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Sedimentation of particulate organic carbon on the Amundsen Shelf, Antarctica

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ABSTRACT

We examined the recent history of sedimentary organic carbon (SOC) accumulation on the western Amundsen Shelf, to help characterize the biological carbon pump in the Amundsen Sea, Antarctica. Vertical sedimentary profiles (in the upper 21-cm) of SOC content, radio- and stable-carbon isotopes were obtained at four locations in the western Amundsen Sea: near the shelf break, inside the polynya near the Dotson Ice Shelf, and at both the periphery and the center of the Amundsen Sea polynya. Profiles were representative not only of various distances from the coast, but also of various summertime sea ice conditions and bottom depths. The SOC content (up to 1.1%) and the radiocarbon content were distinctly higher at the periphery and at the center of the polynya than at the other sites. The SOC and ^{14}C contents were generally consistent with the spatial distribution of primary productivity in the surface water. A linear SOC accumulation rate of about 1.0 g C m^{-2} yr^{-1} was determined from the conventional ^{14}C ages of bulk SOC below the surface mixed layer at the periphery and at the center of the polynya, for the time period of 3.1–4.7 kyr before present (BP). This linear SOC accumulation rate was about 20 times greater than the rates determined at the two other sites for the period of 4.6–15.7 kyr BP. Note that all values are for uncorrected ^{14}C ages. At the center of the polynya, a sudden change in SOC accumulation rate was observed at about 16 cm depth, corresponding to 4.7 kyr BP, implying that changes (during this time period) in physical environments greatly affected primary production, SOC burial and/or supply of allochthonous particles to this site. The vertical distribution of ^{14}C content in the sediments implies that aged organic matter, likely associated with resuspended sediments, was also being deposited inside the polynya, in addition to autochthonous biogenic particles. If our estimation of SOC accumulation is extrapolated to the western Amundsen Shelf between 110°W and 120°W, approximately 3×10^{10} g C yr^{-1} is buried on the shelf, with ~90% of SOC accumulation occurring in the Amundsen Sea polynya.

1. Introduction

The Amundsen Sea, located between the Ross Sea and the Bellingshausen Sea in the western Antarctic (Fig. 1), is rapidly responding to global climate change. Ice shelves and glaciers in the Amundsen Sea have been shrinking at a remarkable rate (Rignot et al., 2008). Sea ice coverage is decreasing especially fast in the western Antarctic (Stammerjohn et al., 2012).

Polynyas, seasonally open water surrounded by sea ice in high latitude regions, often exhibit high primary productivity (Zielinski and Gersonde, 1997; Becquevort and Smith Jr., 2001; Arrigo and van Dijken, 2003). Among the Antarctic polynyas, two coastal polynyas in the Amundsen Sea (the Amundsen Sea polynya and the Pine Island Bay polynya) are reportedly the most productive regions, with satellite-based annual primary production reaching up to 160 g C m^{-2} yr^{-1} (Arrigo and van Dijken, 2003; Arrigo et al., 2012; Fragoso and Smith Jr., 2012). As the ice shelf (Rignot et al., 2008; Pritchard et al., 2009) and sea ice cover (Walker et al., 2007; Stammerjohn et al., 2012) shrink,

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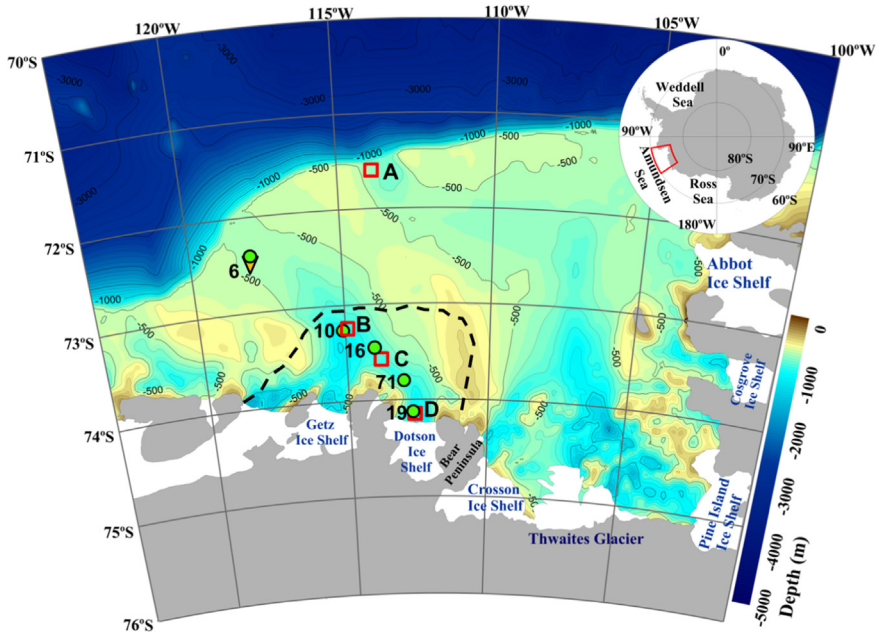

Fig. 1. Bathymetry and sampling locations of sediments (squares) and suspended particles in surface waters (circles). The numbers by the circles are the station numbers. The reversed triangle indicates the location of the sediment trap. The dashed line indicates 10% sea ice concentration in February 2012, as the boundary of the Amundsen Sea Polynya.

more extensive areas of the Amundsen Sea may start resembling polynya in the near future.

