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Redox chemistry of West Antarctic Peninsula margin surface sediments

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ABSTRACT

Continental margin sediments are commonly studied using trace metal enrichments as proxies for characterizing their modern redox conditions and tracking past changes in bottom water ventilation and marine primary productivity. Currently little is known about the sedimentary redox history of the continental shelf west of the Antarctic Peninsula. Yet, environmental conditions in the Antarctic Peninsula region have changed rapidly in recent decades in response to global warming. Paleoclimate archives including bulk sediment trace metal enrichments can provide insight into both past and future environmental changes in this climatically sensitive region, and characterization of redox conditions in surface (modern) sediments is essential for establishing a framework for paleoredox interpretations. In this study we measured concentrations of trace metals (Ag, Cd, Re, and Mo) and productivity proxies (total Ba, organic carbon, and biogenic silica) in surface sediments from the Marguerite Bay, Gerlache Strait, and Bransfield Strait areas. Proxy concentrations suggest that sediments are generally suboxic due to seasonally high export of organic carbon from surface waters. Comparison of West Antarctic Peninsula trace metal/Al ratios to trace metal data from continental margins outside the Antarctic region demonstrates that although the West Antarctic Peninsula water column differs from other locations (e.g., it lacks a strong oxygen minimum zone), sedimentary redox chemistry is similarly controlled by organic matter decomposition, through slow recycling of highly seasonal export production falling through a cold water column.

1. Introduction

Trace metal accumulations in continental margin sediments have been successfully used to document past shifts in sedimentary redox chemistry caused by changes in bottom water oxygenation, ocean circulation, and primary productivity (e.g., Dean et al., 2006; Hendy and Pedersen, 2005, 2006; McKay et al., 2005; Morford et al., 2001; Muratli et al., 2010; Nameroff et al., 2004). Often, redox changes at a single location are interpreted to indicate larger-scale shifts in ocean–atmosphere circulation, biogeochemical cycling, and/or glacial processes that provide insight into Earth's climate dynamics. Most trace metal studies have focused on continental margin sediments—such as the eastern Pacific—where reducing conditions are more likely to occur within strong oxygen minimum zones and under coastal upwelling zones that feed high primary productivity. Despite seasonally high surface productivity that could create reducing conditions in underlying sediments, the sedimentary redox chemistry of the West Antarctic Peninsula (WAP) continental margin has been little studied. The unique oceanographic and geological setting of the WAP should influence nonlithogenic trace metal accumulation in a manner that contrasts with other continental margins. First, well-ventilated waters are present (Hofmann et al., 1996) that could inhibit trace metal accumulation or remobilize trace metals precipitated under reducing conditions (Scholz et al., 2011). Second, glacial ice extends to the coast, and delivers lithogenic debris to the shelf and slope (Griffith and Anderson, 1989) that could potentially obscure the nonlithogenic trace metal signal. Third, the phytoplankton growing season is light limited both by solar insolation and sea ice cover (Smith et al., 1996), resulting in a compressed timeframe for biogenic particle export to the seafloor. Finally, waters as cold as −1.8 °C (Smith et al., 1999) lower metabolic rates (Gillooly et al., 2001) and potentially slow organic matter recycling, allowing more organic matter to reach the seafloor. Thus it is uncertain whether sediments of the WAP shelf and slope accumulate trace metals similarly to other continental margins.

Paleoclimate studies utilizing marine and terrestrial records provide a window into the environmental effects of climate variation, and therefore have the potential to help predict the outcomes of future warming in the Antarctic Peninsula region. Trace metal studies of marine sediment paleoredox conditions could provide additional perspective about past ventilation and export production changes associated with warming events. However, interpreting downcore sedimentary trace metal enrichments requires first characterizing modern WAP sedimentary redox chemistry and the controls primarily responsible for that

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chemistry. Therefore in order to determine the influences of ventilation and carbon rain on modern sedimentary redox chemistry, we measured trace metal (silver [Ag], cadmium [Cd], rhenium [Re], and molybdenum [Mo]), productivity proxy (total barium [Ba], organic carbon [C_{org}], and biogenic silica [Si_{bio}]), and aluminum (Al) concentrations in surface sediments from 35 box cores collected from the WAP shelf, including coastal areas and fjords (water depths 300–2200 m). These data were then compared to previously published continental margin trace metal and productivity data to place the WAP margin in a global context.

