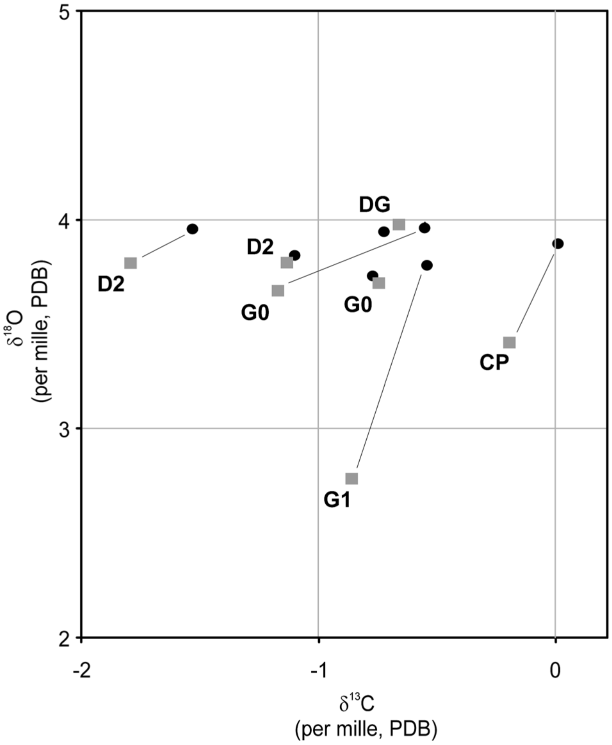

Fig. 4. δ^{18}O vs δ^{13}C values measured on *Globocassidulina biora* (black circles) and *C. webbi* (grey squares) from the same depths of selected cores, indicated on the graph.

Stable isotope analyses were conducted on two foraminiferal species, *Globocassidulina biora* and *Cribroelphidium webbi* from selected sections of five cores. For each measurement, 5–10 specimens were separated from the 150–500 µm size fractions. Wherever possible, complete, well-preserved specimens were chosen, i.e. those showing a transparent test wall. The isotope analyses were performed at the University of Florida and run on a Finnigan MAT 252 mass spectrometer coupled to a Kiel III carbonate preparation device. The data were related to isotopic standard NBS-19, which had a δ^{18}O value of -2.19‰ PDB, and a δ^{13}C value of 1.92‰ PDB, through 14 standard replicates. Standard deviations, calculated from these additional measurements for oxygen and carbon isotopes, were 0.09‰ and 0.03‰, respectively. All isotopic ratios are expressed in standard delta notation relative to VPDB (Vienna Pee Dee Belemite).

The investigated foraminifer collection is housed at the Institute of Paleobiology of the Polish Academy of Sciences (Warszawa) under the catalogue number ZPAL F.45.

Results

Cribroelphidium webbi *sp. nov. distribution in Admiralty Bay*

Large number of *C. webbi* specimens found in surface samples and cores from Admiralty Bay were used to establish the new species (Appendix A). Among the 38 surface samples, *C. webbi* was present at 13 locations within the three inlets of Admiralty Bay (Fig. 1). Whilst water depths of these sites range between 34 and 165 m, 11 locations are shallower than 100 m. Importantly, all these sites are located deep within the inlets and no further than 2 km from tidewater glaciers. *Cribroelphidium webbi* abundances in the upper 10 cm of sediment range between 0.03 and 3.15 specimens per cm^2 (Fig. 1). From a total of 357 *C. webbi* specimens, only two were "living". They came from 2–3 cm and 3–4 cm depth intervals at sites 13 and 21 respectively. For more information on accompanying "living" and "dead" benthic foraminiferal assemblages refer to Majewski (2005).

