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Diatom evidence for Holocene paleoclimatic change in the South Scotia Sea, West Antarctica

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ABSTRACT: Diatom data of the core sediment from a deep basin in the South Scotia Sea, West Antarctica provide high-resolution information on changes in oceanographic processes and paleoclimate during the late Quaternary. Three main climatic changes can be distinguished in diatom assemblages: Last Glacial Maximum (LGM), mid-Holocene climatic optimum and Neoglacial cold event. Diatom assemblages have been deposited in a variable sea ice condition over the last 25,000 yr in response to the climate change. During the LGM to early-Holocene (23,370-8,300 yr BP), the core site might be influenced by increased dense sea-ice cover, which could reduce biogenic flux from the surface water, depositing relatively increased amount of sea ice-related diatoms (*Actinocyclas actinochilus*, *Eucampia antarctica*, *Fragilariopsis curta*, and *Fragilariopsis cylindrus*). During these periods, it is likely that the increased sea ice cover between the Weddell and Scotia seas would have severely prevented *Chaetoceros* resting spores in the Weddell Sea ice margin from being laterally advected to the Scotia Sea, resulting in the reduction of *C.* resting spore abundance in the sediment. Afterward, a warm period followed from 8,300 to 2,400 yr BP in the mid Holocene when open water assemblages (*Rhizosolenia styliformis* and *Thalassiosira antarctica* (warm)) were deposited. Significant dilution of the number of *Fragilariopsis kerguelensis* indicates the opening of communication between the Weddell and Scotia seas allowing lateral advection of *C.* resting spores from the Weddell Sea to the Scotia Sea. A colder condition (Neoglacial cooling) then resumed since < 2,400 yr BP in the late Holocene supported by other paleoclimatic records in the Antarctic Peninsula. The assemblage is characterized either by the increase of sea ice-related diatoms (*A. actinochilus* and *F. cylindrus*) or by the decrease of open water taxa (*R. styliformis* and *T. antarctica* (warm)) compared to that in the mid-Holocene optimum. The loose sea-ice assemblage was, however, different from dense sea-ice assemblage deposited in the LGM. Similarity of abundance of *Chaetoceros* between the Neoglacial and the mid-Holocene implies that the loose sea ice condition was not able to sufficiently restrict the lateral advection of *C.* resting spore to the Scotia Sea from the Weddell Sea.

Key words: diatom, Scotia Sea, late Quaternary, sea ice, paleoclimate

1. INTRODUCTION

The identification and interpretation of paleoclimatic events in the Antarctica is of importance in understanding its response to predicted global climate change. Recent paleoclimatic studies from the Antarctic fjords and lakes demonstrate that the Holocene (< 11,500 yr BP) has been a period of rapid and variable climate change (Domack and Mayewski, 1999; Rosqvist et al., 1999). Centennial- to millennial-scale variations in primary production (Leventer et al., 1996; Shevenell et al., 1996; Rosqvist et al., 1999; Domack et al., 2001) and similar patterns have been observed in the western continental shelf of Antarctic Peninsula (Yoon et al., 2002). Yet the paleoenvironmental record of this area remains poorly understood with regard to rapid climate change (Domack and Mayewski, 1999).

Given that the Scotia Sea has been influenced by Weddell Sea Bottom Water and Antarctic Circumpolar Current, both of which are significantly functional for the most dramatic and rapid periods of climatic warming in recent history (Smith et al., 1999). Previous data from down-core sedimentary and geochemical variables in the core SS01 of the South Scotia Sea was presented here by Yoon et al. (2005). The age of core bottom is ~25,000 yr BP including the paleoclimatic events during the late Quaternary. We add results of down-core diatom assemblage analysis in the core SS01. Diatom distribution is controlled by a combination of environmental parameters including water temperature, salinity and stability as well as light, nutrient availability, and sea ice cover (Defelice and Wise, 1981; Dunbar et al., 1985; Leventer and Dunbar, 1996; Zielinski and Gersonde, 1997; Cunningham and Leventer, 1998). In particular, diatom assemblage analysis provides one of the best sources of paleoenvironmental information.

During the late Quaternary, it is widely used to elucidate either biological productivity or sea ice condition in the higher latitude regions (Medlin and Priddle, 1990; Stoermer and Smol, 1999). We compare the assemblages with sedi-

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*Corresponding author: kcyoo@kopri.re.kr mentary and geochemical variables to assess its correspondence to global climatic records.

2. PHYSICAL SETTING

The Scotia Sea is a relatively small ocean basin (1.3×10^6 km^2) (Fig. 1) formed during the final stages of the continental fragmentation of Gondwana and the consequent Late Paleogene separation of the Antarctic Peninsula from South America (Barker et al., 1991; Livermore et al., 1994). It extends from Drake Passage, at 65°W between South America and the Antarctic Peninsula, eastwards to the South Sandwich island arc at 27°W. It is bounded by the North Scotia Ridge at 54°S and the South Scotia Ridge at 60°S in the north and south, respectively (Pudsey and Howe, 1998). The majority of the basin plain of the Scotia Sea is located at depths of 3,000-4,500 m and it is isolated from major sources of sediment supply at the continental margins (Maldonado et al., 2003). The present circulation in the South Scotia Sea is mainly governed by the Weddell Sea Deep Water (WSDW) associated with the Weddell Gyre and the Antarctic Circumpolar Current (ACC) flows northeastward. Bottom potential temperatures are cooler in the proximity of the South Orkney Islands (−0.6°C), reflecting a bottom water origin of the WDSW in the south Scotia Sea (Locarnini et al., 1993; Orsi et al., 1995).

