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Magnetostratigraphy and Paleoproductivity of Late Holocene Marine Sediments in the Eastern Bransfield Basin, Antarctic Peninsula

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ABSTRACT. During the 9th (1995-1996) KARP (Korea Antarctic Research Program) Expedition, a laminated diatom-rich sediment core (A9-EB2) was obtained from the eastern Bransfield Basin, Antarctic Peninsula region. Total organic carbon (TOC) and magnetic susceptibility (MS) in the core sediments clearly record the oscillation of depositional conditions. In particular, the high-resolution MS variation is a distinct feature to differentiate the high MS values for terrigenous (low TOC) hemipelagic part from the low values for biogenic pelagic (high TOC) part. In contrast to the anoxic condition under which the deep-sea laminated structures in the Santa Barbara Basin can be preserved completely without the obliteration by active bioturbation (Behl and Kennett, 1996), the oscillatory MS feature in the Bransfield Basin may be attributed to the climatically-forced and enhanced productivity cycles and less dilution of terrigenous particles. In spite of poor chronology due to the lack of available data as well as some contaminated datings, the core A9-EB2 shows the cyclic pattern of paleoproductivity in terms of MS signals which has been maintained in the Bransfield Basin, Antarctica during the late Holocene.

Key Words: Magnetic susceptibility, Paleoproductivity, Bransfield Basin, Late Holocene

Introduction

A substantial volume of literature has been compiled to understand the depositional processes and sedimentary regime in the high-latitude regions, particularly for the Antarctic fjords and continental shelves (Griffith and Anderson 1989; Domack and Ishman 1993; Pudsey *et al.* 1994; Domack and McClennen 1996; Kirby *et al.* 1998). The rather complex sedimentation in the Antarctic environments is likely governed by several sedimentary processes including ice rafting and biogenic, meltwater, and eolian processes (e.g., Griffith and Anderson 1989). Recent studies on the Antarctic continental shelves found that the climatic variations were recorded in the marine sediment cores because of proximal location to the periphery of the continent (Domack *et al.* 1992). To date, however, the appropriate and accessible core sediments still remained limited and unexamined in the deeper part of the Antarctic Ocean.

Antarctic Ocean is one of the significant areas of primary production in the world because it is situated in the sea ice and open water, and in regions of sea-ice melts known as marginal ice zones (see review by Smith and Sakshaug 1990). It is also becoming clear that the Antarctic Ocean is characterized by the apparent sensitive nature of ecosystem to climatic changes (Leventer *et al.* 1996; Bárcena *et al.* 1998). There has been a great increase of our interests on the primary productivity signal in modern circum-Antarctic waters. Thus, it is imperative to examine the extent of paleoproductivity within sediment core as a way to evaluate a proxy representing climatically-forced productivity cycles.

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Although total organic carbon (TOC) content in the sediments is generally influenced by particle size, the supply by primary production from the surface water is of more importance; the higher value resulting from biogenic flux is likely to imply elevated level of primary productivity whereas the lower value is mostly related to the hemipelagic sedimentation with more terrigenous input (Domack *et al.* 1992; Bárcena *et al.* 1998). The nature of the magnetic susceptibility (MS) signal is another evidence to reflect an environmental condition. The high MS values correspond to a hemipelagic sedimentation enriched in siliciclastic and terrigenous particles, particularly silts and clays (Domack and Ishman 1992; Kirby *et al.* 1998). Whereas the low MS is governed by pelagic sedimentation of biogenic (siliceous) materials, suggesting an increased regional primary productivity (Leventer *et al.* 1996).

Recently, a sediment core (A9-EB2) collected from the eastern Bransfield Basin, Antarctic Peninsula region contains cyclic laminated structure which comprises alternating clastic-rich and biogenic-rich layers (KORDI 1996). TOC and MS data were obtained to address an importance of the oscillations in recognizing paleoproductivity in terms of these properties. We also demonstrate that the preservation of these properties can be closely associated with climatic variations during the late Holocene.