Cribroelphidium webbi was also found in seven out of the fourteen sediment cores analysed. Six cores were from Martel Inlet, and one core (CP) was from Mackellar Inlet (Fig. 1). These cores were from water depths 33–88 m and close to retreating tidewater glaciers (Table I). At least four of these cores (G0, D0, D1, D2, and possibly CP) were from areas that were still occupied by glaciers 50 yrs ago (Braun & Gossmann 2002 and Fig. 1). In all seven cores, *C. webbi* is considerably abundant (up to eight specimens per gram of dry sediment) in horizons between 6 and 26 cm below sediment floor (cm b.s.f.) (Figs 2 & 3, and Table I). In most of the cores, the peaks in *C. webbi* are within muddy horizons and correlate with lows in the >150 µm grain size. *Cribroelphidium webbi* is accompanied by a variable number of other benthic foraminifera, including *Globocassidulina biora* and *Psammosphaera fusca*, which are the most abundant (Appendix B for complete species list). All the accompanying foraminiferal species are typical for the assemblage inhabiting "open inlets" as described by Majewski (2005). Except for cores DG and CP, this foraminiferal association occurs in sediments overlying barren or almost barren sediments.

Stable isotopic results

The stable isotopic values measured on *G. biora* in cores DG and G1 show stable δ^{18}O values throughout with variability within the method precision (Figs 2 & 3). δ^{13}C in DG shows considerable variability and lower values below 20 cm b.s.f., which is below the *C. webbi* event. Oxygen and carbon isotopic values analysed on opaque and transparent specimens of *G. biora* in DG show very similar results. As shown on Fig. 4, δ^{18}O and δ^{13}C values measured on *G. biora* and *C. webbi* from the same samples of five selected cores exhibit significant variability. In three samples, carbon and oxygen stable isotopic values measured on the two species are identical. However, in two samples, *C. webbi* shows significant depletion in δ^{18}O, and in other two depletion in δ^{13}C, with respect to *G. biora* (Fig. 4).

Discussion

Cribroelphidium webbi *sp. nov. habitat*

It was found at 20 locations but most commonly in water shallower than 100 m. The two deepest sites (165 and 102 m water depth) yielded other Rose Bengal stained benthic foraminifera, which may suggest *in situ* position of the sediment, without significant transportation to greater water depth. Overall, it appears that in Admiralty Bay, *C. webbi* is restricted to near-shore settings, in close proximity to retreating tidewater glaciers (Braun & Gossmann 2002, Fig. 1). In this respect, it may resemble *Cribroelphidium excavatum clavatum*, a member of the *Cribroelphidium excavatum-C. incertum* group typical of brackish environments throughout high and intermediate latitudes of Northern Hemisphere (e.g. Conradsen 1993, Polyak *et al*. 2002). *Cribroelphidium excavatum clavatum* is a highly opportunistic form dominating the near glacial settings in Arctic fjords (e.g. Hald *et al*. 1994, Hald & Korsun 1997, Majewski & Zajączkowski 2007). It is able to dominate the Northern Hemisphere glacier-proximal settings thanks to its infaunal, highly mobile nature, which helps it in coping with highly variable sedimentation (Hunt & Corliss 1993, Hald *et al*. 1994).

The diversity in stable isotopic values of *C. webbi* (Fig. 4) seems to suggest a similar habitat "mobility" for this foraminifer, at least with respect to *G. biora*, of which 70% of the modern population inhabits the uppermost 2 cm of Admiralty Bay sediments (unpublished results). The potentially more infaunal habitat of *C. webbi* than that of *G. biora* is supported by lower δ^{13}C values of the first (Fig. 4). On the other hand, the interspecific stable isotopic offsets may be due to seasonal effects. *Cribroelphidium webbi* may grow under the influence of meltwater during the summer (and therefore would have lower δ^{18}O and δ^{13}C values) while *G. biora* may grow throughout the year or at least over a longer period and therefore would show a less pronounced meltwater signal.

We do not have reliable distribution data for living *C. webbi* in Admiralty Bay. Among a total of 357 *C. webbi* specimens from the surface samples, only two were "living", (Rose Bengal stained). A repeated search for this foraminifer at the same locations in early 2007 revealed no living specimens. Consequently, there are doubts if these two "living" specimens, retrieved from the surface samples, contained actual *C. webbi* living cells, or were its empty tests inhabited by different microrganisms.

