Planktonic centric diatom *Minidiscus chilensis* dominated sediment trap material in eastern Bransfield Strait, Antarctica

Jae-Shin Kang*, Sung-Ho Kang, Dongseon Kim, Dong-Yup Kim

Polar Sciences Laboratory, Korea Ocean Research & Development Institute (KORDI), Ansan PO Box 29, Seoul 425-600, Republic of Korea

ABSTRACT: The planktonic centric diatom *Minidiscus chilensis* Rivera was collected over 1 yr in a sediment trap at 1000 m depth in one of the deep basins in the eastern Bransfield Strait, Antarctica. The valves of this diatom are 3 to 8 μm in diameter and quadrangular in girdle view. The center of each valve is prominently hyaline with 3 strutted processes and a labiate process. *M. chilensis* was observed in all of the sediment trap samples collected between December 25, 1998 and December 24, 1999. The flux of *M. chilensis* into the trap varied considerably according to season, with the highest flux of 2.4×10^9 valves m^{-2} d^{-1} (87 % of total diatom valve flux) occurring in mid January when the mooring area was free of sea-ice. The dominance of *M. chilensis* among planktonic diatoms in Antarctic open waters has not been previously recorded. Our study suggests that *M. chilensis* should be included in future quantitative analyses and should be considered an important species for understanding the ecological structure of Antarctic waters.

KEY WORDS: *Minidiscus chilensis* · Sediment trap · Bransfield Strait · Diatom valve flux · Dominance

INTRODUCTION

Centric diatoms of the genus *Minidiscus* Hasle were first reported by Taylor (1967) in samples from the SW Indian Ocean; the species was initially recorded as *Coscinodiscus trioculatus* Taylor. Hasle (1973) assessed the classification and renamed the diatom *Minidiscus trioculatus*. Currently, 3 species are included in the genus: *M. trioculatus*, *M. comicus* Takano, and *M. chilensis* Rivera.

With a diameter usually <10 μm, *Minidiscus* is one of the smallest known centric diatoms. *M. trioculatus* is a cosmopolitan species; it has been described from the north and south Atlantic Oceans and the Indian Ocean (Hasle 1973), the Gulf of Mexico and the Pacific northwest near Vancouver (Hasle 1976), the subarctic Pacific Ocean (Booth et al. 1982), Australia (Hallegraeff 1984), and Japanese coastal waters (Takano 1997).

Minidiscus comicus was first observed in Japanese waters (Takano 1981) where it caused the 1980 Red Tide in Tokyo Harbor (Takano 1981, 1997). It has also been reported from the SW Atlantic coast of Argentina (Lange 1985). *M. comicus* forms aggregate flocks (Takano 1981), although individuals in the genus usually consist of a single cell.

Minidiscus chilensis was first reported from coastal areas of Chile (Rivera & Koch 1984). This species has also been recorded from the Argentinian coast (Ferrario 1988), Saanich Inlet and British Columbia (Sancetta & Calvert 1988), Pacific and Atlantic Ocean sediments between ca. 60° N and 50° S (Sancetta 1990), and the western Pacific Ocean near Japan (Takano 1997).

In Antarctica, *Minidiscus* has previously been observed only in the shallow coastal waters of Maxwell Bay and Marian Cove (Kang 2000, Kang et al. 2002). The genus has not been recorded from open waters in Antarctica, possibly because its small size has precluded positive identification during microscope observations. In addition, the genus can be confused with

Fragilariopsis cylindrus (Grunow) Krieger and *F. pseu-donana* Hasle, because of their similar shapes in girdle view (Kang & Lee 1995, Kang et al. 2001).

This study documents *Minidiscus chilensis* as the dominant centric diatom throughout the water column in the eastern Bransfield Strait region. Our data were obtained using a time-series sediment trap deployed over 1 yr. This methodology is valuable for acquiring year-round information on diatom export and the vertical flux of diatoms from the euphotic zone to the sea floor, especially in remote regions such as the Southern Ocean (Gersonde & Zielinski 2000). In this paper, we describe the ultrastructure of *M. chilensis* and show seasonal variations of the species, highlighting its numerical importance in the open water of the eastern Bransfield Strait, Antarctica.

MATERIALS AND METHODS

A time-series sediment trap (Mark 78G-21, McLane) was deployed in the eastern Bransfield Strait region (61° 45.770' S, 54° 59.097' W), which is seasonally covered or influenced by sea-ice (Fig. 1). The trap was installed at a water depth of 1000 m (maximum water depth 2134 m). Data on the diatom assemblages in the trap were collected from December 25, 1998 to December 24, 1999.

A total of 21 bottles were used to collect trap samples (Table 1). Samples were collected at different intervals depending on the season; during a period of high material flux from November to February, samples were collected every 10 d, but in other months the flux was low and samples were collected every 30 d. Each bottle was filled with neutralized formaldehyde (5%) with boric acid for *in situ* preservation of the trap materials. The recovered trap samples were divided into 4 subsamples using a Folsom splitter and were further subdivided using 2 different methods. The cleaning of subsamples and the preparation of permanent mounts for light microscopy followed a modification of the method described by Bodén (1991).

