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Glacial–interglacial records from sediments in Powell Basin, Antarctica

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Abstract: Palaeoenvironmental history is reconstructed from diatoms in two sediment cores, GC01-PW02 and GC03-PW02, recovered from Powell Basin, Antarctica. A total of 43 species belonging to 21 genera are identified from GC01-PW02. A total of 61 species belonging to 27 genera are identified from GC03-PW02. The number of diatom valves g^{-1} of dry sediment ranges from $0.1–48.3 \times 10^6$ valves g^{-1}. Based on diatom abundance, six assemblage zones were identified from GC01-PW02, and five diatom zones were identified from GC03-PW02. Barren intervals represent glacial periods, while intervals with higher diatom abundances were deposited during interglacial periods and reduced sea ice cover. The occurrence of *Rouxia leventerae* only within the deepest zone of each of the cores indicates that the core sediments were deposited since marine isotope stage (MIS) 6.

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Key words: diatom zones, GC01-PW02, GC03-PW02, MIS 6

Introduction

Diatoms from Quaternary Southern Ocean sediments are extremely useful biomarkers for palaeoceanographic interpretation (Gersonde & Zielinski 2000, Taylor & McMinn 2002, Taylor & Leventer 2003, Armand *et al.* 2005, Crosta *et al.* 2005, Stickley *et al.* 2005, Maddison *et al.* 2005, 2006) including glacial–interglacial variability and deglacial processes (Barbara *et al.* 2010, Bart *et al.* 2011, Tolotti *et al.* 2013). Biological productivity at the surface is closely related to the distribution of sea ice, and diatoms in underlying sediments can record changes in sea-ice extent. Organic particle flux is at a maximum during seasons of open water, whereas vertical flux of diatoms is extremely low during periods with heavy sea-ice cover (Abelmann & Gersonde 1991). Today, Powell Basin is covered by sea ice for about nine months a year (Naval Oceanography Command Detachment 1985), with primary productivity during times of open water. However, during glacial periods, more extensive sea-ice cover may have precluded primary productivity. The purpose of this study is to investigate the late-Pleistocene glacial–interglacial cycles that are recorded in sediments from cores GC01-PW02 and GC03-PW02 collected in Powell Basin.

Materials and methods

Regional setting

Powell Basin is in the north-west of the Weddell Sea, east of the Antarctic Peninsula and west of the South Orkney Islands (Fig. 1). Powell Basin was created by the eastward motion of the South Orkney microcontinent (SOM) relative to the Antarctic Peninsula (King & Barker 1988). The SOM was incorporated into the Antarctic Peninsula during the Miocene as a consequence of the end of basin spreading (Rodriguez-Fernandez *et al.* 1997). The Antarctic Peninsula is the main source of terrigenous sediments carried into Powell Basin (Pudsey 1992).

In the region of Powell Basin, Antarctic surface water (ASW) occurs to a depth of *c.* 200 m. It is very cold, low in salinity and rich in dissolved oxygen. Surface waters show strong seasonal fluctuations due to the formation of sea ice. Below the ASW is Circumpolar Deep Water (CDW), to a depth of *c.* 800 m. The occurrence of CDW, which is warmer and higher in salinity than the surface water, is significant because this water mass continuously delivers heat to the lower section of the Antarctic ice shelves (Dinniman & Klinck 2004). On the Antarctic continental shelves, CDW transport has an important biological influence. The upwelling of CDW brings nutrients into the euphotic zone and can increase primary productivity of diatoms (Prézelin *et al.* 2000, Dinniman *et al.* 2011). The sea-ice distribution map is taken from Gersonde & Zielinski (2000) (Fig. 2).

Materials

Gravity cores GC01-PW02 and GC03-PW02 were collected from Powell Basin at 50°31'W, 61°32'S (3144 m below sea level, core length 800 cm) and 48°49'W, 60°14'S (2564 m below sea level, core length 780 cm). GC01-PW02 and GC03-PW02 both are affected by the Weddell Sea Deep Water. It is also the area where the sea-ice distribution changes in the glacial–interglacial period (Gersonde & Zielinski,