Primary production and subsequent export of particulate organic carbon (POC) in the form of sinking particles is an essential part of the biological pump (Volk and Hoffert, 1985). The role of the polynyas in CO_2 absorption and their consequent impact on global carbon cycling is affected by the efficiency of the biological pump. However, our understanding of the behavior of POC after its production in the Amundsen Sea is greatly limited. Recently, Ducklow et al. (2015) reported sinking particle flux obtained from a sediment trap that was moored for a year at the center of the Amundsen Sea polynya. A brief but high particle flux event in the austral summer (up to 96 mg C m^{-2} d^{-1}) reflected an intensive plankton bloom in the surface water of the polynya (Ducklow et al., 2015). During the same time period, a comparable POC flux (up to 55 mg C m^{-2} d^{-1}) was also observed in the sea ice zone of the Amundsen Sea (Kim et al., 2015). However, the fate of this exported POC on the Amundsen Shelf is not well studied.

A close examination of the past record of sedimentary organic carbon (SOC) accumulation may allow us to better predict the future behavior of carbon sequestration in this region. Studies of SOC accumulation rate and radiocarbon chronology on the Amundsen Shelf have mainly focused on deglaciation history, i.e., $>10{,}000$ yr (e.g., Smith et al., 2011). We examined the nature of SOC accumulation on the Amundsen Shelf as part of a larger study to characterize the current status of the biological pump and its operation in the recent past (up to several thousand years ago). We studied the biogeochemical properties of sedimentary organic matter at four locations with different physical characteristics (such as summertime sea ice concentration and bottom depth) on the western Amundsen Shelf and attempted to reconstruct the past depositional environment, mainly based on radiocarbon analysis of bulk SOC in the upper 21-cm sediment horizons.

2. Sample collection and analyses

2.1. Sample collection

Suspended particle and sediment samples were collected during a cruise aboard the IBRV *Araon* from January to March 2012 (Fig. 1). Sediment samples were collected at three locations along the western paleo ice stream trough from the Dotson Ice Shelf (Dotson trough) and one location near the shelf break in the western Amundsen Sea (Fig. 1). Station A (71.70°S, 114.04°W; 543 m bottom depth) is located in the sea ice zone near the shelf break of the Amundsen Sea. Unfavorable sea ice conditions and coarse sediment composition (suggested by a multi-beam survey) discouraged us from collecting sediments near the shelf break inside the Dotson trough. Station B (73.23°S, 114.91°W; 802 m) is located at the periphery of the Amundsen Sea polynya. Even during the summer minimum in sea ice concentration, Station B was not fully rid of sea ice unlike the central polynya (Fig. 2). We used a multi-core (KC Denmark A/S) at Station B. Station C (73.62°S, 113.80°W; 777 m) represents the central polynya where the sea ice concentration was reduced to near zero in the austral summer (Fig. 2). Station D (74.20°S, 112.52°W; 1080 m) is within the Amundsen Sea polynya but is characterized by close proximity to the Dotson Ice Shelf (approximately 2 km away from the ice shelf). After several failures with the multi-core, a box-core (Marine Tech. Korea) was used at Stations A, C, and D. Upon detachment of the box-core canister, plastic barrels of 8 cm diameter and 60 cm length were gently pushed in for sub-cores. Each sediment core was sliced into 1-cm layers on board and stored in pre-baked (450 °C for 4 h) glass jars and kept frozen until analysis.

Suspended particles in the surface water were collected by filtering sea water drained from the ship's uncontaminated sea-water intake system (~7 m below the surface) on pre-baked (450 °C for 4 h) 47 mm GF/F filters (0.7 μm nominal pore size, Whatman) under low vacuum (500 mmHg) without any pre-filtration at five sites on the shelf (Fig. 1). These suspended particle samples contained plankton in addition to phytodetritus. Each filter was folded and stored frozen (−20 °C) in a pre-combusted aluminum foil pouch until further analysis.

2.2. Sample analyses

In the laboratory, the frozen sediment samples were thawed and dried in an oven at 45 °C prior to analyses. For carbon concentration and isotope analyses, each sediment sample was finely ground, weighed in a silver cup, and fumigated with concentrated HCl in a desiccator for 20 h at room temperature (Hedges and Stern, 1984; Komada et al., 2008). The samples then placed on a heating plate at about 45 °C for 4 h to remove HCl vapor. The sample in a silver cup was