Fifty ml of each well-mixed subsample were rinsed with deionized water and allowed to settle. The supernatant liquid was then siphoned off and the settled material dried and weighed. These subsamples were then subjected to ca. 10 ml of H_2O_2 (30%) in a 600 ml beaker for 24 h. During this time, the subsamples were heated to 60° C on a hot plate to enhance the reaction and evaporate the peroxide. HCl was also added to remove any organic carbonate. Once the hydrogen peroxide had stopped boiling, the subsamples were suspended in deionized water, allowed to settle for a further 24 h, and the supernatant was then siphoned off. This washing process was repeated at least 5× until the acid was completely removed.

Following the washing procedure, each subsample was transferred into a 50 ml graduated falcon tube. The tubes were thoroughly shaken to homogenize the sample solution, and then an aliquot of 300 to 1500 µl was taken from the center of each tube, using an automatic micropipette, and transferred into settling containers (Nalgene, 500 ml, plastic, straight-side, wide-mouth jar; diameter: 10.6 cm; height: 7 cm). These had been prepared by attaching 4 grease-free cover glasses (25 × 25 mm) at the bottom of each one using a glue stick, before filling them with deionized water containing a small amount of gelatin (0.85 ml l^{-1}) to enhance attachment of the diatom cells to the cover glasses during settling (Gersonde & Zielinski 2000). Once the samples had been added, the settling containers were placed in a dry oven at
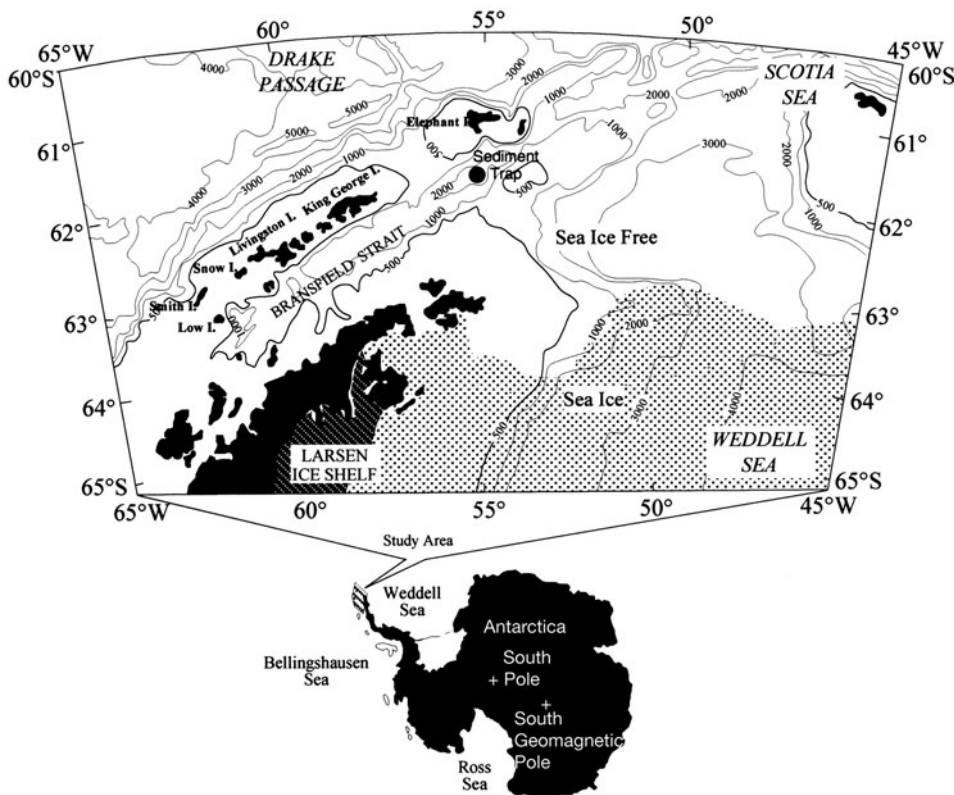

Fig. 1. Location of the sediment trap mooring site (site is marked by a closed circle, ●)

Table 1. Sampling intervals of sediment trap samples. Dates are year/month/day. Times are hour:minute

Sampling bottle #	Sampling intervals
1	98/12/25 11:11–99/01/04 11:11
2	99/01/04 11:11–99/01/14 11:11
3	99/01/14 11:11–99/01/24 11:11
4	99/01/24 11:11–99/02/03 11:11
5	99/02/03 11:11–99/02/13 11:11
6	99/02/13 11:11–99/02/23 11:11
7	99/02/23 11:11–99/03/05 11:11
8	99/03/05 11:11–99/04/05 11:11
9	99/04/05 11:11–99/05/05 11:11
10	99/05/05 11:11–99/06/05 11:11
11	99/06/05 11:11–99/07/05 11:11
12	99/07/05 11:11–99/08/05 11:11
13	99/08/05 11:11–99/09/05 11:11
14	99/09/05 11:11–99/10/05 11:11
15	99/10/05 11:11–99/10/20 11:11
16	99/10/20 11:11–99/11/04 11:11
17	99/11/04 11:11–99/11/14 11:11
18	99/11/14 11:11–99/11/24 11:11
19	99/11/24 11:11–99/12/04 11:11
20	99/12/04 11:11–99/12/14 11:11
21	99/12/14 11:11–99/12/24 11:11

adhesive tape, and were then coated with gold-palladium.