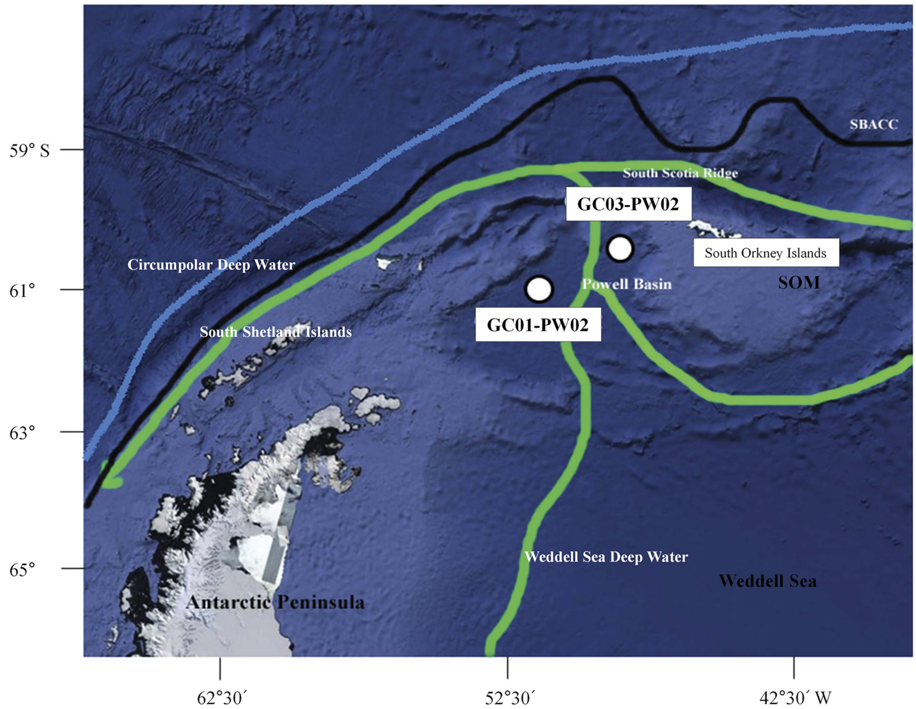

Fig. 1. Core locations map of the GC01-PW02 and GC03-PW02 core sediments in Antarctica (Google Earth, 2017). SOM: South Orkney Microcontinent, SBACC: Southern Boundary of the Antarctic Circumpolar Current.

2000). GC01-PW02 mainly consists of mud and sandy mud, with clay distributed in the intervals 20–80 cm, 210–310 cm and 575–625 cm. The interval from 420–480 cm was devoid of sediment. GC03-PW02 consists mostly of mud and sandy mud, with sand and silty mud in the interval from 151–205 cm.

Methods

A total of 38 and 43 samples were collected from cores GC01-PW02 and GC03-PW02 respectively, and the following process was used to extract diatom fossils (Bak & Lee 2017).

The dry samples (2 g) were placed in a 500 ml beaker into which 25 ml of hydrogen peroxide (H_2O_2: 30%) and 25 ml hydrochloric acid (HCl: 10%) were added. These samples were heated to 100 °C to oxidize the organic material and dissolve the carbonates, and then allowed to stand for 24 h. After completion of the reaction, samples were washed three times with distilled water. The residue was transferred to a 60 ml bottle and diluted to 60 ml for analysis. Slides for quantitative analysis of diatoms were made using the random settling method of Scherer (1994). All diatoms were counted up to a minimum of 200 specimens excluding the resting spores of *Chaetoceros* spp. Diatom counts were conducted mainly by using the 400X and 800X magnifications of a Nikon E400 microscope, and small individuals were observed at 1000X. We observed 400 fields of view in slides of the horizons with very few diatoms.

Results

Diatom assemblage zones of GC01-PW02

A total of 43 diatom species belonging 21 genera were identified from GC01-PW02 (Fig. 3). Absolute abundance in valves g^{-1} of dry sediment ranged from $0–48.3 \times 10^6$ valves g^{-1}. Valve abundance ranges widely, and the number of samples with diatoms is limited to three intervals within the core. Barren zones are defined as intervals with no diatoms, and occur from 45–320 cm,