Study Area

The Bransfield Basin, located between South Shetland Islands and northern Antarctic Peninsula, exhibits a complex bathymetry (Fig. 1; KORDI 1996). The basin forms a unusually deep asymmetrical trough including SW-NE trending three subbasins separated by the Deception and Bridgeman volcanic islands; the western Bransfield Basin (WBB), central Bransfield Basin (CBB) and eastern Bransfield Basin (EBB). The WBB, lying southwest of Deception Island, has the shallowest (<1000 m) depth. The CBB, lying between King George Island and northeastern tip of the Antarctic Peninsula, is characterized by an axial and discontinuous volcanic ridge, and reaches up to 2000 m in water depth. The EBB, located in the southwest of the Elephant and Clarence islands, is the deepest (2500 m) and includes several lozenge-shaped depressions separated by structural and volcanic highs.

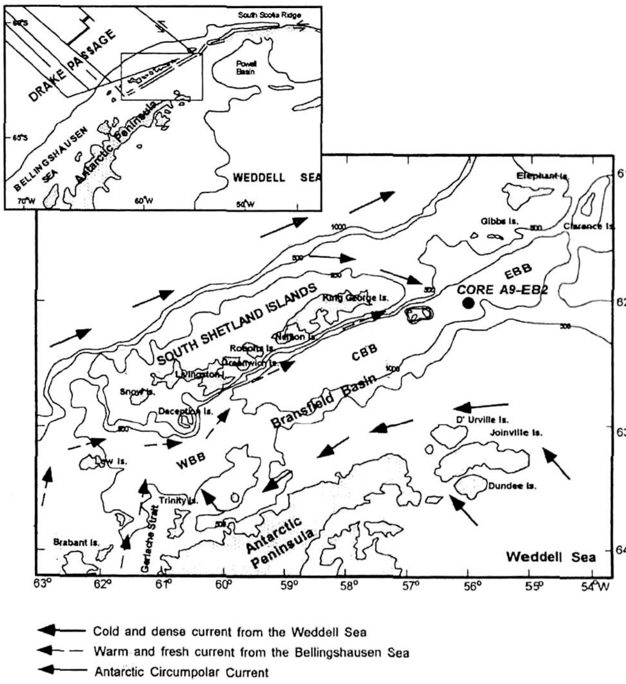

Fig. 1. Location of core A9-EB2 in the Bransfield Basin with coarse-scale bathymetry. Arrows represent the dominant surface water masses with flow direction. WBB: western Bransfield Basin, CBB: central Bransfield Basin, EBB: eastern Bransfield Basin.

Surface waters enter into the Bransfield Basin from the two principal areas, i.e., the Bellingshausen Sea to the southwest and the Weddell Sea to the east (Fig. 1). The northeastward current flowing into the Bransfield Basin from the Bellingshausen Sea brings warm and relatively less saline waters, contouring Deception Island and sweeping the slope and shelf of the South Shetland Islands (Gordon and Nowlin 1978). In contrast, the southwestward current, flowing out of the Weddell Sea and entering into the Bransfield Basin, provides a large volume of cold and saline waters, and continues to flow southwestward along the coast of the Antarctic Peninsula (Gordon and Nowlin 1978). In addition, Circumpolar Deep Water is another water mass advected from Drake Passage into the Bransfield Basin, but limited due to the shallow sills.

Materials and Methods

A sediment gravity core A9-EB2 was recovered during the R/V *Yuzhmorgeologiya* cruise in the Bransfield Basin (61°58.9'S, 55°57.4'W) on the 9th (December, 1995) Korea Antarctic Research Program operated by Korea Ocean Research and Development Institute (Fig. 1). The 455 cm-long core A9-EB2 was taken at 2202 m depth in the eastern subbasin (EBB). In the laboratory, total organic carbon contents were analyzed on a Carlo Erba NA-1500 Elemental Analyser at 10 cm intervals. The magnetic susceptibility was measured using a Bartington MS-2C magnetic susceptibility sensor (units in centimeter grams seconds [cgs x 10^{-6}], scanning at a 1 cm interval with point sensor. Radiocarbon (C-14) datings of acid insoluble organic matter were conducted at the University of Arizona tandem accelerator mass spectrometer (AMS) facility.