2. Background

2.1. Oceanographic setting

The West Antarctic Peninsula region can be divided oceanographically into the shelf-slope area directly west of the peninsula, and Bransfield Strait, which is separated from Drake Passage by the South Shetland Islands (Fig. 1). The southernmost front of the Antarctic Circumpolar Current (ACC) closely follows the outer edge of the continental shelf, while the Antarctic Polar Front is positioned in the open ocean north of the South Shetland Islands (Orsi et al., 1995). Cyclonic surface circulation composed of two separate gyres is present near Gerlache Strait and Marguerite Bay, with the ACC flowing offshore to the northeast and a southwestward-flowing current returning along the coast (Hofmann et al., 1996). Cross-shelf water transport is thought to occur between the two gyres and in association with bathymetric features (Savidge and Amft, 2009). Cold, relatively fresh Antarctic Surface Water occupies the upper water column (Smith et al., 1999), but the most prominent water mass west of the peninsula is warm, nutrient-rich, and well-oxygenated Upper Circumpolar Deep Water (UCDW) which floods the continental shelf to a depth of 150–200 m on the inner shelf and 400–700 m on the outer shelf (Hofmann et al., 1996). Bathymetric upwelling of UCDW at the shelf break has been shown to be an important source of nutrients for diatoms (Prézelin et al., 2000).

Inside Bransfield Strait, clockwise surface circulation is also developed (Savidge and Amft, 2009), and warmer water from the ACC enters Bransfield Strait between Smith and Snow Islands (Hofmann et al., 1996). Additional inflow of cold water to the strait is from the Weddell Sea to the east and from Gerlache Strait to the west (Hofmann et al., 1996; Smith et al., 1999). Consequently, the upper water column displays a complex water mass structure derived from mixing of different water types (Hofmann et al., 1996). Circumpolar Deep Water is recognizable primarily in the western part of the strait and along the southern margin of the South Shetland Islands (Hofmann et al., 1996). Elsewhere, cold deep waters are dominated by Bransfield Strait Water, which may originate in the Weddell Sea (Whitworth et al., 1994).

2.2. Sea ice and primary productivity patterns

West of the Antarctic Peninsula, the seasonal ice zone is characterized by substantial interannual variability, with maximum sea ice extent occurring during August and the minimum during March

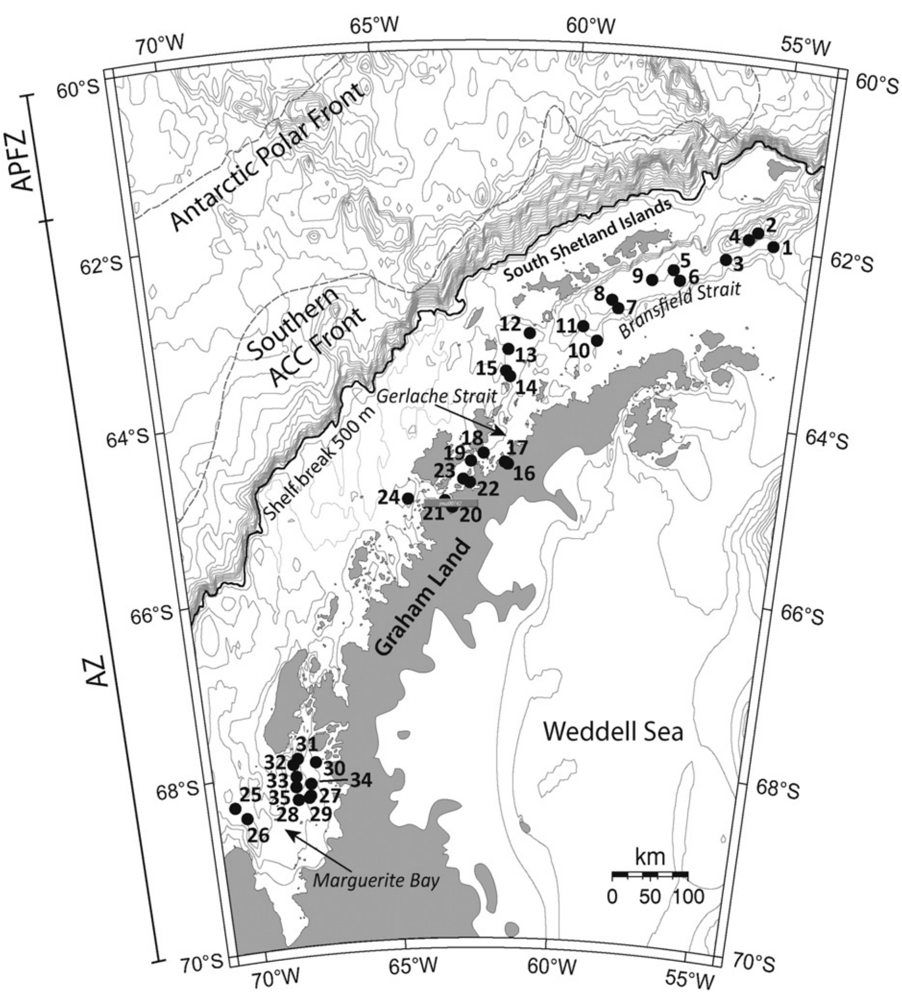

Fig. 1. Locations of cores used in this study. See Table 1 for number references to cores. Fronts of the Antarctic Circumpolar Current (ACC) are indicated by dashed grey lines (after Orsi et al. (1995)). APFZ—Antarctic Polar Frontal Zone; AZ—Antarctic Zone.