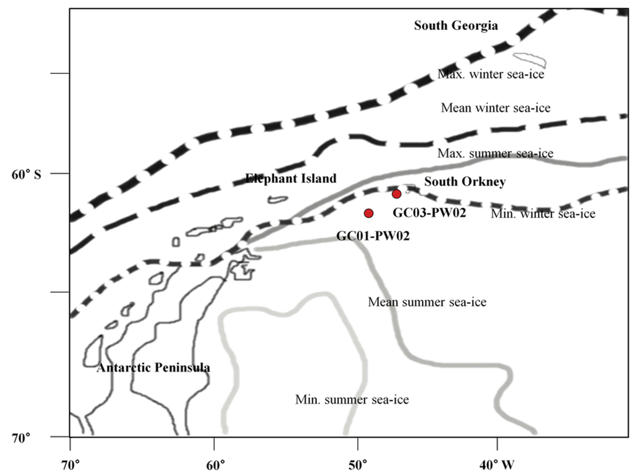

Fig. 2. The schematic diagram of sea-ice distribution is according to Naval Oceanography Command Detachment (1985) and Gersonde & Zielinski (2000). Solid line: summer, dotted lines: winter minimum, maximum and mean.

520–640 cm and 760–790 cm. The dominant species in the diatomaceous intervals is *Fragilariopsis kerguelensis* (O'Meara) Hustedt (20%), followed by *Eucampia antarctica* (Castracane) Mangin var. *antarctica* (13%), *Actinocyclus actinochilus* (Ehrenberg) Simonsen (10.1%), *Fragilariopsis curta* (Van Heurck) Hustedt (9.7%), and *Odontella weissflogii* (Grunow) Grunow (6.4%) (Plate 1). *Chaetoceros* resting spores are observed only in the uppermost horizon (0–20 cm).

Based on diatom abundances and assemblages, three barren and three assemblage zones were identified. Absolute diatom abundance and relative species abundances are plotted in Fig. 3.

Diatom assemblage zone I (740–660 cm): absolute diatom abundance ranges between 0.9×10^6 and 48.3×10^6 valves g^{-1}, and reaches a maximum at 740 cm. *Eucampia antarctica* var. recta (Mangin) stat. nov. peaks at 680 cm. The open water species *F. kerguelensis*, and *O. weissflogii* and *Thalassiosira antarctica* Comber warm type are also common.

Diatom assemblage zone II (500–340 cm): diatom abundances range from $1.2–21.6 \times 10^6$ valves g^{-1}. *A. actinochilus* and *E. antarctica* var. *recta* are most abundant between 340 cm and 410 cm. The sea-ice species *F. curta* reaches a maximum at 400 cm. The open water species *F. kerguelensis* and *O. weissflogii* occur throughout this interval.

Diatom assemblage zone III (20–1 cm): diatom abundance is highest in the uppermost sediment. *Eucampia antarctica* var. *antarctica* and *Thalassiosira antarctica* warm type occur at 20 cm, while *Actinocyclus actinochilus*, *Thalassiosira antarctica* cold type, and *Chaetoceros* resting spores dominate the uppermost sample at 1 cm.

Diatom assemblage zones of GC03-PW02

In total, 61 diatom species belonging 27 genera were identified from GC03-PW02. Diatom abundance ranges from $0.1–37 \times 10^6$ valves g^{-1}. The dominant species was *E. antarctica* var. *recta* (17.6%), followed by *F. curta* (14.9%), *F. kerguelensis* (13.7%), *A. actinochilus* (12.3%), and the warm type of *T. antarctica* (5.5%). *Chaetoceros* resting spores are abundant from 2–100 cm. A total of five diatom assemblage zones were established for GC03-PW02, based on the vertical distribution of selected species (Fig. 4).