Biogenic opal content was determined by time-series dissolution using 0.5 N NaOH at 85°C (DeMaster 1981). The precision of biogenic silica was 2% based on the duplicate analyses.

RESULTS

Observation

Minidiscus chilensis cells were quadrangular in girdle view (Fig. 2A,B) and discoid in valve view (Fig. 2C). The pervalvar axis was usually shorter than the valve diameter, which was generally 3 to 8 µm. The valve mantle was smooth and curved, and the asymmetrical valve face was slightly concave (Fig. 2C). The center of each valve was prominently hyaline (Fig. 2C,D). Nine to 10 areola were located near the valve margin in 10 µm cells (Fig. 2D) but a marginal process was not

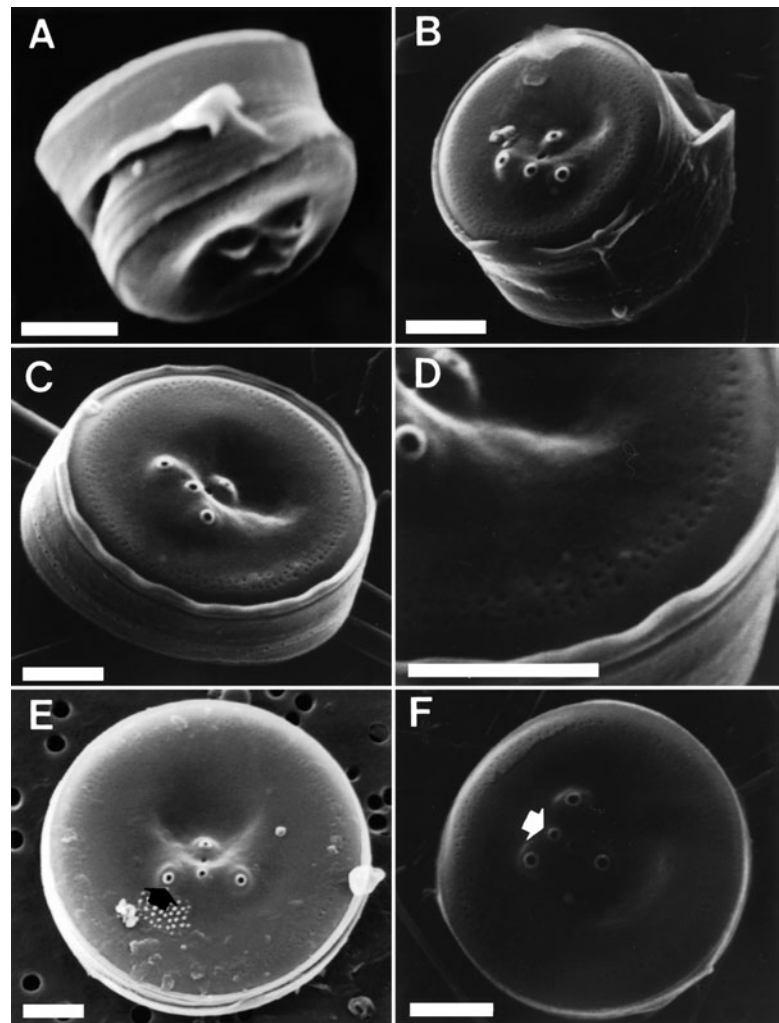40°C to speed water evaporation and to avoid dust contamination. The dried cover glasses were then removed and mounted on microscope slides using a permanent mounting media ($n_D^{20°} \sim$ min. 1.50). The settled gelatin over the cover glasses prevented particles on the glass from shifting during the mounting process.

For observation with a scanning electron microscope (SEM, Philips 515), aliquots of the washed subsamples were cleaned further using $KMnO_4$ and HCl, according to Hasle & Fryxell (1970). The acid-cleaned samples were neutralized in deionized water and centrifuged. This cleaning process was repeated at least 10×. After neutralization, the samples were filtered through 0.4 µm pore-size Nuclepore filters. The filters were dried and attached to an SEM stub using double

Fig. 2. *Minidiscus chilensis.* Microphotographs using SEM. Scale bars = 1 µm. (A) Marian Cove, Maxwell Bay, girdle view of whole cell. (B) Eastern Bransfield Strait (Bottle #20), external valve view of whole cell. (C–D) Eastern Bransfield Strait (Bottle #8), external valve view of whole cell. (E) Eastern Bransfield Strait (Bottle #3), external valve view. Note central strutted processes (shown by arrow). (F) Eastern Bransfield Strait (Bottle #3), external valve view. Note that labiate process is smaller than strutted process (shown by arrow)

observed in the valve margin. The center of each valve showed 3 strutted processes (Fig. 2E), between 2 of which was a labiate process—similar to a strutted process, but smaller (Fig. 2F). An internal view of the valve showed the labiate process opening through the valve wall with a longitudinal slit surrounded by 2 lips (Fig. 3A–C). In the internal view, each strutted process had 2 small satellite pores near its base (Fig. 3C). An external pore between the labiate and strutted processes was also present in the center of the valve (Fig. 3D–F).