Cribroelphidium webbi *sp. nov. stratigraphical distribution*

In all the sections where *C. webbi* was observed, it occurs in well-defined sub-Recent horizons between 8 and 20 cm b.s.f., at the base of coarser, rich in biota, "open water" sediment section overlapping subglacial deposits (Figs 2 & 3, and Table I). Only in core DG located farthest away from tidewater glaciers and to less extent in core CP (Fig. 1) were relatively rich "open water" biota also present below the *C. webbi* horizon (Fig. 2).

The presence of the *C. webbi* layers suggests *in situ* occurrences of the sediments analysed with no downslope displacement. Age of these horizons is difficult to determine. Sedimentation rates may vary greatly within a single fjord, depending upon sediment supply and bottom water current activity. Based on ^{14}C dating, sedimentation rate for upper core S-2, located near our core MI, was 0.24 cm yr^{-1} (Khim *et al*. 2001), while for PD 88-176 from central Admiralty Bay ~ 0.36 cm yr^{-1} (Straten 1996). Our unpublished ^{210}Pb results suggest sedimentation rates at DG and AB to be ~ 0.13 cm yr^{-1}. According to these values the *C. webbi* horizons could be deposited somewhere between 30 and 80 yrs ago. Moreover, at sites G0, D0, D1, D2, and possibly CP, that are located in the areas occupied by glaciers 50–10 yrs ago (Fig. 1) the age of these horizons could be younger than 50 yr but considerably older than 10 yr.

Cribroelphidium webbi *sp. nov. association with meltwater*

As mentioned above, the Northern Hemisphere *C. excavatum-C. incertum* group is typical for brackish environments. As a matter of fact, in two samples (cores CP and G1, Fig 4), *C. webbi* shows δ^{18}O depletion in respect to *G. biora* by 0.5–1.0‰, which may suggest a brackish water inclination for this foraminifer. Khim *et al*. (2001) reported a subglacial meltwater discharge event on King George Island that was recorded by *G. biora* δ^{18}O excursion in the upper 60 cm of core S-2, located close to our core MI (Fig. 1). Keeping these factors in mind, we followed the procedure of Khim *et al*. (2001), and analysed *G. biora* from our cores G1 and DG for its δ^{18}O values to test a possibility of meltwater events during the *C. webbi* peaks in these profiles.

Our data do not show any significant changes in *G. biora* δ^{18}O throughout the analysed cores (Figs 2 & 3), which shows no influence of relatively recent meltwater pulses in the Mackellar and Martel inlets. However, meltwater is significantly lighter than normal salinity seawater and does not normally descend to considerable depths, but may form surface-water sediment-laden layers often observed in Admiralty Bay (Sarukhanyan & Tokarczyk 1988). Therefore, one would not expect a pronounced effect of meltwater pulses on bottom water salinity and δ^{18}O but rather on glaciomarine sedimentation during these events. In the seven cores, where the *C. webbi* horizons are recognized, they do correlate with a decrease in > 150 µm and > 2 mm sediment fraction. Such decline in coarse fraction may indicate either fewer icebergs, carrying ice-rafted debris, or stronger sedimentation of fine material diluting the

>150 µm fraction during *C. webbi* events. The second seems to be consistent with the possible meltwater pulses as the meltwater easily carries suspended fine material, which may be deposited even several kilometres away from glacier front by settling due to increasing salinity, decreasing velocity, and flocculation (e.g. Zajączkowski 2008).

Nature of C. webbi *sp. nov. horizons*

We consider two working hypotheses for the nature of the *C. webbi* horizons. They could be a result of 1) a single meltwater event, in this case producing a synchronous, stratigraphic level, or 2) they are diachronous and formed within an environmental zone that follows progressing deglaciation, remaining in roughly similar distance to tidewater glacier fronts.