Results and Discussion

Figure 2 shows the schematic lithostratigraphy of core A9-EB2 that consists of the alternation of biogenic-rich pelagic sediments and clastic-rich hemipelagic sediments, intervened by turbidite layers. The chronology for core A9-EB2 is based on eight AMS radiocarbon analyses (Table 1; Fig. 3). Although the uncorrected ages are unreasonably fluctuated, if we have taken into accounts of the linear sedimentation rates, it is likely that some of the datings are available to define the overall chronology. Infrequent sediment turbidity flows probably contribute to instant sedimentation, as suggested by the anomalous ages (Fig. 3). The uppermost of the core dates 2928±93 yrBP, which is apparently older than expected. However, such an age is of the same order of magnitude as coretop ages obtained by Harden *et al.* (1992) and Domack *et al.* (1992) in the other Antarctic Peninsula regions. In addition, radiocarbon dating of Antarctic seawater samples and marine organisms yielded anomalously old ages up to 2860 years (Stuiver *et al.* 1981). The older ages of the Antarctic sediments have been explained by either (1) the large and regionally variable reservoir effect of 1200-1400 years (Stuiver *et al.* 1981) or (2) possibly significant inputs of older eroded sediment, reworked and transported by currents or ice rafting (Harden *et al.* 1992). The additional complication of terrestrial organic matter may be unimportant, because most of the organic matter in the sediments is provided by primary producers (Venkatesan and Kaplan 1987). In this study, it is

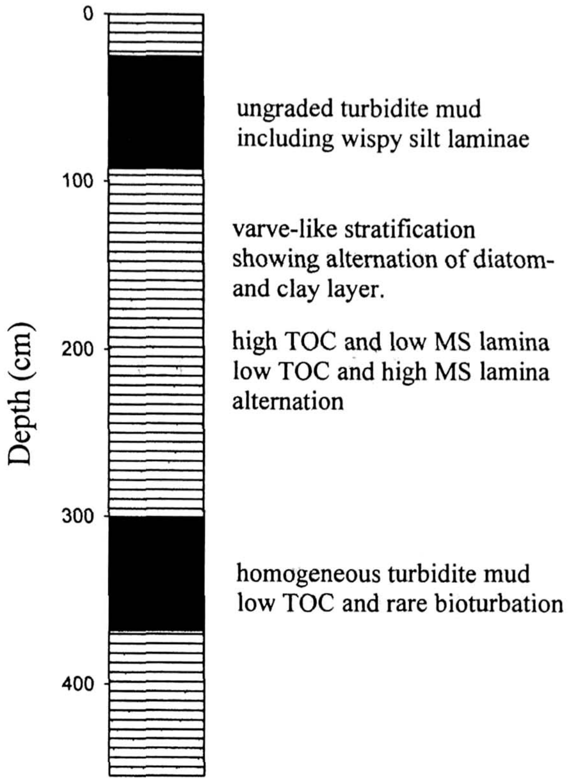

Fig. 2. Schematic columnar description of core A9-EB2 showing the alternating diatom-rich and clastic-rich lamina with intervening turbidites.

Table 1. AMS radiocarbon data (uncorrected) for bulk organic matter samples from core A9-EB2.

Depth (cm)	Age (year)
3	2928±93
85	4363±68
115	4746±68
181	2823±78
248	3651±75
299	4880±72
366	4195±93
417	3790±70

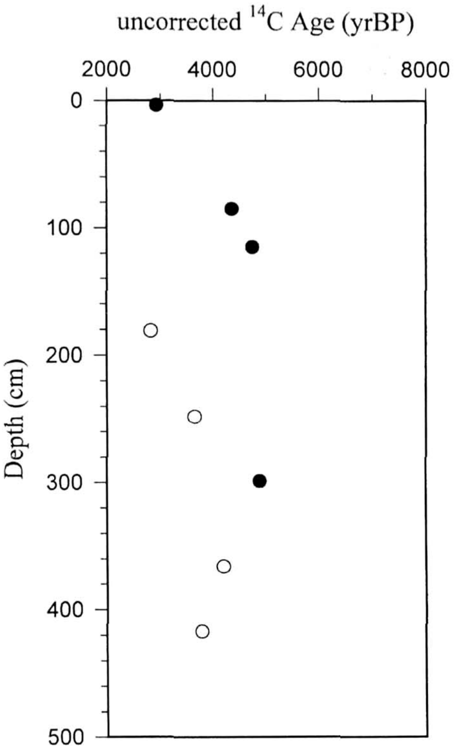

Fig. 3. Conventional age-depth curve for core A9-EB2 based upon AMS radiocarbon dates listed in Table 1. The lack of reasonable downcore linear sedimentation may be due to the possible inputs of reworked sediments with older carbons (closed circles). It is also apparent that the turbidity layers preserve the relatively older age sediments.

very difficult to establish the well-defined chronology of core A9-EB2 due mainly to the lack of accurate dates. Nonetheless, it is apparently addressed that the whole section of core A9-EB2 might constrain the late Holocene period.