Absolute diatom flux and relative abundance in sediment trap samples

There was a significant transfer of diatoms ($>10 \times 10^8$ valves m^{-2} d^{-1}) into the sediment trap during the austral summer (January to March 1999), when the mooring area was free of sea-ice (Fig. 4). The greatest flux of diatom valves (2.4×10^9 valves m^{-2} d^{-1}) occurred between January 14 and 24, 1999, mainly due to a high flux of *Minidiscus chilensis* (87% of the total diatom flux). The fluxes of *Fragilariopsis cylindrus* (Grunow) Krieger and *F. pseudonana* Hasle also increased during this 10 d period in January (Fig. 5).

The diatom assemblage was dominated by *Minidiscus chilensis*, *Pseudo-nitzschia heimii* Manguin, *Thalassiosira antarctica* Comber, and an unidentified *Thalassiosira* sp. (Fig. 5). *Chaetoceros* spp. were also present, but their flux was relatively low in comparison to results from other studies (e.g. Wefer et al. 1990, Leventer 1991). *M. chilensis* was the dominant diatom, accounting for 5 to 87% of the total diatom assemblage from December 25, 1998 to March 5, 1999 (Fig. 6).

The largest diatom flux occurred in mid January, whereas the highest biogenic opal flux occurred in mid February (Fig. 4). The discrepancy between diatom flux and opal flux was due to an increase of *Minidiscus chilensis* in mid January (Fig. 5), suggesting that this small-sized diatom was the major contributor to the diatom flux. In February, with a higher opal flux, the diatom assemblage in the trap samples was different from that observed in January, showing domination by *Pseudo-nitzschia* spp. (mostly *P. heimii*, and an unidentified *Pseudo-nitzschia* sp.) and *Thalassiosira* sp.
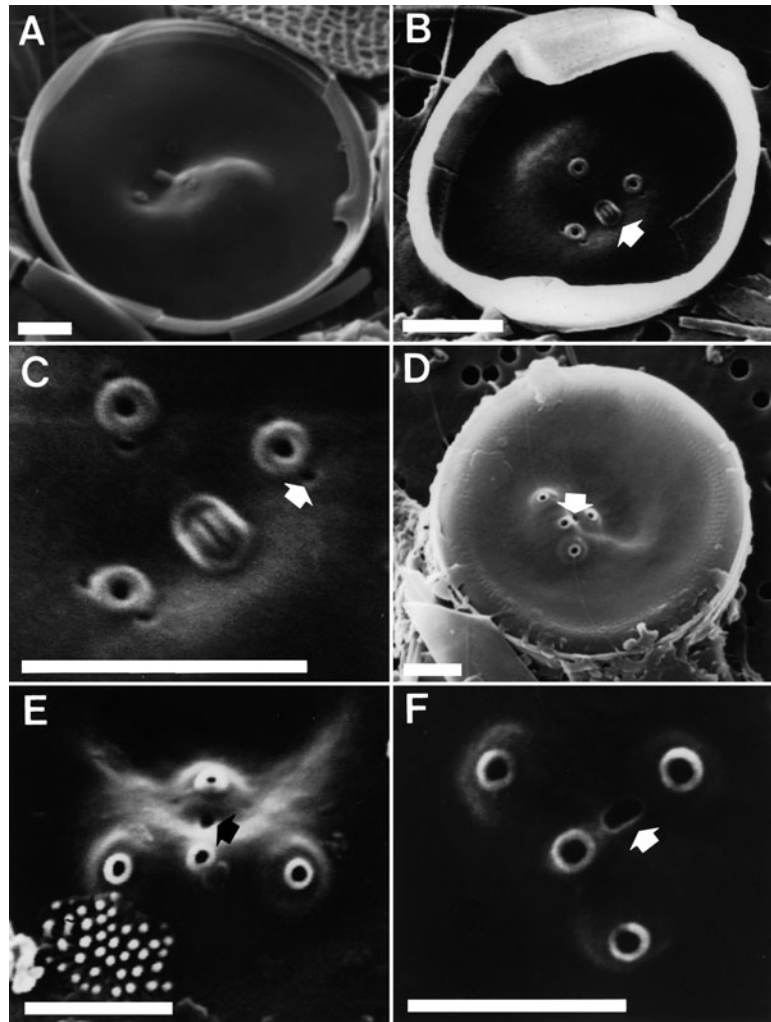