To evaluate the first possibility, a unique mechanism causing a relatively short-lasting, well constrained, and of rather broad geographical impact meltwater pulse needs to be proposed. This event ought to take place between ~50 and 30 yrs ago, which is suggested by the sedimentation rates reported from Admiralty Bay and the presence of most of the *C. webbi* sites in areas covered by glaciers before AD 1956 (Fig. 1). There are no direct data on meltwater delivery to Admiralty Bay over the last half century, but one could assume that it was linked with higher temperatures. Temperature records from selected stations in the vicinity of Antarctic Peninsula (Kejna 2003, King *et al*. 2003) show an overall trend of increasing mean annual temperatures during the last 50 years, overprinted by ±2°C fluctuations of few years in duration. These data do not show a single outstanding warming event during the last 50 yr, which could be attributed to the single (non-repetitive) meltwater pulse supporting the *C. webbi* event.

The second suggestion that the *C. webbi*-rich horizons were formed within an environmental zone following deglaciation could be supported by the fact that they are found in most cores at the same lithologic position, i.e. at the base of marine sediments overlaying glacial diamicton. Moreover, their estimated age between 80 (in fact 50 for most of the cores) and ~30 years ago fits well with the deglaciation processes in the area. If this explanation is true, *C. webbi* may provide a record of past glacier extent and deglaciation rate.

The glacial and sea ice systems in the Antarctic Peninsula have responded directly to the regional warming since the 1940s (Cook *et al*. 2005). During the last 50 years, the rapid warming of air temperature in the western Antarctic Peninsula region was in the range of 0.5–0.6°C per decade (Meredith & King 2005). It was reflected by reduction of glacier ice mass, rapid retreat of glacier fronts, disintegration of ice shelves and subsequent speed-up of inland ice masses (Braun & Gossmann 2002, Cook *et al*. 2005, Rignot *et al*. 2005, Pudełko 2008), as well as by increased coastal meltwater runoff (Vaughan 2006).

The rapidity of environmental change in the Antarctic Peninsula may suggest that *C. webbi* could be considered a facies marker associated with retreating glacier fronts documented for Admiralty Bay by Braun & Gossmann (2002) (Fig. 1). The change from diamicton and subglacial sedimentation to glaciomarine mud is paralleled in most of the cores by upward increase in pigments and biogenic silica concentrations (unpublished results), fining of grain size, and increase in biotic elements (Figs 2 & 3), which usually occur in the sediments accumulated on deglaciated marine areas (Gingele *et al*. 1997, Zajączkowski 2008). In two cores (CP and DG), no significant change between foraminiferal benthic communities from sediments under- and overlying the *C. webbi* horizon is observed (Figs 2 & 3). This lack of faunal change associated with the proposed deglaciation could be explained by floating ice tongues present over these sites before the *C. webbi* maxima. This absence of clear foraminiferal assemblage change is consistent with some observations from the newly ice free areas after the collapse of the northern Larsen Ice Shelf (Murray & Pudsey 2004). However, no elphidiid foraminifera were reported from those settings (Ishman & Szymcek 2003, Murray & Pudsey 2004).

Concluding remarks

Cribroelphidium webbi sp. nov. is the only adequately described elphidiid foraminifer in sub-Recent sediments reported from Antarctica. It shows clear association with shallow water settings in proximity of retreating tidewater glaciers, therefore it carries a great potential as palaeoclimatic indicator. It appears that it shares similar ecological affinities with *Cribroelphidium excavatum clavatum*, well-known from glacier-proximal habitats throughout the Arctic. Despite many questions concerning its ecology, *C. webbi* appears to be a sensitive glacier-proximal indicator. The layer bearing its enhanced concentration is clearly related to deglaciation and regional warming. It appears that the *C. webbi*-rich horizons are diachronous, formed within an environmental zone following deglaciation and they may provide a record of past glacier extent and rate of deglaciation.