TOC and MS profiles of A9-EB2 are shown in Figure 4. TOC contents are fairly low, which are similar to those reported in the other areas of Antarctic Peninsula region (Fig. 4a; Domack *et al.* 1992). From the base of core to about 420 cm, TOC content increases slightly and above the 420 cm is relatively consistent, except for several points. Figure 5 show the relationship between TOC and clay contents, from which the correlation is poor because TOC is not completely controlled by the textural property. The highest value of 1.75% at 130 cm downcore matches the diatom-rich light lamina whereas the lower values above 120 cm are related to the hemipelagic layers. MS values for core A9-EB2 are relatively low (between 2.2 and 190.1 cgs), compared especially to those measured in fjord sediments along the Antarctic Peninsula (Fig. 4b; Domack and McClennen 1996; Kirby *et al.* 1998). Such low values may be attributed to the lack of magnetic minerals, primarily a function of dilution

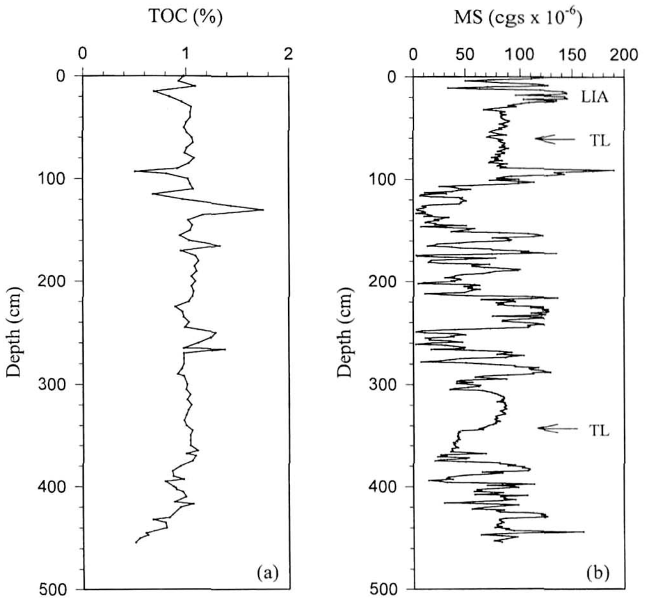

Fig. 4. (a) Total organic carbon (%) and (b) Magnetic susceptibility values (cgs x 10^{-6}) throughout the core A9-EB2. The relatively higher TOC corresponds to low MS, which is associated with the pelagic (diatom-enriched) sedimentation of biogenic (siliceous) materials, suggesting an increased regional productivity during a warmer climate regime. High MS and low TOC are mostly related to the hemipelagic sedimentation enriched in siliciclastic and terrigenous particles. TL: turbidite layer, LIA: Little Ice Age.

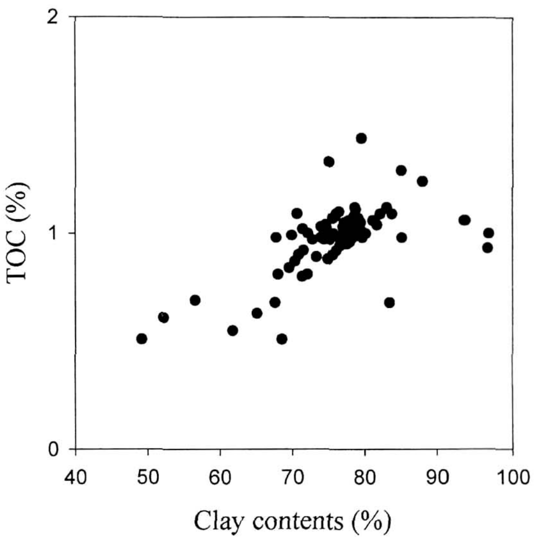

Fig. 5. Relationship between TOC and clay content of core A9-EB2 sediments. The widely scattered trend reflects that TOC is not totally influenced by the grain size.

by biogenic materials. The two intervening turbidite layers show the uniformly consistent values. The laminated intervals correspond well with MS low for the light layer and MS high for dark layer in X-radiographs (KORDI 1996).