Fig. 3. *Minidiscus chilensis.* Microphotographs using SEM. Scale bars = 1 μm. (A) Eastern Bransfield Strait (Bottle #7), internal valve view. (B) Eastern Bransfield Strait (Bottle #8). Note internal valve view with labiate process (shown by arrow). (C) Eastern Bransfield Strait (Bottle #8). Note internal valve view with 2 small satellite pores near basal part of process (shown by arrow). (D) Marian Cove, Maxwell Bay. Note external valve view with a unique pore in valve center (shown by arrow). (E–F) Eastern Bransfield Strait (Bottle #3). Note external valve center with a pore (shown by arrow)

DISCUSSION

Biogenic opal flux showed large seasonal variations in January, February, and March only. The Bransfield Strait is usually covered with sea-ice from April to October (http://polar.wwb.noaa.gov/seaice/Historical.html). Thus, the minimal biogenic opal fluxes from April to October are probably due to sea-ice cover at the sediment trap site during these months. Diatom valve flux was also concentrated in the months of January through March, when the mooring area was free of sea-ice. The dominant diatom during these months was *Minidiscus chilensis*.
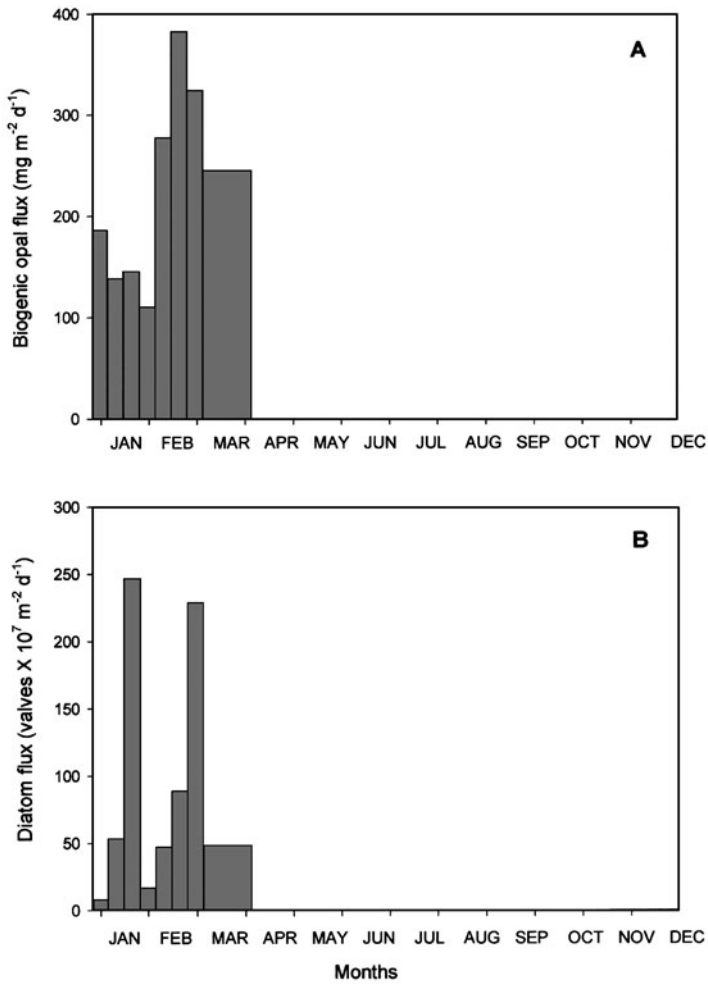
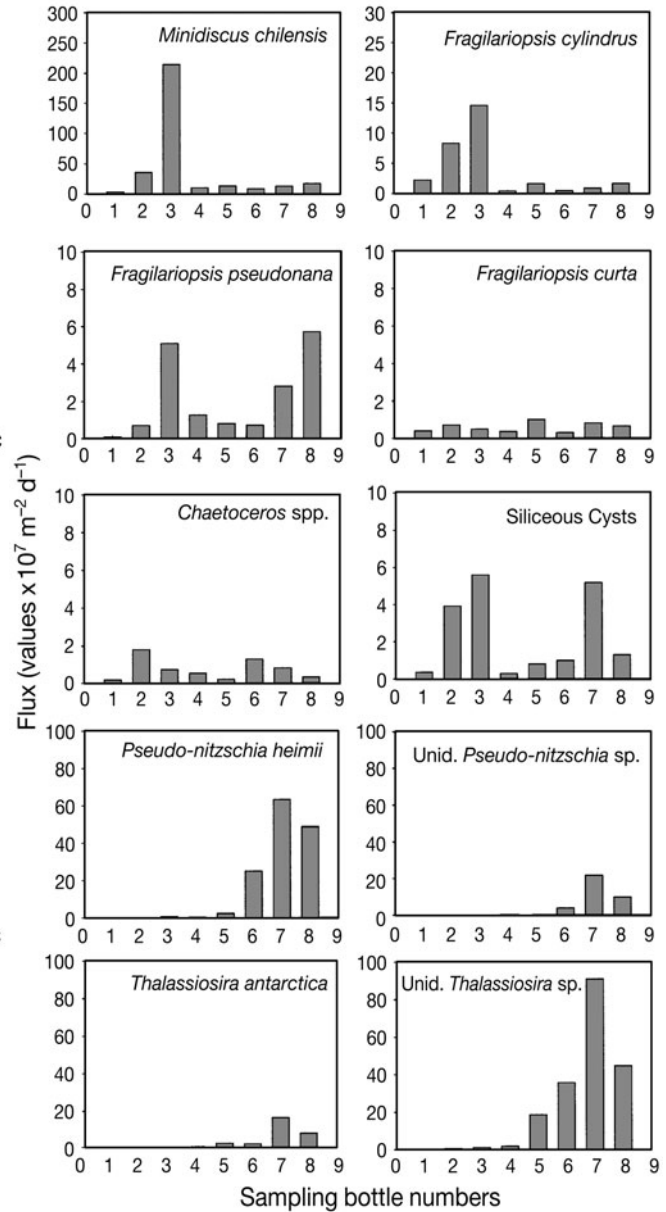Fig. 4. (A) Biogenic opal flux, (B) absolute diatom valve flux in the year-round sediment trap samples