The big question brought up by discovery of this foraminifer is why are there so few elphidiids present in Antarctica, while they are so widely distributed throughout the Arctic? Some members of the *Cribroelphidium excavatum*-*C. incertum* group are present as far south as in New Zealand and nearby sub-Antarctic islands, as well as in Chilean fjords (Hayward *et al*. 1999, 2007, Hromic *et al*. 2006). Possibly, the isolation of Antarctica is so severe, taking into account the lack of typical shelf areas and oceanographic pathways of cross-frontal exchange similar to the North Atlantic Current, that it prevented dispersal of these foraminifera. Perhaps, the Antarctic environment is not right, due to much less fresh/meltwater discharge than in the Arctic, particularly during periodic glacial advance to the edge of shelf, and a lack of great rivers which support widespread development of brackish environment.

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Appendix A

Description of new species

Genus. *Cribroelphidium* Cushman and Brönnimann, 1948

Cribroelphidium webbi sp. nov. Majewski

(Figs 5 & 6)

Description. Test planispiral, involute, lobulate in outline, with 6 to 8 chambers in the final whorl, gradually increasing in size, periphery broadly rounded with no keel. Multiple interiomarginal aperture. Sutures nearly radial, slightly depressed, with up to 5 short, irregularly disposed septal bridges on each side. Umbilical area slightly to moderately depressed, covered by fine papillae, which are also prominently developed around the aperture and along the sutures forming a star shape and frequently obscuring septal bridges. In some specimens, radiating grooves are clearly visible on the apertural face (Fig. 5.2). Diameter to width ration between 1.3 and 1.8.

Ethymolgy. The species is named in honour of Professor Peter Noel Webb, Department of Geological Sciences of the Ohio State University (Columbus).

Remarks. Cribroelphidium webbi may resemble *Haynesina orbiculare* or some forms from the highly variable *Cribroelphidium excavatum–C. incertum* group common in the Northern Hemisphere. *Cribroelphidium excavatum* was also noted from New Zealand and Chilean fjords (Hayward *et al.* 1999, Hromic *et al.* 2006). *Cribroelphidium webbi* differs from *H. orbiculare* by the numerous sutural bridges, and from *C. excavatum* by more globular chambers and more prominently developed fine papillae. Moreover, the unique distribution of *C. webbi* inside Antarctic fjords suggest its genetic differentiation from the Northern Hemisphere high latitude species, similarly as it was recently shown for Antarctic vs. Arctic monothalamous benthic foraminifera by Pawlowski *et al.* (2008).

Distribution. In Admiralty Bay, it is common in near-shore settings up to 2 km away from tidewater glaciers and water depths between 33 and 165 m, but commonly not deeper than 100 m. Specimens came from sub-Recent horizon overlapping subglacial deposits. No unequivocally living specimens were found despite targeting search. Woo *et al.* (1996) and Li *et al.* (2000) reported a presence of some elphidiid foraminifera, assigned to *Elphidium* sp. and *Elphidium incertum*, in similar settings from Admiralty Bay and the nearby Maxwell Bay. Also Mayer (2000) reported *Cribroelphidium bartletti* from water depth 20–30 m in Potter Cove, King George Island. All these findings represented most likely *Cribroelphidium webbi*. *Cribroelphidium* cf. *bartletti*, that could resemble *Cribroelphidium webbi*, was also recorded by Ward & Webb (1986) from Late Quaternary raised deposits of Ross Island, McMurdo Sound.

Size. Maximum diameter 600 μm; holotype, 450 μm.

Holotype. ZPAL F.45/1 (Fig. 5.1).

Type locality. Martel Inlet, 39 m water depth, 3–4 cm sediment depth.