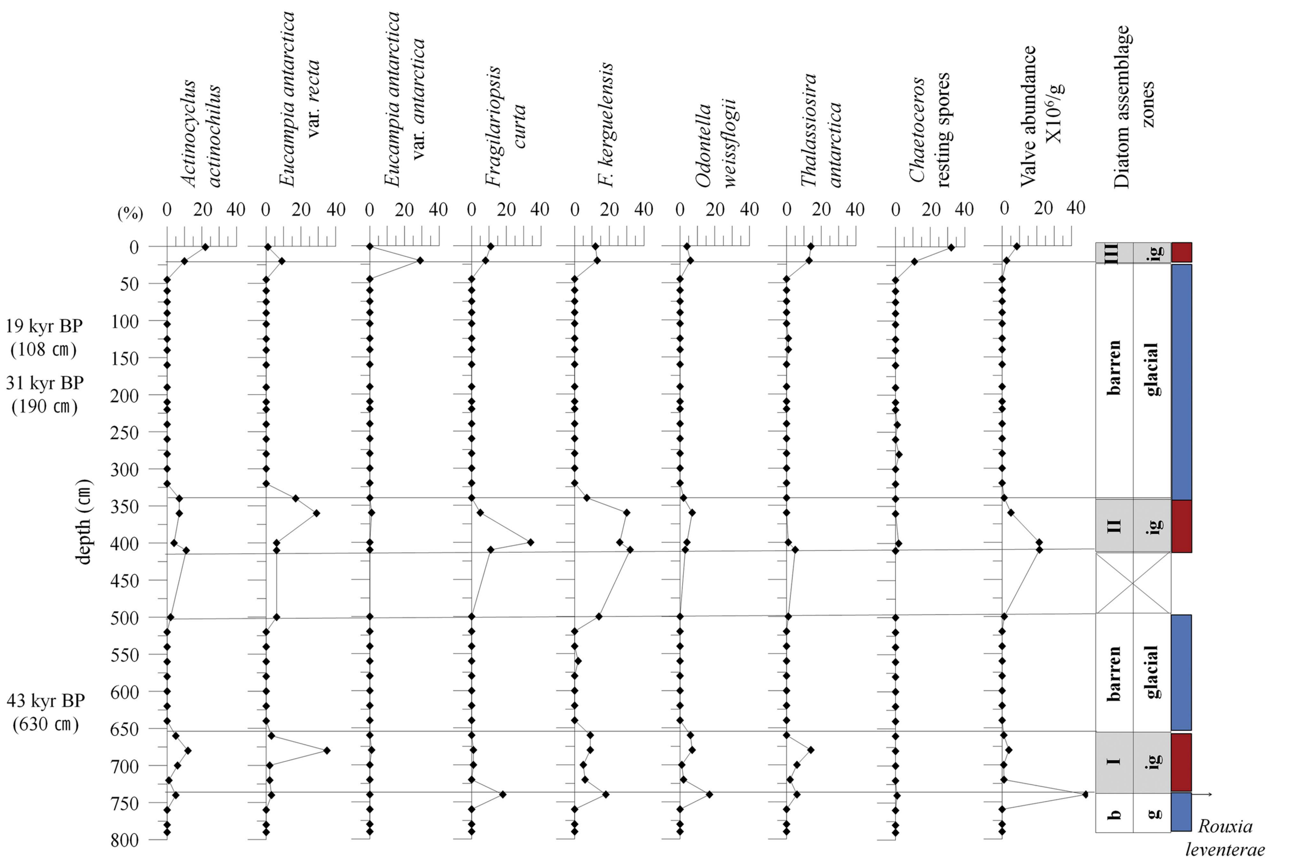

Fig. 3. Downcore variations of relative abundance of the characteristic species and diatom assemblage zones from GC01-PW02. b: barren, Ig: interglacial, g: glacial.

