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Relationship between magnetic susceptibility and sediment grain size since the last glacial period in the Southern Ocean off the northern Antarctic Peninsula – Linkages between the cryosphere and atmospheric circulation

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ABSTRACT

Magnetic susceptibility (MS) values in Scotia Sea sediments showed strong correlations to ice core non-sea salt Ca^{2+} concentration (dust input), which emphasizes the role of atmospheric circulation in the Southern Ocean. As a result, the correlation between these values was suggested as a powerful tool for age reconstruction of marine sediments in the Southern Ocean. However, controls on MS variation in Scotia Sea sediments are not clear. In this study, we documented records of grain size, MS values (10^{-6} CGS/g) of bulk sediments, and MS values of sand-sized (> 63 μm), coarse silt-sized (16–63 μm), and fine sediment fractions (< 16 μm) at sediment cores from the Southern Ocean off the northern Antarctic Peninsula (the south Scotia Sea and the northern Powell Basin) to reveal which size fraction is responsible for increased MS values during the glacial period and how this size fraction is transported to the Southern Ocean deep-sea. The MS values of all cores GC02-SS02, GC03-C2, GC03-C4, and GC04-G03 increased along with increased sand- and coarse silt-sized fractions and decreased fine sediment fraction. Although The MS values of all size fractions increased during the glacial period, the increased glacial MS values are more related to fine sand- to coarse silt-sized fractions than they are to the fine sediment fraction. The fine sand- to coarse silt-sized sediments with the highest MS values during the glacial period show (semi-)normal distribution patterns, indicating that they are transported by the same mechanism. The sediments are considered to be transported as ice rafted debris (IRD) during the glacial period. Based on our record, the strong correlation between marine core MS values and ice core dust record thus suggests a strong linkage between the cryosphere (iceberg calving activity) and atmospheric circulation (dust) in the Southern Ocean off the northern Antarctic Peninsula.

1. Introduction

The Southern Ocean plays an important role in global climate changes through deep-water formation (Orsi et al., 1995) and the biological pump (Takahashi et al., 2002). However, paleoclimatic/paleoceanographic studies in the Southern Ocean have a chronic problem with age reconstruction due to lack of foraminifers and the influence of old carbon (Gordon and Harkness, 1992; Nakada et al., 2000; Anderson et al., 2002; Heroy and Anderson, 2005; The RAISED Consortium et al., 2014). It was reported that magnetic susceptibility (MS) records in Scotia Sea sediments were well correlated with the non-sea salt Ca^{2+} ($nssCa^{2+}$) concentration, a proxy for dust input (Röthlisberger et al., 2004; Lambert et al., 2011), of the European Project for Ice Coring in Antarctica (EPICA) Drauning Maud Land (EDML) ice core (Weber et al., 2012; Xiao et al., 2016 and references therein). Through graphical correlation between MS records of sediment cores in the Scotia Sea and EDML ice core $nssCa^{2+}$ record, high-resolution age reconstructions for sediment cores became possible and the established age models were consistent with other stratigraphic data (Pugh et al., 2009; Allen et al., 2011; Weber et al., 2012; Xiao et al., 2016).

Considering the importance of MS for sediment age establishment, it is essential to understand the controlling mechanism of MS in marine sediments in the Scotia Sea. Although Patagonia/southern South America is the main dust source region for the Antarctic continent (Haberzettl et al., 2009), the mechanisms transporting fine sediments to the Scotia Sea remain controversial (Hofmann, 1999; Diekmann et al., 2000; Pugh et al., 2009; Weber et al., 2012). Since the magnetic properties of marine sediments are often associated with grain size changes (Evans and Heller, 2003), grain size changes should be examined for MS variations in the Scotia Sea. Grain size changes in the

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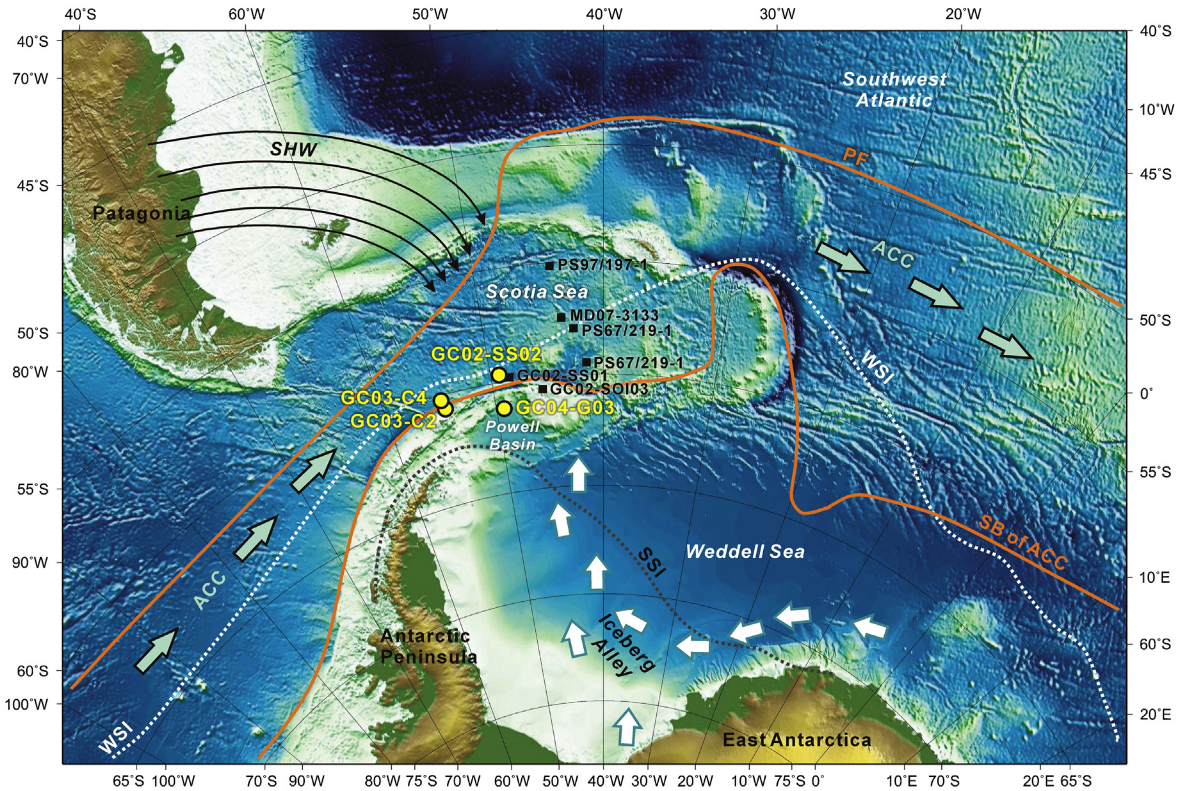