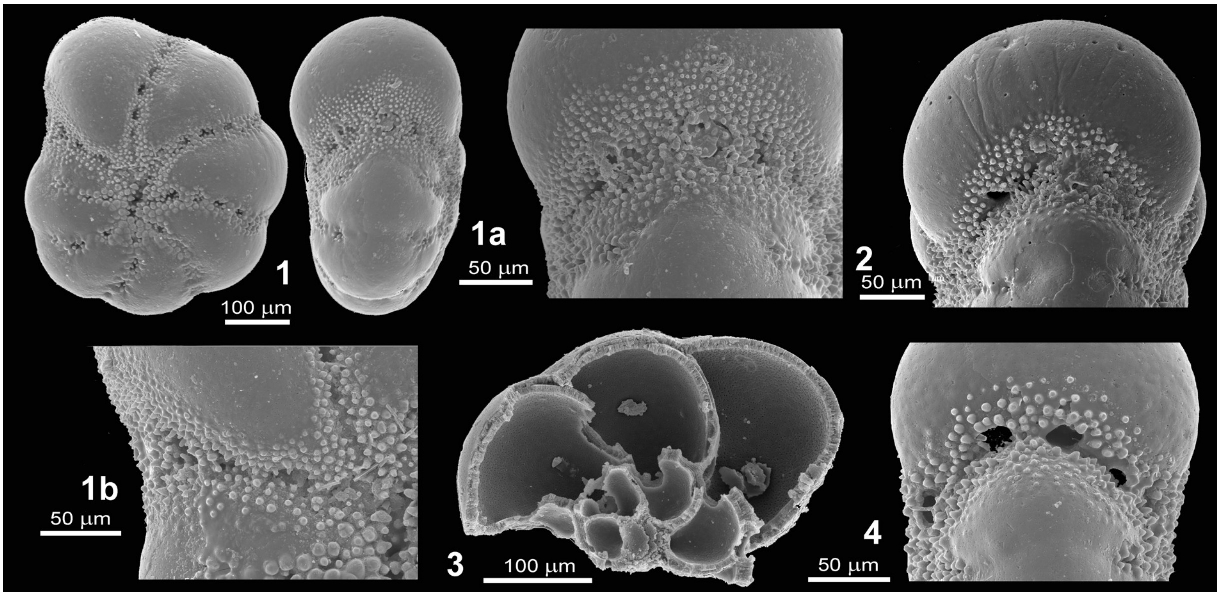

Fig. 5. *Cribroelphidium webbi* sp. nov.; **1.** 21, 3–4 cm (holotype ZPAL F.45/1), **1a.** Apertural face and apertures, **1b.** Umbiliculus and the last suture. **2.** Apertural face with radiating grooves, DG, 10–12 cm, **3.** Cross section, 13, 2–3 cm. **4.** Apertural face and apertures, 13, 10–15 cm. Core symbol and sites numbers as on Fig. 1.