Most of the terrigenous sediments deposited in the Bransfield Basin are transported from nearby Antarctic Peninsula margin. In general, the enhanced preservation of organic carbon in the sediments is interpreted as representing the period of greater vertical flux of organic carbon throughout the water column than normal (e.g., Domack *et al.* 1992). Yoon *et al.* (1994) also reported that the high TOC in Bransfield Strait sediments is caused by the increased paleoproductivity in surface water. In our study of core A9-EB2, the high values of TOC associated with diatom-enriched sediments are likely to imply the pelagic sedimentation which maintains elevated level of primary productivity different from the present-day. Thus, relatively higher levels of TOC are preserved within the sediments probably during a warmer climate regime in which the primary production might occur favorably. Leventer *et al.* (1996) also observed that higher TOC was associated with drops in magnetic susceptibility, and attributed this to warmer climatic conditions.

The high MS values corresponds to a hemipelagic sedimentation enriched in siliciclastic and terrigenous particles, particularly silts and clays (Domack and Ishman 1992; Kirby *et al.* 1998). Whereas the low MS levels are characterized by a depositional condition governed by pelagic sedimentation of biogenic (siliceous) materials, suggesting an increased regional productivity. Our interpretation is in close agreement with the previous studies (Domack and McClennen 1996; Bàrcena *et al.* 1998) and indicates that the fluctuations of MS values may be attributed to the constituent properties of supplied materials. In some cases, the decrease in MS within the core sediments may be due to the diagenetic dissolution of magnetite with depth or iron-sulfur diagenesis controlled by higher carbon content in the high productivity area (Karlin 1990). However, as our case that signal attenuation or dilution via increased productivity by the correlative increase in biogenic components (Leventer *et al.* 1996), the lithostratigraphy of core A9-EB2 apparently suggests that the MS changes cast back a switch of corresponding depositional condition.

Based on the unique MS oscillation of core A9-EB2, the productivity record contains a significant change throughout the whole core; the high frequency cycles are associated with the increase and decrease in the influence of sea-ice margin. As a model for late Holocene changes in oceanographic conditions in the Antarctic Peninsula region, in particular, the role of temporal variability in primary production and subsequent fluctuations in the biogenic flux to the sea floor seems to be a key controlling the susceptibility signal through dilution of the magnetic signature by biogenic material. Jordan and Pudsey (1992) and Leventer *et al.* (1996) postulated that enhanced primary production occurs close to the receding ice edges, as a result of the sea ice melting and increased upper water column stratification, which results in the low MS values in the bottom sediments.

The oscillatory productivity signal imprinted in core A9-EB2 as continuous fluctuation of MS is likely to represent the climatic changes recognized in somewhere of the world and recently documented in coastal Antarctica (Domack *et al.* 1991; Baroni and Orombelli 1994). Specially, we believe that the uppermost of A9-EB2 represent a cooling trend of Little Ice Age (LIA) that was hardly identified in the Antarctic Peninsula region. The presence of LIA agrees with those recognized in lake sediments on the South Shetland Island (Björck *et al.* 1996) and with decreases in biogenic sedimentation in Lallemand Fjord (Domack and McClennen 1996). Therefore, high concentration of biogenic components in the Bransfield Basin sediments suggests that phytoplankton blooming has occurred repeatedly during the late Holocene.

Conclusions

(1) Based on eight AMS radiocarbon datings, the chronology of core A9-EB2 shows unreasonable

fluctuations due to some contaminated materials. Taken into accounts of the linear sedimentation rate, the overall chronology is likely available to apparently address that the core A9-EB2 might record the late Holocene period.

(2) The relatively higher levels of TOC in A9-EB2 are associated with the pelagic (diatom-enriched) sediments, which implies favorably elevated level of primary productivity during a warmer climate regime.

(3) The MS high of A9-EB2 is mostly related to the hemipelagic sedimentation enriched in siliciclastic and terrigenous particles, whereas the MS low is characterized by pelagic sedimentation of biogenic (siliceous) materials, suggesting the increased productivity.

(4) The oscillation in the MS stratigraphy of A9-EB2 in the Bransfield Basin may be a record of the climatically-forced and high-level paleoproductivity cycles and less dilution of terrigenous particles. In addition, MS signals suggest that core A9-EB2 contains the cyclic nature of paleoproductivity maintained during the late Holocene in the Bransfield Basin, Antarctica.

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