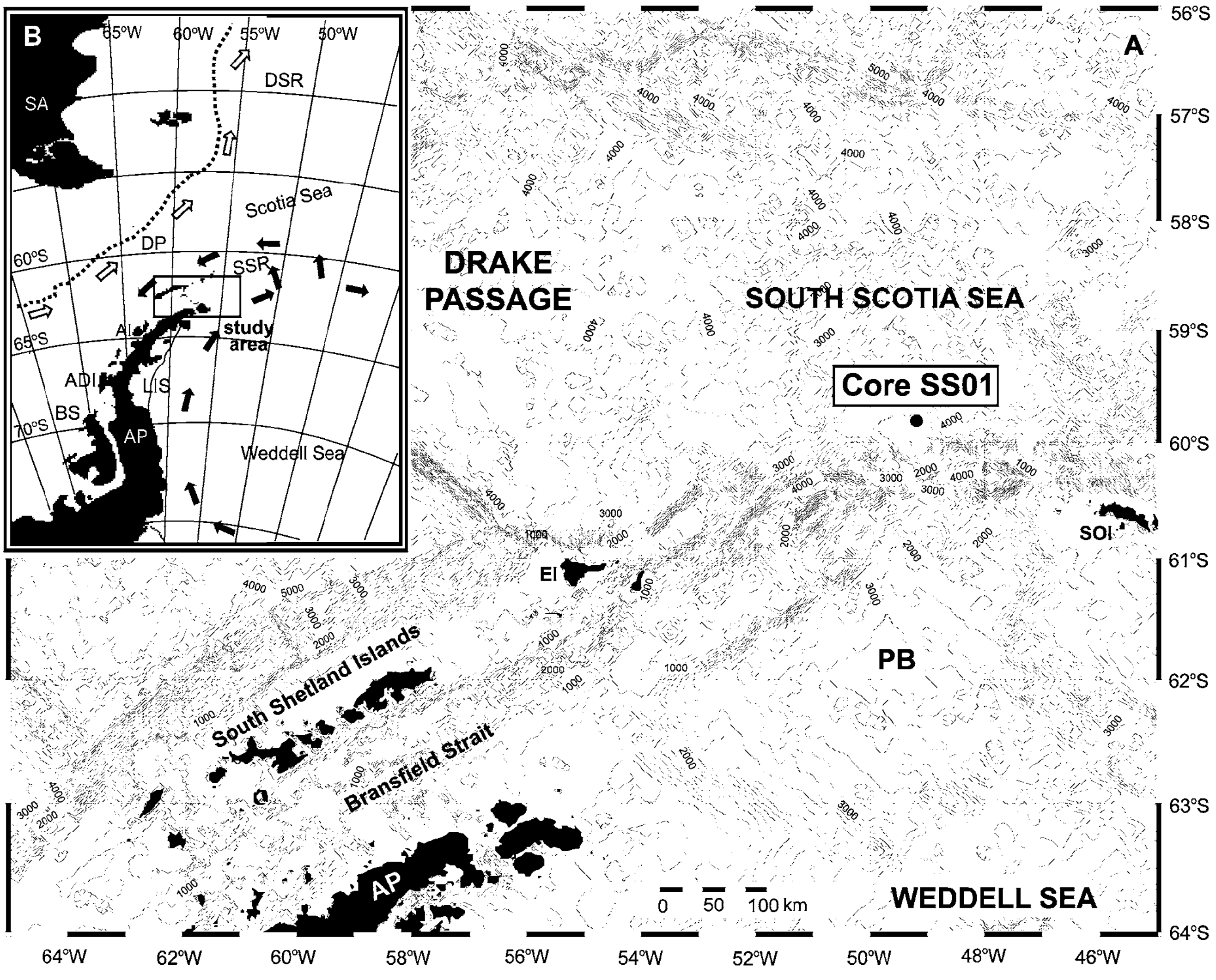

Fig. 1. (A) Bathymetry and core locations (black circle) around the South Scotia Sea. Contours in meters (Modified from Yoon et al., 2005). EI=Elephant Island; PB=Powell Basin; SOI=South Orkney Island. (B) Map showing the ocean circulation systems around the northern Antarctic Peninsula, Weddell Sea and South Scotia Sea. Note the Antarctic Circumpolar Current (open arrows) axis along the Polar Front (dashed line). Black arrows represent the Antarctic Deep Water and Weddell Gyre. AP=Antarctic Peninsula; SA=South America; ADI=Adelaide Island; AI=Anvers Island; BS=Bellingshausen Sea; DP=Drake Passage; LIS=Larsen Ice Shelf; SSR=South Scotia Ridge.

3. MATERIALS AND METHODS

3.1. Core Description

Sedimentology and depositional environments for core SS01 have been studied by Yoon et al. (2005), who divided the core into three distinctive lithofacies, based on the visual inspection of X-radiograph, grain size distribution and geochemical properties: lower unit (540–285 cm), deposited by sluggish to active bottom current during the LGM and early Holocene; middle unit (285–90 cm), deposited in open water condition during the mid Holocene warm, and upper unit (90–0 cm), deposited under the extended sea ice cover during the Neoglacial cold event.

Lower unit accounts for the lower half of core SS01, including LGM and early Holocene and consists of dark grey, strongly bioturbated silty to sandy mud with ice-rafted debris (IRD). Unbioturbated sections only occupy less than about five percent showing vague laminations in the upper part of the lower unit. The laminations are, however, poorly defined and laterally discontinuous. Middle unit is composed of mainly olive gray diatomaceous mud characterized by intercalation of diffuse bands or layers of diatom ooze in a diatomaceous mud. The diatomaceous mud is thoroughly disturbed by intensive bioturbation, while diatom ooze layers are relatively well-defined by density difference observed in X-radiographs (Figure 4 in Yoon et al., 2005). The ooze layers mostly comprise well-preserved monospecific diatom assemblage such as *Chaetoceros* resting spore (more than 80%) and/or *Rhizosolenia* spp. (more than 40%). Upper unit is composed of brown diatomaceous silty to sandy mud, sometimes exhibiting vague and indistinct laminae, characterized by discontinuous trains or lens of silt grains. The sediments are partly mottled and IRD is sparse, forming less than 5%.