Fig. 5. Absolute diatom valve flux of most common species in the year-round sediment trap samples from December 25, 1998 to March 5, 1999 (Bottles #1 to #8). Samples from Bottles #1 to #7 were collected every 10 d, but samples from Bottle # 8 were collected every 30 d

Minidiscus chilensis has previously been reported in Antarctica; in the summer of 1996, it was found in the surface waters of Maxwell Bay and at a fixed station in Marian Cove (Kang et al. 1997, Kang 2000). However, a high abundance of *M. chilensis* in sediment trap materials from open waters has not been reported before (Figs. 2A & 3D). Several studies have been carried out on phytoplankton assemblages in the Bransfield Strait. These have used a variety of collection techniques, including water samples (Villafañe et al. 1993, 1995, Kang & Lee 1995, Lee et al. 1995, Kang et al. 2001), surface sediment samples (Bárcena et al. 1998, Gersonde & Zielinski 2000), and sediment trap samples (Bodungen 1986, Bodungen et al. 1986, Liebezeit & Bodungen 1987, Wefer et al. 1988, 1990, Leventer 1991, Karl et al. 1991, Gersonde & Zielinski 2000). The difference between all of these studies and the diatom assemblage reported here is the presence of *M. chilensis*, which was not mentioned previously. Al-

though direct evidence is lacking, *M. chilensis* may have been overlooked during light microscope observations because of its small size and the problem of dissolution, which leads to poor preservation. In Antarctic waters, the presence of *Fragilariopsis cylindrus* and *F. pseudonana*, which have girdle views of a similar shape to *M. chilensis*, makes it difficult to identify and count *Minidiscus* cells in quantitative analyses (Kang & Lee 1995, Kang et al. 2001).
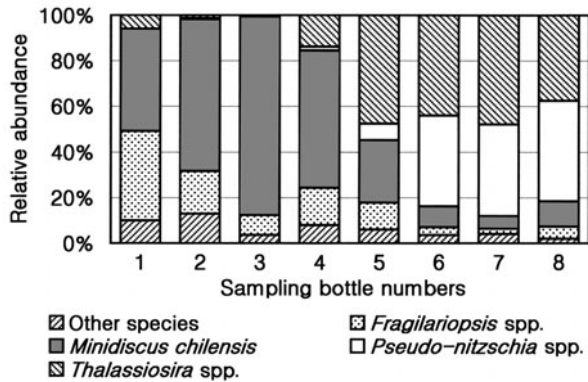
Fig. 6. Relative abundance of the most common species of diatoms in the year-round sediment trap sample from December 25, 1998 to March 5, 1999 (Bottles #1 to #8)

The high flux of *Minidiscus chilensis* in the sediment trap materials of open ocean waters is interesting. Numerically, *M. chilensis* was the most important species in the diatom assemblage during January, indicating that this species is a major food source for zooplankton, such as copepods, salps, and krill, during the early austral summer in the eastern Bransfield Strait region. According to Bodungen (1986), material collected in a moored trap in the western Bransfield Strait was dominated by zooplankton feces. In our trap materials, the *M. chilensis* frustules were found in fecal pellets (Fig. 7).