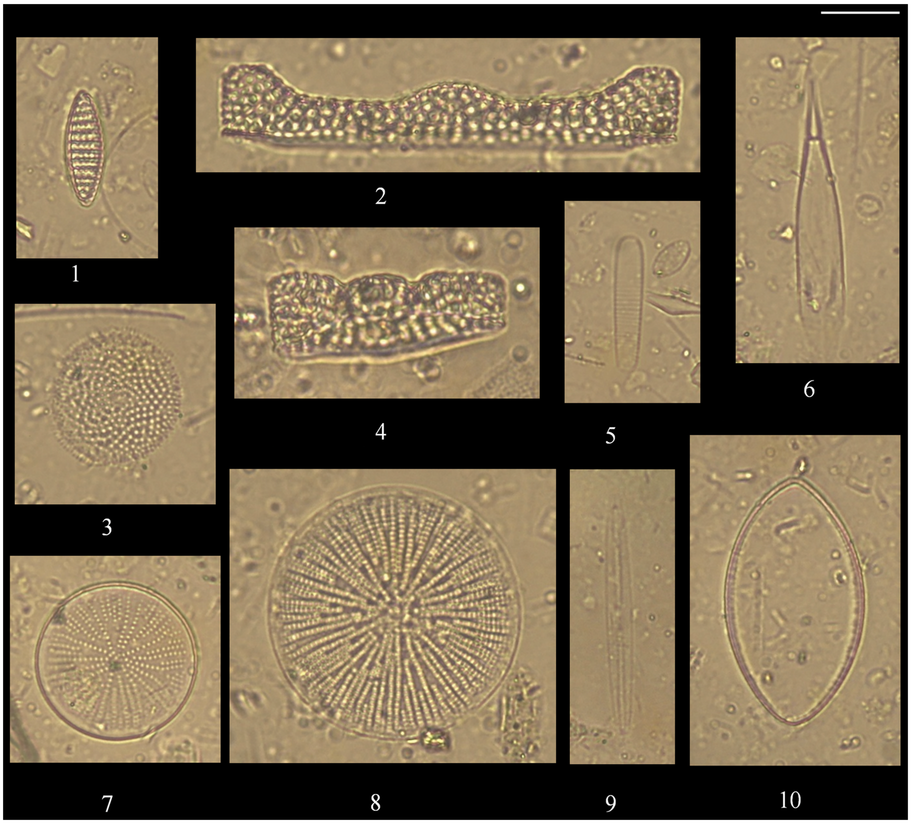

Plate 1. 1. *Fragilariopsis kerguelensis* (O'Meara) Hustedt, GC01-PW02 20 cm, 2. *Eucampia antarctica* var. recta (Mangin) stat. nov., GC01-PW02 360 cm, 3. *Thalassiosira antarctica* Comber, GC01-PW02 1 cm, 4. *Eucampia antarctica* (Castracane) Mangin var. *antarctica*, GC01-PW02 20 cm, 5. *Fragilariopsis curta* (Van Heurck) Hustedt, GC03-PW02 120 cm, 6. *Rhizosolenia styliformis* Brightwell, GC03-PW02 520 cm, 7. *Actinocyclus actinochilus* (Ehrenberg) Simonsen, GC03-PW02 480 cm, 8. *Actinocyclus octonarius* Ehrenberg, GC01-PW02 1 cm, 9. *Rouxia leventerae* Bohaty *et al.*, GC03-PW02 780 cm, 10. *Odontella weissflogii* (Grunow) Grunow, GC03-PW02 440 cm. Bar scale: 10 μm.

Barren zones (740–580 cm, 320–160 cm): these intervals are characterized by low abundances, ranging from $0–0.4 \times 10^6$ valves g^{-1}.

Diatom assemblage zone I (780–760 cm): diatom abundances range between 19×10^6 and 24.3×10^6 valves g^{-1}. In this zone, the ice edge species *A. actinochilus* and *E. antarctica* var. *recta* are abundant, as are the open water species *F. kerguelensis* and *O. weissflogii*.

Diatom assemblage zone II (560–340 cm): diatom abundances range between 0.2×10^6 and 4.8×10^6 valves g^{-1}. The ice edge species *A. actinochilus* and *E. antarctica* var. *recta* and the sea-ice species *F. curta* are abundant from 560–420 cm. The open water species *F. kerguelensis* and *Odontella weissflogii* are most abundant from 460–420 cm, and *Thalassiosira antarctica* warm type peaks from 480–460 cm.

Diatom assemblage zone III (140–2 cm): Diatom abundance range from $6.3–37 \times 10^6$ valves g^{-1}, and increases upcore. *Eucampia antarctica* var. *recta* abundances are low as compared to abundances in zone I and II. In contrast, *E. antarctica* var. *antarctica* is observed between 40 and 60 cm. The sea-ice species *F. curta* is more abundant than observed in diatom assemblage zone II, and *Thalassiosira antarctica* cold type is also abundant. In addition, *F. kerguelensis*, *Odontella weissflogii* and *Thalassiosira antarctica* warm type are consistently present. *Chaetoceros* resting spores are the most abundant diatom group observed, peaking in the surface-most sediments.

Discussion

Age

Two approaches were utilized to develop chronologies for these cores, radiocarbon dating, in GC01- PW02 only, and a diatom biostratigraphic marker, specifically the occurrence of *Rouxia leventerae*, which is a marker for the MIS6/5 boundary, with its last occurrence 0.13–0.14 Ma (Zielinski *et al.* 2002, Cody *et al.* 2008). The use of diatom biomarkers is especially useful for Southern Ocean sediments in which calcareous microfossils can be very rare.