Fig. 1. Site location map with cores examined in this study and previous studies. White open arrows indicate iceberg alley of Anderson and Andrew (1999). Black arrows indicate the main wind direction of Southern Hemisphere Westerlies (SHW). Polar Front (PF) and Southern Boundary of Antarctic Circumpolar Current (SB of ACC; Orsi et al., 1995) are indicated by orange lines. The dark gray and white dashed lines are the summer (SSI) and winter (WSI) sea ice extent, respectively (Gersonde et al., 2005). ACC is shown by light green arrows. Information on core locations is listed in Table 1.

Table 1
Information on cores shown in Fig. 1.

Core ID	Latitude	Longitude	Water depth (m)	Source
GC02-SS02	59°29′S	49°36′W	4033	This study
GC03-C2	60°34′S	55°55′W	3750	This study
GC03-C4	60°33′S	55°52′W	3778	This study
GC04-G03	61°19′S	49°48′W	2907	This study
GC02-SS01	59°49′S	49°14′W	4141	Yoon et al., 2005
GC02-SOI03	60°22′S	47°00′W	786	Lee et al., 2010
MD07-3133	57°26′S	43°27′W	3101	Weber et al., 2012
MD07-3134	59°25′S	41°28′W	3663	Weber et al., 2012
PS2319-1	59°47′S	42°41′W	4320	Diekmann et al., 2000
PS2515-3	53°33′S	45°19′W	3522	Diekmann et al., 2000
PS67/197-1	55°08′S	44°06′W	3837	Xiao et al., 2016
PS67/219-1	57°57′S	42°28′W	3619	Xiao et al., 2016

Scotia Sea have been rarely reported (e.g., Yoon et al., 2005), and the relationship between changes of MS and grain size has not been discussed previously.

The modern Southern Ocean off the northern Antarctic Peninsula, including the south Scotia Sea and the Powell Basin, is located in the core of iceberg alley (Fig. 1), which originates in the Weddell Sea (Reid and Anderson, 1990; Diekmann and Kuhn, 1999). As sea ice and an ice sheet expanded during the last glacial period (Gersonde et al., 2005; Larter et al., 2014; Minzoni et al., 2015), more ice-rafted debris (IRD) was found in the marine sediments in the Southern Ocean (Diekmann et al., 2000; Hillenbrand et al., 2005). However, IRD (> 2 mm) abundance was not correlated to high MS values of Scotia Sea sediment cores during the last glacial period. IRD is not only limited to gravel-sized particles but also sand-sized grains are transported by icebergs (Andrews, 2000; Jonkers et al., 2012, 2015). Indeed, sand size grains (63–150 μm to 2 mm) were considered IRD in high-latitude deep-sea areas in both the Southern and Northern Hemispheres (e.g., Kanfoush et al., 2000; Sakamoto et al., 2005, 2006; Peck et al., 2007, 2015; Bailey et al., 2013; Teitler et al., 2015). Thus, it is necessary to re-examine the role of IRD in MS variation in the Southern Ocean off the northern Antarctic Peninsula using new representative IRD size criteria.

In this study, we document grain size distributions and MS values of the Southern Ocean off the northern Antarctic Peninsula to 1) determine which size fraction is related to MS variation since the last glacial period and 2) define the transport mechanism for this size fraction. An additional purpose is to provide the most suitable size criteria for IRD in the Southern Ocean deep-sea cores.

2. Materials and methods

A gravity core GC02-SS02 (59°29′S, 49°36′W, 4033 m deep, 478 cm long) was obtained from the south Scotia Sea by R/V *Yuzhmorgeologiya* during the 2002/2003 Korea Antarctic Research Program (KARP) cruise (Fig. 1, Table 1). Gravity cores GC03-C2 (60°34′S, 55°55′W, 3750 m deep, 834 cm long), GC03-C4 (60°33′S, 55°52′W, 3778 m deep, 840 cm long), and a box core BC03-C2 (60°34′S, 55°55′W, 3750 m deep, 38 cm long) were obtained from the south Scotia Sea by R/V *Yuzhmorgeologiya* during 2003/2004 KARP Cruise (Fig. 1, Table 1). A gravity core GC04-G03 (61°19′S, 49°48′W, 2907 m deep, 596 cm long) was obtained from the northern part of the Powell Basin by R/V *Yuzhmorgeologiya* during 2004/2005 KARP Cruise (Fig. 1, Table 1). All cores were opened, described, and sub-sampled at the Korea Polar Research Institute (KOPRI).

2.1. Physical properties (magnetic susceptibility and water content measurement)

The MS values for all sediment cores were measured at 1 cm intervals on split half core sections using a Bartington MS-2B susceptibility