In this study we confirmed that *Minidiscus chilensis* exists in Antarctic waters and can be an abundant species in both open and nearshore waters. We have also found that this diatom species was a major component of the Antarctic phytoplankton assemblage during the austral summer. It is not clear whether this new-found abundance of *M. chilensis* is the result of the species being introduced and becoming adapted to a new environment, or because the species has been overlooked in previous microscope observations. Our study suggests that *M. chilensis* should be included in future quantitative analyses and that it should be considered an important species for understanding ecological structure in Antarctic waters. Future work with *Minidiscus* species will focus on (1) understanding their worldwide distribution, and (2) relating their distribution to physicochemical parameters in order to understand their ecology.
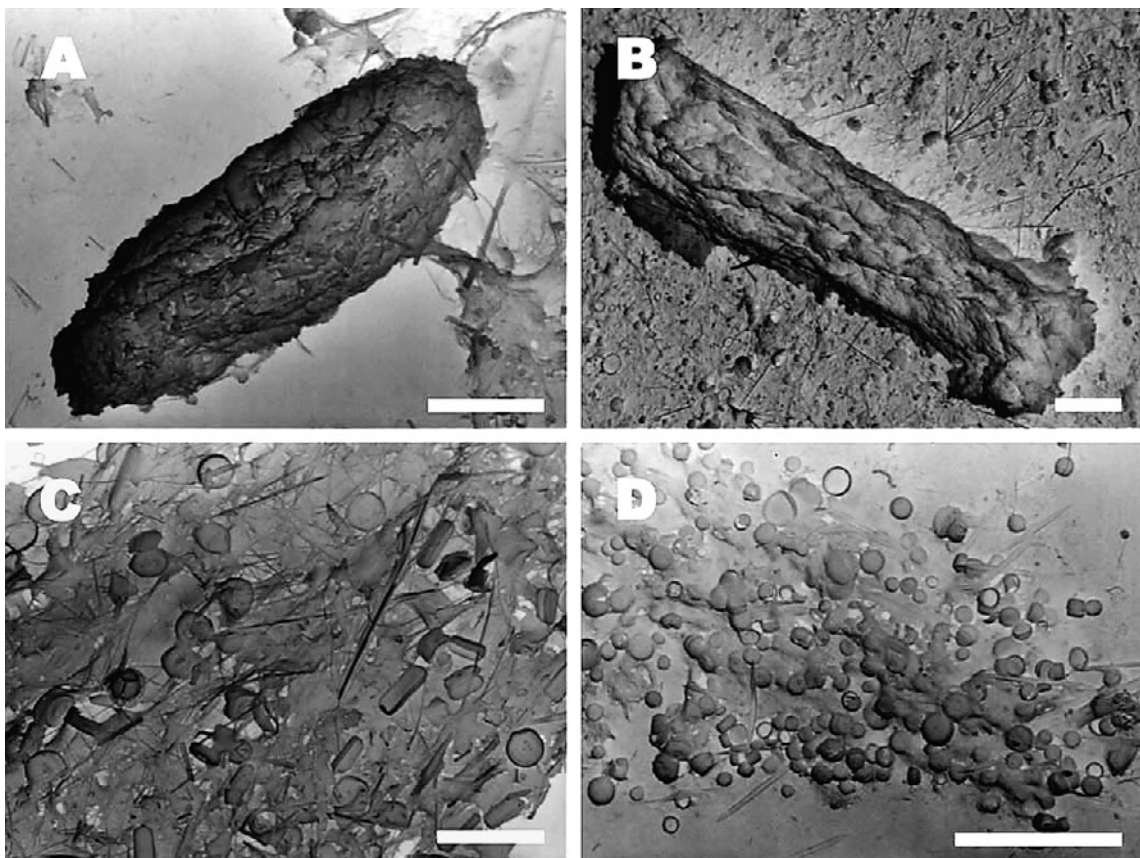

Fig. 7. Microphotographs of fecal pellet and aggregate flocks in sediment trap samples. (A) Ellipsoidal fecal pellet/aggregate (Bottle #2), scale bar = 25 µm. (B) Cylindrical pellet probably produced by Euphausiids (Bottle #5), scale bar = 10 µm. (C) Close-up of surface of pellet (Bottle #20), scale bar = 10 µm. (D) Aggregate diatom flock with *Minidiscus chilensis* and *Thalassiosira* spp. (Bottle #18), scale bar = 100 µm

LITERATURE CITED

Bárcena MA, Gersonde R, Ledesma S, Fabrés J, Calafat AM, Canals M, Sierro FJ, Flores JA (1998) Record of Holocene glacial oscillations in Bransfield Basin as revealed by siliceous microfossil assemblages. Antarct Sci 10:269–285

Bodén P (1991) Reproducibility in the random settling method for quantitative diatom analysis. Micropaleontology 37: 313–319

Bodungen B (1986) Phytoplankton growth and krill grazing during spring in the Bransfield Strait, Antarctica—implications from sediment trap collections. Polar Biol 6: 153–160

Bodungen B, Smetacek VS, Tilzer MM, Zeitzschel B (1986) Primary production and sedimentation during spring in the Antarctic Peninsula region. Deep-Sea Res 33:177–194

Booth BC, Lewin J, Norris RE (1982) Nanoplankton species predominant in the subarctic Pacific in May and June 1978. Deep-Sea Res 29:185–200