Accelerator mass spectrometry (AMS) ^{14}C dates were acquired for three samples in GC01-PW02, all completed on the planktonic foraminifera *Neogloboquadrina pachyderma* (Ehrenberg) (sinistral coiling). Three dates were based on samples with the diatom barren glacial zones. Low abundances of *N. pachyderma* (s.) are found in the water under permanent ice in the Antarctic and Arctic (Carstens & Wefer 1992). However, *N. pachyderma* (s.) is also in high abundance in some Antarctic sea-ice samples (Spindler & Dieckmann 1986). The uncorrected radiocarbon ages increase downcore from 19 kyr BP at 108 cm, to 31 kyr at 190 cm and 43 kyr at 630 cm.

Rouxia leventerae was observed only at 740 cm in GC01-PW02, and at 780 cm in GC03-PW02 (Figs 3 & 4).

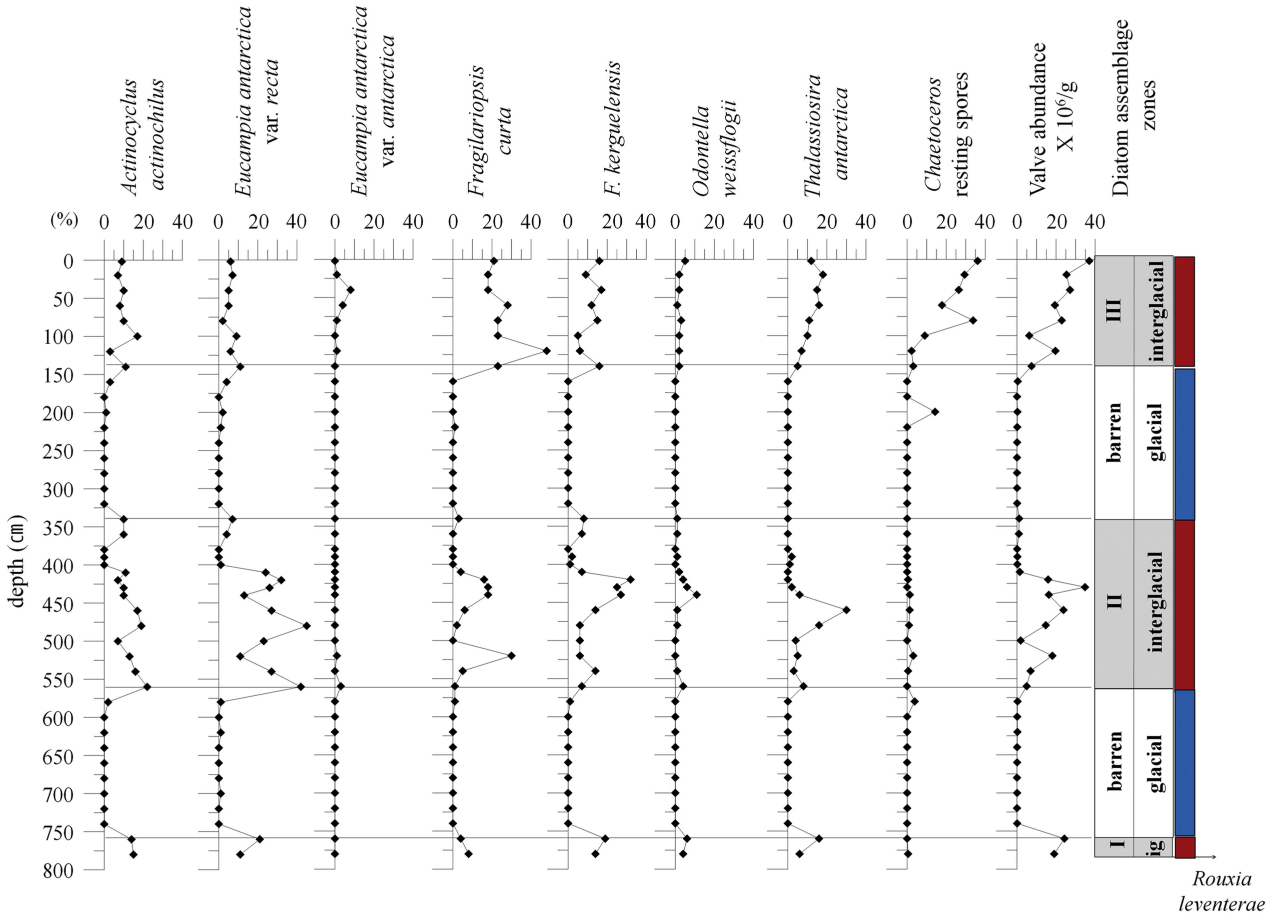

Fig. 4. Downcore variations of relative abundance of the characteristic species and diatom assemblage zones from GC03-PW02. Ig: interglacial.