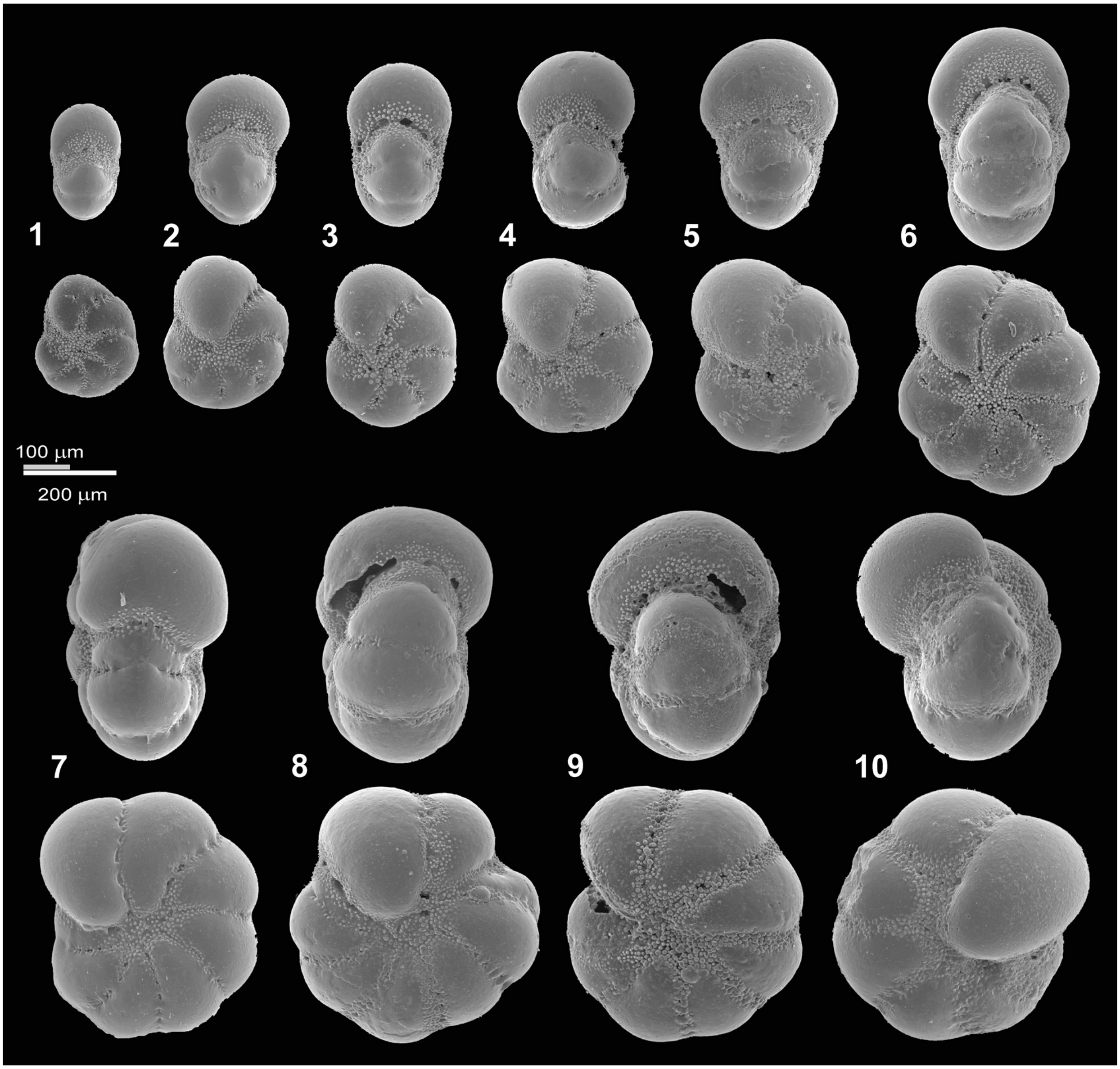

Fig. 6. *Cribroelphidium webbi* sp. nov.; **1, 2.** 13, 2–3 cm, **3.** 13, 10–15 cm (paratype ZPAL F.45/2), **4, 8.** 13, 8–9 cm, **5, 7** 21, 8–9 cm, **6.** 7, 6–7 cm (paratype ZPAL F.45/3), **9.** 13, 9–10 cm, **10.** 21, 9–10 cm. Sites numbers as on Fig 1.

Paratypes. Two specimens (ZPAL F.45/2, Fig. 6.3 and ZPAL F.45/3, Fig. 6.6) from Ezcurra Inlet, 47 m water depth, 10–15 cm sediment depth and from in front of the Lange Glacier, 165 m, 10–15 cm, respectively.

Appendix B

List of species noted in discussed cores and shown on Figs 2 & 3

Cassidulinoides parkerianus (Brady, 1881)
Cribroelphidium webbi sp. nov.
Globocassidulina biora (Crespin, 1960)
Lagenammina arenulata (Skinner, 1961)
Miliammina arenacea (Chapman, 1916)
Nodulina dentaliniformis (Brady, 1884)
Portatrochammina antarctica (Parr, 1950)
Psammosphaera fusca Schulze, 1875
Spiroplectammina biformis (Parker *et* Jones, 1865)