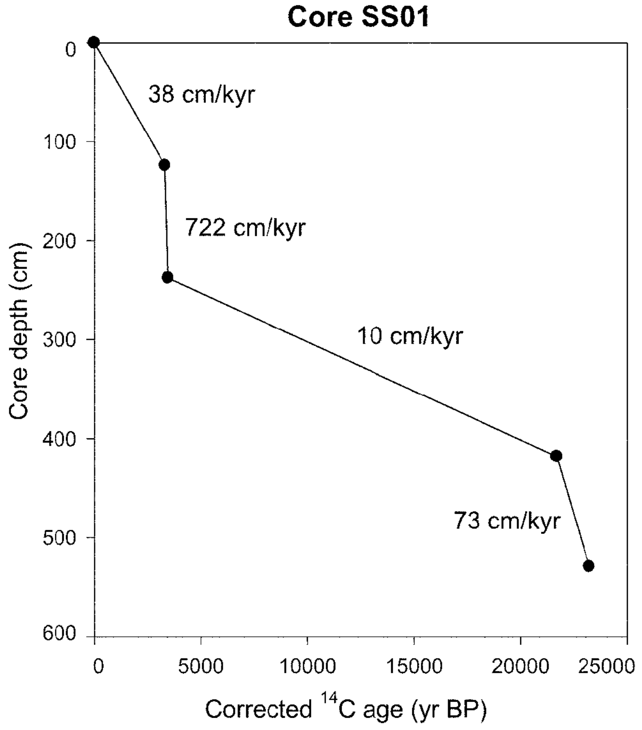

Fig. 2. Sediment depth versus AMS ^{14}C dating and sedimentation rates for core SS01 (Modified from Yoon et al., 2005). The core exhibits the variability in sedimentation rate, with high values in the upper and middle sections and low values in the lower section (>300 cm in core depth) of core SS01.

3.2. Radiocarbon Dates

Radiocarbon dating on bulk sediments of core SS01 was conducted at the University of Arizona Accelerator Mass Spectrometer (AMS) laboratory. A reservoir correction age of 8,200 yr±40 yr was obtained from surface sediment of a box core near the core SS01 site (Yoon et al., 2005). Core chronology for the present study is based on the previous work on core SS01 (Fig. 2).

3.3. Sample Preparation for Diatom Analysis

To study diatom assemblages, the core was sub-sampled at 4 cm or 8 cm intervals, and dried in the oven for 24 hours. The dry samples were placed in the beaker in which 25 ml of 30% hydrogen peroxide (H_2O_2) had been added. 10% Hydrochloric acid (HCl) were then added to remove organic carbonate, and samples allowed to stand for another 24 h. They were then centrifuged three times at 1,700 rpm for 15 second and washed in distilled water to remove chemical residue and salt crystals between centrifuging. Washed samples were diluted in 30 ml distilled water and was filled with 5 ml of the diluted solution in the settling chamber (containing 25 ml of distilled water). The slides were dried in oven at 50°C and then put on a glass coverslip using Canada balsam.

Diatoms were identified and counted at 800× magnification using Nikon light microscope. Each slide was traversed horizontally until at least 400 valves were counted. We split *Thalassiosira antarctica* into two separate varieties based upon morphological types: warm species with valve diameter of more than 20 μm and shoes (TW); cold species with valve diameter of under 20 μm and no shoes (TC).

4. RESULT AND DISCUSSION

Fifty-four species of diatoms have been identified from core SS01. Diatom assemblage is largely dominated by *C.* resting spore and *Fragilariopsis kerguelensis* which account for up to 60% and 40% of the total, respectively. The rest of the assemblages include taxa such as *Eucampia antarctica, Rhizosolenia styliformis, T. antarctica*, and *Actinocyclas actinochilus* (Fig. 4). Another interesting component of

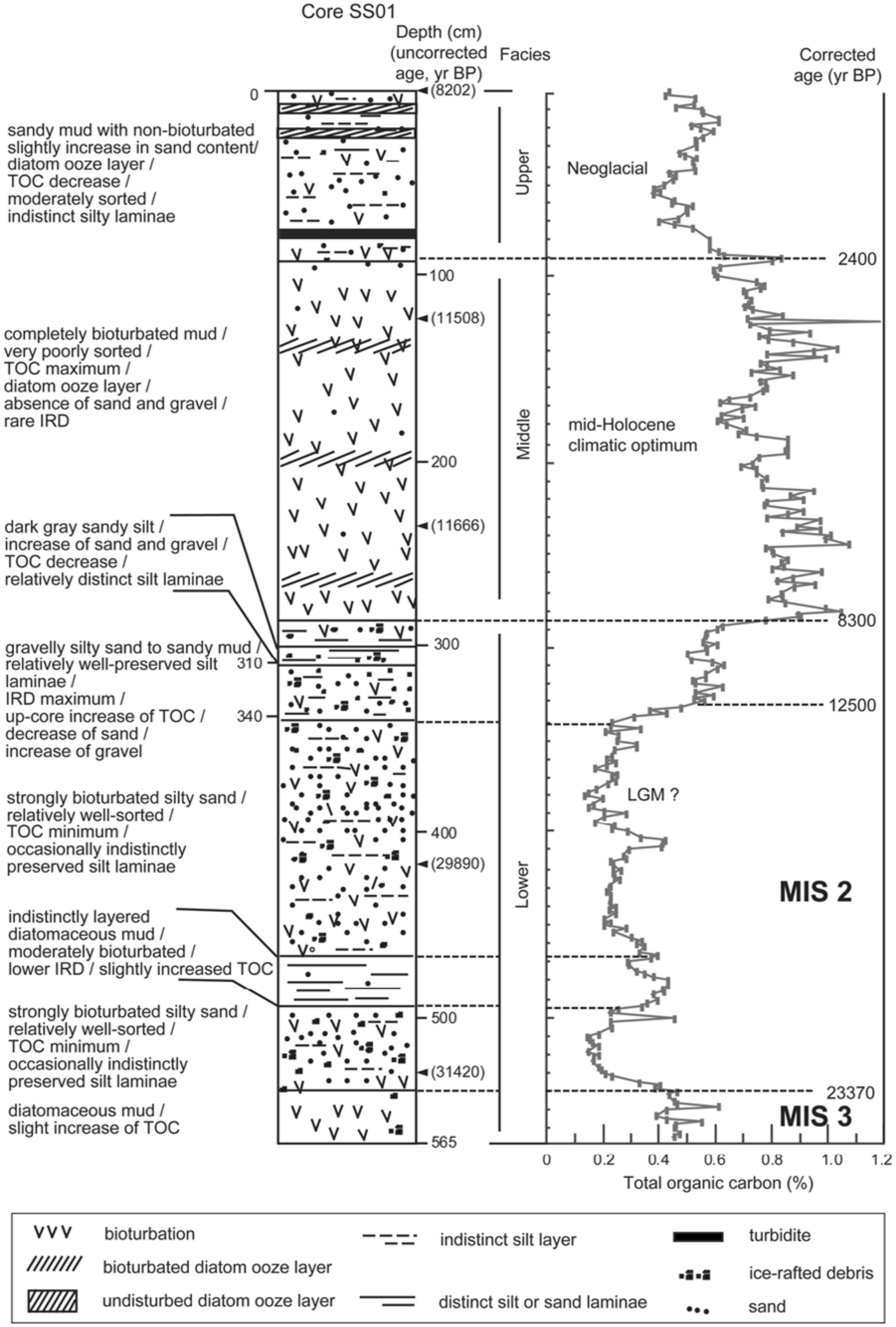

Fig. 3. Visual core log and TOC curve for core SS01 (Modified from Yoon et al., 2005).