The total number of *R. leventerae* was very low, and complete specimens were not observed. In the case of GC01-PW02, the presence of *R. leventerae* occurs at the boundary between the lowermost barren unit and the overlying interglacial; the data suggest this is the MIS6/5 boundary and that the overlying sediments were deposited after 0.13 Ma. In GC03-PW02, the observation of this species in the lowermost sample may reflect that the core penetrated just barely into MIS 6, and that as in GC01-PW02, overlying sediments were deposited after 0.13 Ma.

Palaeontological interpretation

One of the primary goals of this work was to provide a chronological and palaeoenvironmental context for the alternating diatom-abundant versus diatom-poor sediments recovered in two gravity cores from Powell Basin. Given the role of sea-ice cover in restricting light penetration and hence primary productivity, these sediments are interpreted to reflect interglacial and glacial conditions respectively. The record in these two cores provides evidence for expanded sea-ice extent during glacial periods such that diatom production was severely limited. In the Bransfield Strait during interglacial periods, particle flux peaks occur with open water conditions and the vertical flux of siliceous organisms from surface waters is extremely low under ice cover (Abelman & Gersonde 1991). Across both cores, three presumed interglacial intervals were recovered. In GC01-PW02, two glacial intervals were recovered, while in GC03-PW02, three glacial intervals were recovered.

This study has established six and five diatom zones from the cores GC01-PW02 and GC03-PW02 respectively. At the same time, these cores also contain two and three barren zones that almost completely lacked diatoms; these zones correspond to glacial periods during which the research area was covered with sea ice, and so had almost no diatoms as well as poor preservation.

The interglacial intervals were identified by the presence of abundant diatoms, with assemblages that are typical of the Southern Ocean (Armand *et al.* 2005, Crosta *et al.* 2005) and reflect an environment with seasonal sea-ice cover. Species present include those associated with sea ice and the marginal ice zone, such as *F. curta* (Scott *et al.* 1994, Leventer & Dunbar 1996), *A. actinochilus* (Gersonde 1984, Horner 1985, Tanimura *et al.* 1990, Garrison 1991), and those associated with more open Southern Ocean waters, including *F. kerguelensis* (Crosta *et al.* 2005).

Interestingly, *Chaetoceros* resting spores are only abundant within the uppermost interglacial unit, zone III, and in both cores its abundance increases upward within this unit. In addition, *Eucampia antarctica* var. *antarctica*, is also present in higher abundances in the youngest interglacial. These data suggest that this zone may reflect the most productive time period recovered by these cores.

Reworked species were also observed, though in very low abundances. Species observed include *Actinocyclus ingens* Rattray, *Denticulopsis hustedtii* (Simonsen &