DeMaster DJ (1981) The supply and accumulation of silica in the marine environment. Geochim Cosmochim Acta 45: 1715–1732

Ferrario ME (1988) Ultrastructure de deux taxa de la famille Thalassiosiraceae. Cryptogamie, Algologie 9:311–318

Gersonde R, Zielinski U (2000) The reconstruction of late Quaternary Antarctic sea-ice distribution—the use of diatoms as a proxy for sea-ice. Palaeogeogr Palaeoclimatol Palaeoecol 162:263–286

Hallegraeff GM (1984) Species of the diatom genus *Thalassiosira* in Australian waters. Bot Mar 27:495–513

Hasle GR (1973) Some marine plankton genera of the diatom family Thalassiosiraceae. Nova Hedwigia 45:1–49

Hasle GR (1976) The biogeography of some marine planktonic diatoms. Deep-Sea Res 23:319–338

Hasle GR, Fryxell GA (1970) Diatom cleaning and mounting for light and electron microscopy. Am Microsc Soc Trans 89:460–474

Kang SH, Lee S (1995) Antarctic phytoplankton assemblage in the western Bransfield Strait region, February 1993: composition, biomass, and mesoscale distributions. Mar Ecol Prog Ser 129:253–267

Kang JS, Kang SH, Lee JH, Chung KH, Lee MY (1997) Antarctic micro- and nano-sized phytoplankton assemblages in the surface water of Maxwell Bay during the 1997 austral summer. Korean J Polar Res 8:35–45

Kang JS, Kang SH, Lee JH, Lee S (2002) Seasonal variation of microalgal assemblages at a fixed station in King George Island, Antarctica, 1996. Mar Ecol Prog Ser 229:19–32

Kang JS (2000) The ecology of Antarctic microaglae in Maxwell Bay. PhD thesis, Sangmyung University, Chonan

Kang SH, Kang JS, Lee S, Chung KH, Kim D, Park MG (2001) Antarctic phytoplankton assemblages in the marginal ice zone of the northwestern Weddell Sea. J Plankton Res 23: 333–352

Karl DM, Tilbrook BD, Tien G (1991) Seasonal coupling of organic matter production and particle flux in the Bransfield Strait, Antarctica. Deep-Sea Res 38:1097–1126

Lange KB (1985) Spatial and seasonal variations of diatom assemblages off the Argentinian coast (South Western Atlantic). Oceanol Acta 8:361–369

Lee MY, Kang SH, Lee S, Chung KH, Chio JK (1995) Distribution and biomass of phytoplankton and bacterioplankton: relationships to environmental parameters during an Antarctic austral summer in the Bransfield Strait. Korean J Polar Res 6:31–47

Leventer A (1991) Sediment trap diatom assemblages from the northern Antarctic Peninsula region. Deep-Sea Res 38: 1127–1143

Liebezeit G, Bodungen B (1987) Biogenic fluxes in the Bransfield Strait: planktonic versus macroalgal sources. Mar Ecol Prog Ser 36:23–32

Rivera P, Koch P (1984) Contributions to the diatom flora of Chile II. In: Mann DG (ed) Proc 7th Int Diatom Symp. Koeltz, Koenigstein, p 279–298

Sancetta C (1990) Occurrence of Thalassiosiraceae (Bacilariophyceae) in two fjords of British Columbia. Nova Hedwigia 100:199–215

Sancetta C, Calvert SE (1988) The annual cycle of sedimentation in Saanich Inlet, British Columbia: implications for the interpretation of diatom fossil assemblages. Deep-Sea Res 35:71–90

Takano H (1981) New and rare diatoms from Japanese marine waters. VI. Three new species in Thalassiosiraceae. Bull Tokai Reg Fish Res Lab 105:31–43

Takano H (1997) Class Bacillariophyceae. In: Chhara M, Murano M (eds) An illustrated guide to marine plankton in Japan. Tokyo University Press, Tokyo, p 169–260

Taylor FJR (1967) Phytoplankton of the southwestern Indian Ocean. Nova Hedwigia 12:433–476

Villafañe VE, Helbling EW, Holm-Hansen O (1993) Phytoplankton around Elephant Island: distribution, biomass and composition. Polar Biol 13:183–191

Villafañe VE, Helbling EW, Holm-Hansen O (1995) Spatial and temporal variability of phytoplankton biomass and taxonomic composition around Elephant Island, Antarctica, during the summers of 1990–1993. Mar Biol 123:677–686

Wefer G, Fischer G, Fütterer DK, Gersonde R (1988) Seasonal particle flux in the Bransfield Strait, Antarctica. Deep-Sea Res 35:891–898

Wefer G, Fischer G, Fütterer DK, Gersonde R, Honjo S, Ostermann D (1990) Particle sedimentation and productivity in Antarctic waters of the Atlantic sector. In: Bleil U, Thiede J (eds) Geological history of the polar oceans. Kluwer Academic Publishers, Dordrecht, p 363–379