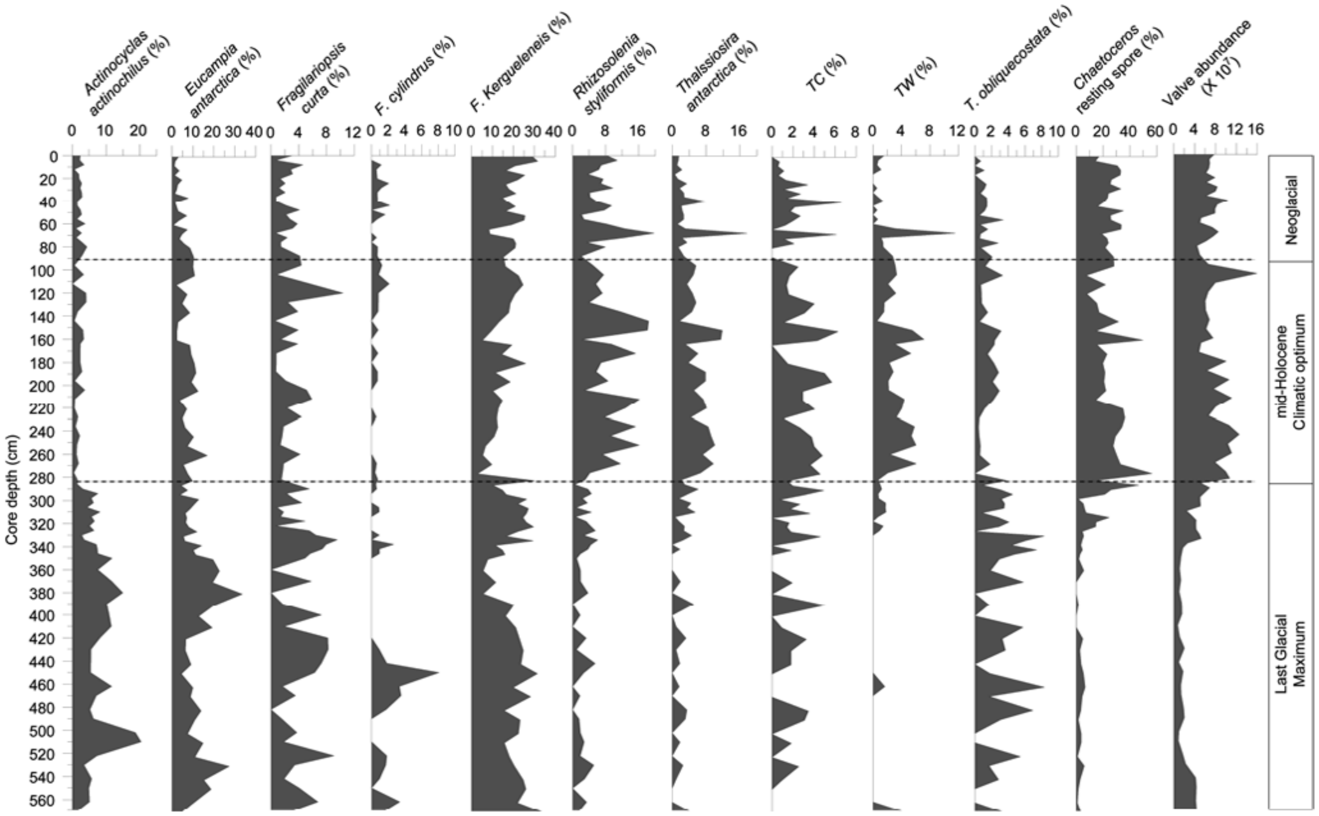

Fig. 4. Vertical distribution of selected sea-ice taxa and open water species for core SS01. TW=warm species of *Thalassiosira antarctica*; TC=cold species of *Thalassiosira Antarctica.*

the diatom assemblage is *Fragilariopsis curta* and *Fragilariopsis cylindrus*. Reworked diatoms like *Denticulopsis dimorpha* (Last common occurrence: 10.1 Ma) and *D. hustedtii* (Last occurrence: 4.5 Ma) were also found through the core.

Distinct faunal trends are observed in three different sedimentary units: upper unit (Neoglacial; 0–90 cm), middle unit (mid-Holocene warm; 90–285 cm), and lower unit (LGM-early Holocene; 285–540 cm) (Fig. 4). The number of diatom valves per gram of sediment (diatoms gram^{-1}) is consistently greater than 8×10^7 from the middle to upper units of the core, and is negligible in the lower unit with the lowest value at 410 cm of the core (Fig. 4). The abundance changes of *C.* resting spore are parallel to those found in the total diatom valves in the core. *C.* resting spore is the dominant taxon from middle to upper units, forming up to 58% of frustules counted in all samples, while it is insignificant in the lower unit (Fig. 4).

4.1. Lower Unit

This unit counts for the lower half of core SS01 (Figs. 3 and 4) and includes the periods between early-Holocene and LGM. *F. kerguelensis*, *E. antarctica*, *A. actinochilus*, are the more abundant species, while *C.* resting spore is poor (Fig. 4). *F. kerguelensis* is also numerically high up to 35% in the lower unit and more significant compared to the upper and middle units. It is a valuable paleoindicator, used to identify open marine environment. Today it is dominant between 52 and 63°S (Burckle et al., 1987), where summer surface water temperature are more than 0°C (Krebs et al., 1987). Its abundance is also known to be negatively correlated with sea ice distribution (Burckle et al., 1987) and to increase with distance from the Antarctic continent in surface water (Kozlova, 1966).