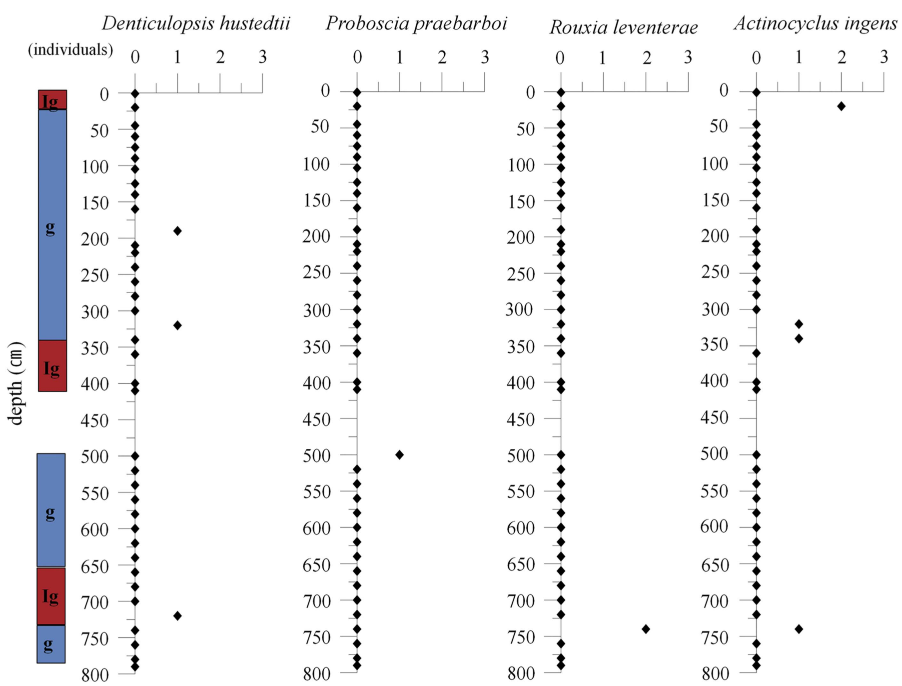

Fig. 5. Distribution of reworked species and age index (GC01-PW02). Ig: interglacial, g: glacial.

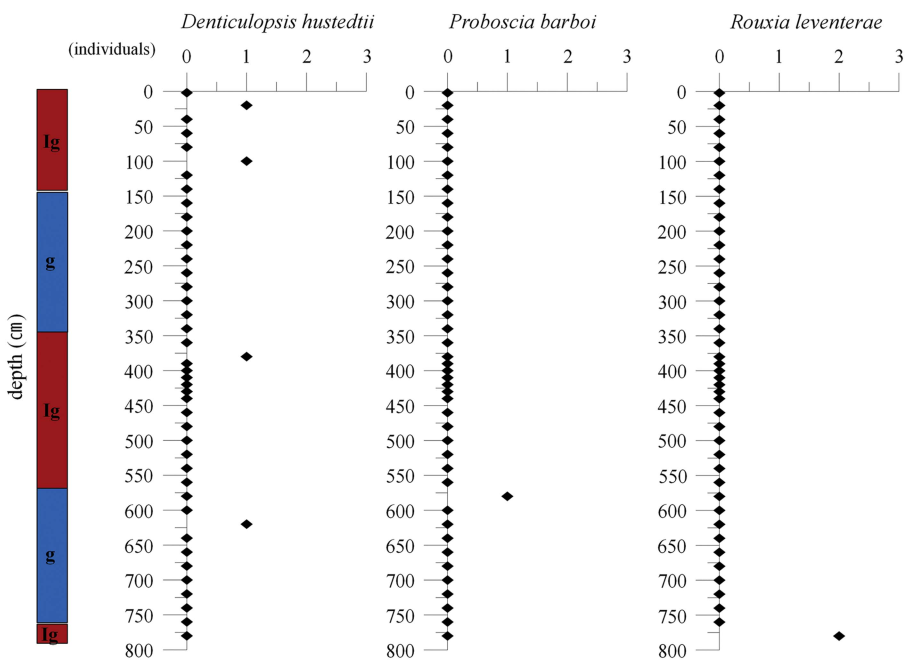

Fig. 6. Distribution of reworked species and age index (GC03-PW02). Ig: interglacial, g: glacial.

Kanaya) Simonsen, *Proboscia barboi* (Brün) Jordan & Priddle 1991, and *Proboscia praebarboi* (Schrader) Jordan & Priddle 1991 (Figs 5 & 6).

These reworked species may have been transported by the ice-rafted debris during the summer season of the interglacial periods.

Also, Powell Basin is influenced by a strong bottom current, which causes reworked species to be transported.

Conclusions

A total of 43 species of 21 genera and 61 species of 27 genera of diatoms were identified from two cores, GC01-PW02 and GC03-PW02, collected near Powell Basin. Based on diatom abundance and assemblage data, this study established six diatom assemblage zones in GC01-PW02, comprised of alternating glacial (barren zones) and interglacial (diatom assemblage zones). These changes are directly related to changes in palaeoclimate. GC03-PW02 is defined to five diatom assemblage zones; three zones with abundant diatoms (interglacials), alternate with two barren zones (glacials). Core chronologies based on limited radiocarbon dating and a key diatom biostratigraphic indicator, *R. leventerae*, for the MIS 6 / MIS 5 boundary provide support for the interpretation that these cores contain sediments deposited since MIS 6.

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Author contributions

Lee and Yoon led the project planning and field activities. Bak carried out the comprehensive analysis and microscopic observation of the diatoms. Yoo analysed the results from sedimentological data. All authors contributed to the discussion of the results and to writing the manuscript.

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