E. antarctica is numerically high more than 30% and its abundance is also relatively high compared to the upper and middle units (Fig. 4). It is widely considered to be a sea ice diatom (Burckle et al., 1990), although Zielinski and Gersonde (1997) suggest that it is most abundant where surface waters are −2 to 0°C and 2.2 to 5.5°C, indicating that it is related to surface waters in the Antarctic and the Polar Front Zone of the Southern Ocean. The centric *A. actinochilus* is numerically not high, but its abundance is more significant compared to the upper and middle units (Fig. 4). It is considered to be a typical Antarctic, neritic species (Kozlova, 1966) that occurs in the ice edge zone (Medlin and Priddle, 1990). *F. curta* and *F. cylindrus* are subdominant in the lower unit, but their abundances are relatively high compared to the upper and middle units (Fig. 4). In particular, *F. curta* occurs commonly in ice edge (Scott et al., 1994; Leventer and Dunbar, 1996) and in meltwater-stratified surface water layers associated with retreating sea ice (Garrison et al., 1987). Leventer and Dunbar (1996) hypothesized that the high abundance of *F. curta* within the water column and surface sediment of the Ross Sea is due to its being seeded into the water column from fast ice during the spring ice recession. In surface sediment diatom assemblages from Prydz Bay and the Ross Sea, *F. curta* occurs in high abundance where sea ice often persists throughout summer (Taylor et al., 1997; Cunningham and Leventer, 1998).

Less abundant, but statistically significant, indicator taxon in the lower unit is *Fragilariopsis obliquecostata* (Fig. 4). It is considered to be ice associated (Garrison and Buck, 1985; Medlin and Priddle, 1990). This taxon has been observed in sub-ice microalgal strands under coastal fast ice (Watanabe, 1988). Based on the known ecology of the abundance and indicator taxa in the lower unit, most of the diatom assemblage in this unit is described as sea ice associated, except for *F. kerguelensis*, which is typical open marine diatom.

4.2. Middle Unit

Middle unit characterizes the mid-section of core SS01 (Figs. 3 and 4). The most abundant taxon in the middle unit is *C.* resting spore, reaching more than 60% (Fig. 4). High concentrations of *Chaetoceros* in Antarctic sediments are considered to be indicative of high primary production in the water column (Donegan and Schrader, 1982; Leventer, 1992). Sediment trap data from the Gulf of California demonstrate the dominance of the spring bloom, in particular, by *Chaetoceros* (Sancetta, 1995). *Chaetoceros* are typical of spring blooms as they are capable of rapid growth (Grimm et al., 1997; Kemp et al., 2000). During spring diatom blooms, surface waters can become so nutrient-depleted that diatom growth is limited (Nelson and Smith, 1986; McMinn et al., 1995) and spore formation is induced (Davis et al., 1980).

F. kerguelensis is also numerically high (maximum abundance 35%), but its abundance is less significant compared to the upper and lower units (Fig. 4). It is a characteristic species of the modern Antarctic Circumpolar Current (Fenner et al., 1976; Burckle et al., 1987) and is extremely common in the sediment trap assemblages and surface sediments of Drake Passage and nearby Scotia Sea (Gersonde and Wefer, 1987; Abelmann and Gersonde, 1991; Leventer, 1991). *R. styliformis* is subdominant with a maximum abundance up to 25%, but its abundance is more significant compared to the upper and lower units (Fig. 4). In particular, *Rhizosolenia* spp. is dominant in the monospecific diatom ooze layers in the middle unit (Yoon et al., 2005). *T. antarctica* is subdominant, but its abundance is significantly high compared to the upper and lower units. In particular, *T. antarctica* (TW) forms a unique indicator in the assemblage of the middle unit. The genus *Thalassiosira* is widespread in Antarctic water, where it generally occurs in open waters. It is uncommon in sea ice (Fryxell and Kendrick, 1988; Leventer and Dunbar, 1996; Zielinski and Gersonde, 1997), which Fryxell et al. (1987) attribute to its inability to survive in the low light intensity beneath and within sea ice. Based on the ecology of the abundant and indicator taxa in this unit, the diatom assemblage is interpreted to be deposited in an open-water environment.

4.3. Upper Unit

Upper unit is present in the upper 90 cm of core SS01 (Figs. 3 and 4). *F. kerguelensis* in this unit shows a high abundance up to 35% and its abundance is more significant compared to the middle unit. *C.* resting spore is also numerically high with a maximum content of 35%, but its abundance is less significant compared to the middle unit. *R. styliformis*, typical open water species, is common in this unit with a maximum value of 26% but its abundance is also less significant compared to the middle unit. On the other hand, *F. cylindrus* and *A. actinochilus,* sea ice-related taxa, are numerically rare but their abundances are more significant compared to the middle unit. *F. cylindrus* has been observed amongst the dominant taxon in pack and fast ice (Scott et al., 1994) and ice edge blooms (Kang and Fryxell, 1992). The abundance of *T. antarctica* (TW), a warmer water species in the Antarctic Peninsula (Taylor et al., 2001), decreases in the upper unit compared to the middle unit (Fig. 4). Based on the ecology of diatom assemblage, the upper unit generally represents deposition in an open water environment. Besides, its close association with sea ice-associated taxa relative to the middle unit indicates mixed ecological preference, that is, deposition in a condition associated with windy, cool climatic episodes rather than a completely open-water environment of the middle unit.

5. PALEOECOLOGICAL INTERPRETATION

5.1. Lower Unit: Last Glacial Maximum to early Holocene (23,370-8,300 yr BP)

The lower unit corresponds with the sedimentological lower unit of Yoon et al. (2005). It is dominated by ice-associated diatom assemblage (*F. curta*, *F. cylindrus* and *A. actinochilus*). The unit consists of strongly bioturbated, gray, silty to sandy mud with vague lamination, which is characterized by low TOC, high MS and relatively larger mean grain size (Fig. 3; Yoon et al., 2005). The sedimentological structures and properties were inferred to represent weakly developed-bottom current deposition under the expanded sea ice during the Last Glacial Maximum (LGM)

(Yoon et al., 2005) and more bottom current deposition during the early-Holocene deglaciation (Taylor et al., 2001). This is also supported by the relative increase of the ice-associated diatom in the sediment section deposited from at least 12,370 to 8,300 yr BP. Taking into account the maximum abundance of *C.* resting spore in the Weddell Sea ice margin (Kang et al., 2001), a negligible amount of *C.* resting spore in the lower unit could reflect significant change of sea ice and/or oceanographic conditions in the Weddell and South Scotia seas during the LGM and even until early Holocene. The spring sea-ice edge might cover the core site (South Scotia Sea) since it lies at about 55°S in the central Scotia Sea during the LGM (Pudsey et al., 1998). It is therefore possible that biogenic production in the Weddell Sea ice margin was severely reduced even during the summer season. This would have caused lower contents of TOC and *C.* resting spores during the LGM including early Holocene. It is possible that the glacial restriction between the Weddell and the Scotia seas would have established even in the summer during these periods. This would have severely prevented large number of *C.* resting spore in the Weddell Sea from being advected into the South Scotia Sea. Due to this glacial reduction of biological production, the abundance of *F. kerguelensis,* a typical taxon in the South Scotia Sea, might have been much less diluted by the influx of *Chaetoceros*, resulting in the increase in the abundance of *F. kerguelensis*. It is unlikely that the abundance of *C.* resting spore in the lower unit have been diluted by high siliciclastic deposition since sedimentation rate is relatively low in the lower unit of the core compared to that in the upper and middle units (Fig. 2). Combining the diatom, sedimentary and geochemical data, we hypothesize that the lower unit (>8,300 yr BP) represents a period of more dense sea ice than that associated with the loose sea ice associated assemblage of the upper unit (< 2,400 yr BP).

5.2. Middle Unit: mid Holocene (8,300-2,400 yr BP)

The middle unit diatom assemblage is characterized by open water taxa, dominating the mid Holocene in the South Scotia Sea between 8,300 and 2,400 yr BP (Fig. 4). It is composed of diatomaceous mud with monospecific diatom ooze layers and rare scattered IRD. Total organic carbon content is generally high (Fig. 3). It is suggested that climatic warming, which reduced the sea-ice coverage in the Scotia Sea, created a more open marine environment with high biogenic input from surface water (Yoon et al., 2005).

R. styliformis, a typical taxon for open water environment, is more abundant in this unit than in the upper and lower units. In particular, this taxon is dominant in the monospecific diatom ooze layers in the middle unit (Yoon et al., 2005). Similarly, this species has been observed forming monospecific layers in sediments (Sancetta et al., 1991) from the Mediterranean (Schrader and Metherne, 1981; Sancetta, 1994; Kemp et al., 1999), and the Gulf of California (Sancetta, 1995; Pike and Kemp, 1997). Kemp et al. (2000) described a likely scenario responsible for the formation of diatom ooze layers. They proposed that *Rhizosolenia* species often hang out below a strong summer thermocline and its mass sinking is triggered by the breakdown in water column stratification during the transition from summer to autumn (“fall dump” flora). We suggest that this scenario probably also accounts for the occurrence of *Rhizosolenia*-dominated assemblage in the middle unit of core SS01 from the Scotia Sea. During the warm period characterized by strong surface water stratification, warmer surface tempertature, melting sea ice, and/or reduced wind stress probably resulted in the blooms of *Rhizosolenia* beneath the thermocline. In the fall, cooler temperatures and weakening of the thermocline coupled with higher wind stress and strong mixing of the water column may have forced mass sedimentation of the bloom, resulting in the formation of diatom ooze layers in the middle unit of core SS01.

However, the high concentration of *C.* resting spore is unlikely to result from the vertical flux of diatom valves by enhanced biological productivity. Rather, it may be attributed to the lateral advection of *Chaetoceros* from the Weddell Sea ice margin to the Scotia Sea since *C.* resting spore shows a maximum abundance near the marginal ice zone in the northwestern Weddell Sea than in the open water of the Scotia Sea (Kang et al., 2001). That is, communication between the Weddell and Scotia seas would have been established during the deposition of the middle unit (mid Holocene). As a result, large amount of *C.* resting spores in the Weddell Sea could have been advected into the South Scotia Sea. Accordingly, the abundance of *F. kerguelensis,* a typical taxon in the Scotia Sea (Gersonde and Wefer, 1987; Abelmann and Gersonde, 1991; Leventer, 1991), might have been diluted by higher influx of *Chaetoceros* during the mid-Holocene, resulting in the rapid reduction of *F. kerguelensis* abundance in the sediments. The higher TOC levels (Fig. 3) observed in the South Scotia Sea during the mid-Holocene probably reflect either enhanced primary productivity or lateral advection of diatom valves, both of which, in turn, reflects climatic warming and associated sea ice reduction.

Our results, together with those of Yoon et al. (2005), support the hypothesis that the Antarctic Peninsula experienced a climatic optimum during the mid Holocene (e.g. Leventer et al., 1996; Hjort et al., 1998; Rosqvist et al., 1999). Lake sediment data from South Georgia (Birnie, 1990) and James Ross Island (Bjorck et al., 1996), and marine records from the Ross Sea (Cunningham et al., 1999), suggest that during the mid Holocene sea surface temperatures were warmer and atmospheric temperatures were warmer and/or more humid than present.

5.3. Upper Unit: Neoglacial (< 2,400 yr BP)

Diatom assemblage of the upper unit (<2,400 yr BP) is characterized by both slightly increased ice-associated diatom assemblage (*A. actinochilus* and *F. cylindrus*) and decreased open water taxa (*R. styliformis* and *T. antarctica* (TW)) compared to the underlying middle unit deposited during the mid-Holocene. The onset of its deposition of upper unit is hypothesized to represent late Holocene climatic cooling (the Neoglacial) in the Antarctic Peninsula (Domack et al., 2001; Yoon et al., 2002). Based on the diatom taxa, mixed ecological habits of open water taxa with ice-associated taxa and sedimentology, sea ice cover in the South Scotia Sea during the Neoglacial is thought to have been in the form of loose sea ice that expanded and contracted seasonally over water, different from dense sea ice formed during the LGM.

Overall decrease of TOC contents in the upper unit (Fig. 3) was interpreted to reflect decreased primary production in response to the change in depositional regime from an open marine environment with minimal sea ice coverage to one with increased sea ice (Yoon et al., 2005). Yoon et al. (2005) also noted an increase in the siliciclastic (relative to biogenic) component of the sediment and an increase in mean grain size, which is indicative of the deposition under more glacial condition. Yoon et al. (2002) suggested that climatic cooling in the continental shelf of the western Antarctic Peninsula associated with the Neoglacial commenced some time prior to 2,400 yr BP. Based on the diatom record herein, it is suggested that the transition from a seasonally open water condition to one influenced by loose sea ice commenced as early as 2,400 yr BP (Fig. 4). Variation in solar radiation is regarded as one primary climatic forcing mechanism for the Neoglacial (Nesje and Johannessen, 1992), but we hypothesize it is not the mechanism in place here. At polar latitude (60°S), summer insolation reached a Holocene maximum ~2,000 yr BP (Berger, 1978). This is well after the mid Holocene climatic optimum, defined as terminating in the South Scotia Sea 2,400 yr BP based on the transition from the seasonally open water to ice-associated assemblage. The changes in sea ice cover and associated primary production that we revealed in the South Scotia Sea seems to be related more closely to shifts in water mass distribution (namely Circumpolar Deep Water) and sea surface temperature, rather than variations in solar radiations.

6. CONCLUSION

Diatom data of the core sediment from the South Scotia Sea, West Antarctica is interpreted using quantitative analysis to compare diatom assemblages and the primary sedimentological and geochemical proxies. The assemblages have been deposited in a variable sea ice zone over the last ca. 23,370 yr BP in response to a climatic change. In the LGM/early Holocene (23,370-8,300 yr BP), a sea ice diatom assemblage was deposited in the presence of multi-year sea ice and/or retreating sea ice at the South Scotia Sea. In the mid Holocene (8,300-2,400 yr BP), an open water assemblage was deposited and sea ice cover was at a minimum. We associate the assemblages with climatic warming, which characterizes much of the Antarctic Peninsula during the time. A second sea ice assemblage, different from that deposited in the LGM/early Holocene, has been deposited in the South Scotia Sea since the late Holocene (<2,400 yr BP). The assemblage reflects Neoglacial cooling, an increase in sea ice extent in the South Scotia Sea.

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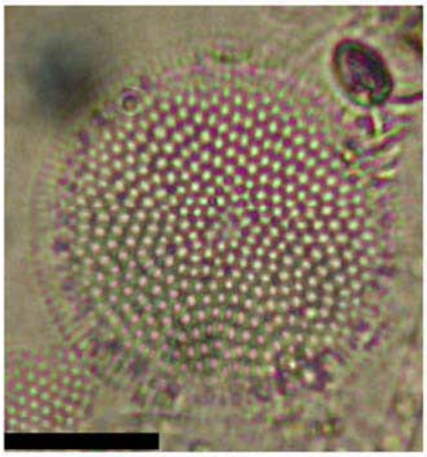
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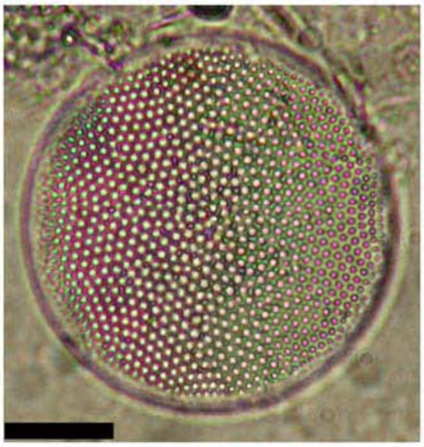
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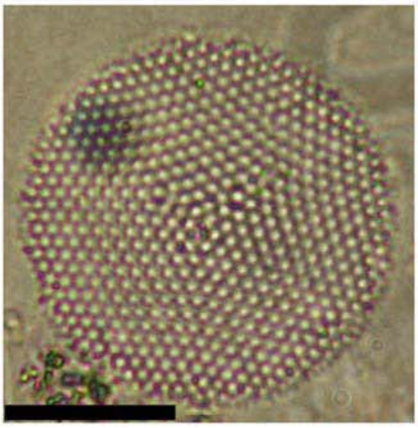
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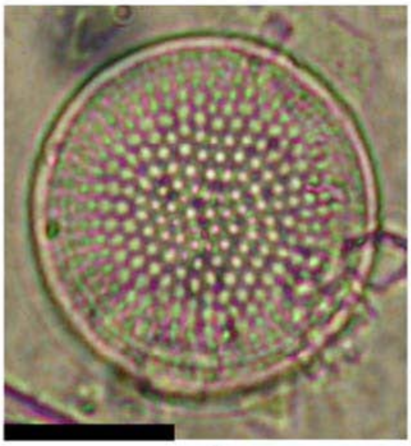
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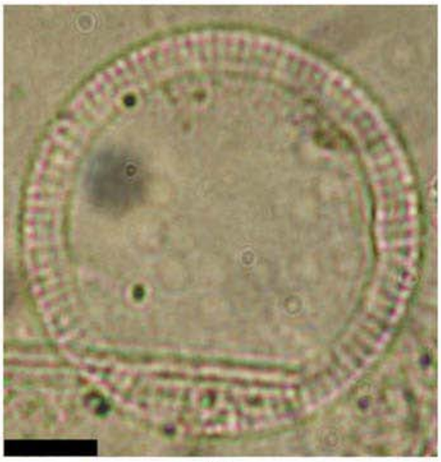
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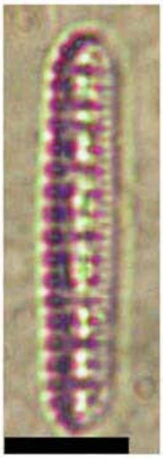
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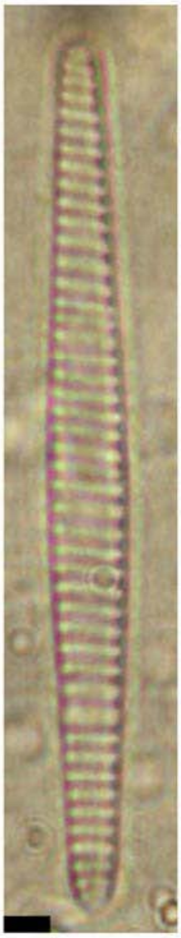
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Plate 1. (barscale: 12.5 μm). Fig. 1. *Thalassiosira antarctica* (warm) Comber; SS01-4 cm, Fig. 2. *Actinocyclus curvatulus* Janisch; SS01-96 cm, Fig. 3. *Thalassiosira elliptiphora* Donahue; SS01-56 cm, Fig. 4. *Cocconeis fasciolata* (Ehrenberg) Brown; SS01-88 cm, Fig. 5. *Thalassiosira antarctica* (cold) Comber; SS01-282 cm, Fig. 6. *Rhizosolenia styliformis* Brightwell; SS01-68 cm, Fig. 7. *Fragilariopsis ritscheri* Hustedt; SS01-338 cm, Fig. 8. *Schimperiella antarctica* Karsten; SS01-204 cm, Fig. 9. *Denticulopsis hustedtii* (Simonsen & Kanaya) Simonsen; SS01-260 cm, Fig. 10. *Eucampia antarctica* (Castracane) Mangin; SS01-260 cm, Fig. 11. *Fragilariopsis obliquecostata* van Heurck; SS01-282 cm.

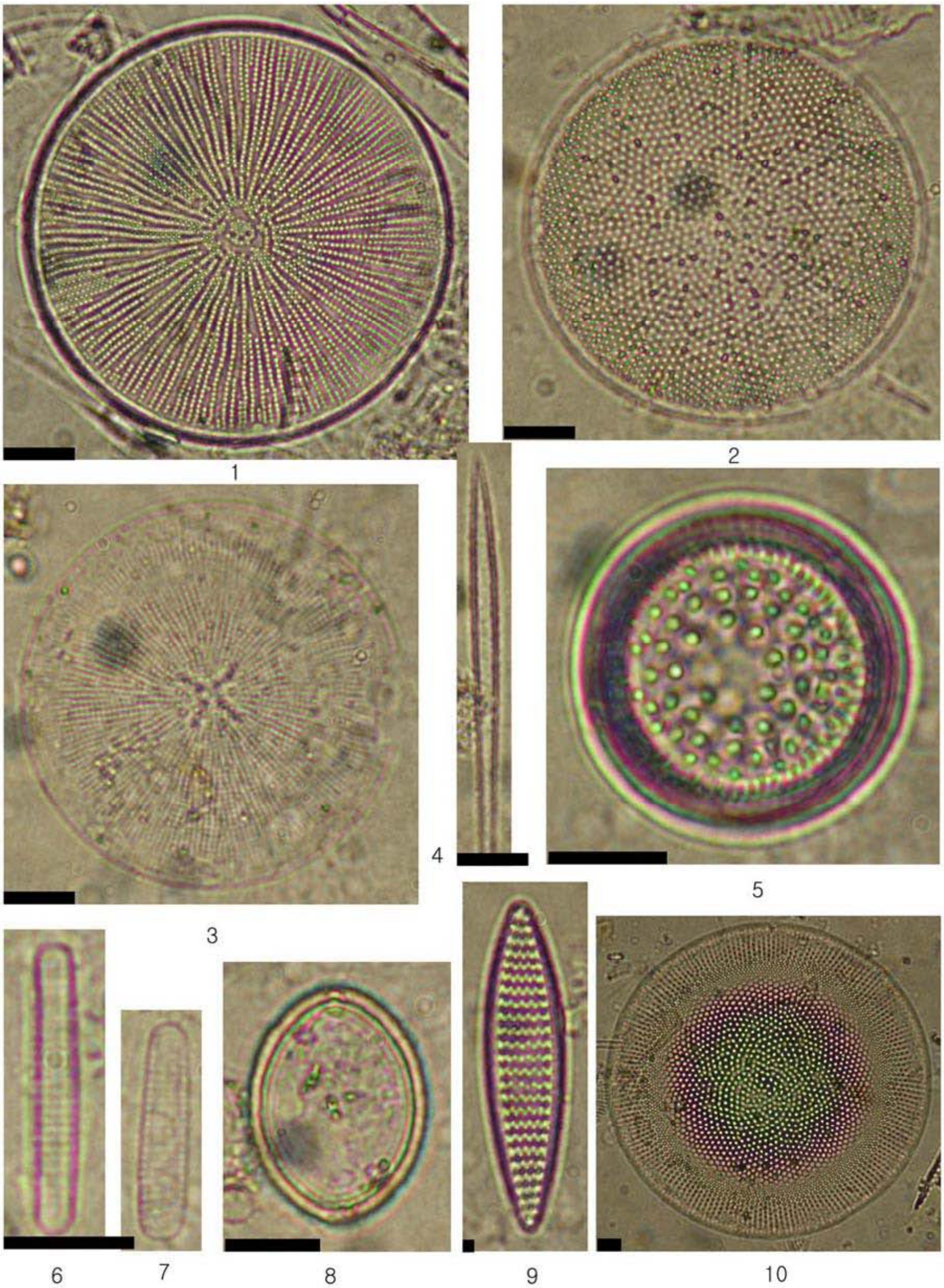

Plate 2. (barscale: 12.5 μm). Fig. 1. *Actinocyclus actinochilus* (Ehrenberg) Simonsen; SS01-80 cm, Fig. 2. *Actinocyclus octonarius* Ehrenberg; SS01-12 cm, Fig. 3. *Stellarima microtrias* (Ehrenberg) Hasle & Slims; SS01-330 cm, Fig. 4. *Thalassiothrix longissima* Cleve and Grunow; SS01-180 cm, Fig. 5. *Actinocyclus ingens* Rattray; SS01-310 cm, Fig. 6. *Fragilariopsis cylindrus* (Grunow) Helmck and Kriege; SS01-52 cm, Fig. 7. *Fragilariopsis curta* (V. Heurck) Hasle; SS01-228 cm, Fig. 8. *Odontella weissflogii* (Janisch) Grunow; SS01-482 cm, Fig. 9. *Fragilariopsis kerguelensis* (O'Meara) Hustedt; SS01-420 cm, Fig. 10. *Coscinodiscus asteromphalus* Ehrenberg; SS01-28 cm.