Marine Chemistry 157 (2013) 24–40

Contents lists available at ScienceDirect

Marine Chemistry

journal homepage: www.elsevier.com/locate/marchem

Iron in land-fast sea ice of McMurdo Sound derived from sediment resuspension and wind-blown dust attributes to primary productivity in the Ross Sea, Antarctica

Jeroen de Jong [a,*], Véronique Schoemann [b], Nathalie Maricq [a], Nadine Mattielli [a], Patricia Langhorne [c], Timothy Haskell [d], Jean-Louis Tison [b]

[a] Laboratoire G-TIME, Géochimie-Traçage Isotopique, Mineral et Elémentaire CP 160/02, Département des Sciences de la Terre et de l'Environnement, Université Libre de Bruxelles, Avenue F.D. Roosevelt 50, B-1050 Brussels, Belgium

[b] Laboratoire de Glaciologie CP 160/03, Département des Sciences de la Terre et de l'Environnement, Université Libre de Bruxelles, Avenue F.D. Roosevelt 50, B-1050 Brussels, Belgium

[c] Sea Ice Group, Department of Physics, University of Otago, P.O. Box 56, Dunedin 9054, New Zealand

[d] Industrial Research Ltd., 69 Gracefield Road, P.O. Box 31310, Lower Hutt 5040, New Zealand

ARTICLE INFO

Article history:
Received 12 January 2013
Received in revised form 16 July 2013
Accepted 17 July 2013
Available online 3 August 2013

Keywords:
Iron
Sea ice
Sediments
Resuspension
Suspended particulate matter
Atmospheric particulates
Primary production

ABSTRACT

We present high-accuracy isotope dilution mass spectrometry data on dissolved Fe (DFe), total dissolvable Fe (TD-Fe) and refractory particulate Fe (REF-Fe) concentrations in snow, land-fast ice and under-ice seawater, sampled at six sites from 14 to 22 January 2003 in Erebus Bay, McMurdo Sound. We also report refractory particulate Fe/Al ratios to help identify Fe sources. Iron concentrations in land-fast ice and snow were two to three orders of magnitude higher than the underlying seawater. Seawater Fe increased in all fractions over the sampling period (8 days), likely caused by sediment resuspension induced by spring tides, which occur twice a month. We propose that entrainment of wind-blown material and sediment-derived Fe is the most important pathway for high Fe concentrations in land-fast ice in McMurdo Sound. Iron fluxes from the sediment were estimated and could fully account for the Fe inventory of the land-fast ice. Wind-blown lithogenic material in the snow on the land-fast ice makes up for 14–68% of the total Fe inventory of the sea ice. It does not appear to penetrate into the sea ice proper as snow-ice forming conditions were not present. The sources of these wind-blown particles are, in decreasing order of strength, the McMurdo Ice Shelf, the Dry Valleys, Ross Island and Erebus volcanic emissions. The data suggest that the usual spring breakup of sediment-laden land-fast ice to the Ross Sea may have a significant potential fertilizing effect on the waters of the Ross Sea Polynya. This is illustrated by the strong diminution of primary production in the Ross Sea Polynya due to the blockade of the annual sea ice breakout by the giant icebergs B-15 and C-19 during the austral summer of 2003.

1. Introduction

The surface of Antarctic sea ice varies seasonally between 3.8×10^6 km^2 (summer) and 19×10^6 km^2 (winter) (Comiso, 2003). As an ocean–atmosphere interface, sea ice has a considerable impact on the polar environment. Its influence ranges from the formation of polar deep water masses involved in the global thermohaline circulation, the global radiation budget via albedo effects on the lower atmosphere as well as via the heat and light distribution in the water column, to an important ecological role as provider of a stable habitat for diverse communities of (micro)-organisms (Garrison et al., 1986; Legendre et al., 1992).

The role that sea ice could play in the marine biogeochemical cycle of iron (Fe) has long been neglected due to the challenging sampling environment. Iron plays an essential role as micronutrient for phytoplankton growth in the regulation of the marine carbon pump (Boyd et al., 2007). The assessment of sea ice as a Fe fertilizing factor for the polar oceans is likely to have consequences for paleo-climatological reconstructions and the prediction of future climate change. A number of recent studies (Grotti et al., 2005; Lannuzel et al., 2007, 2008, 2010; van der Merwe et al., 2009, 2011a,2011b) have highlighted the capability of Antarctic sea ice to accumulate Fe, with observed dissolved and particulate Fe concentrations one to two orders of magnitude higher than the underlying seawater. The mechanism by which the Fe is accumulated is unclear to date, but may involve scavenging during sea ice formation of biogenic (Ackley and Sullivan, 1994) and lithogenic particles (Grotti et al., 2005; van der Merwe et al., 2011a), Fe sequestration by sea ice algae (Lannuzel et al., 2010) and accumulation of atmospheric dust on the ice (Sedwick et al., 2000; Fitzwater et al., 2000; Sedwick and DiTullio, 1997). During the seasonal melting of sea ice, this Fe is released in the surface waters (Lannuzel et al., 2008) and may be a triggering factor for phytoplankton blooms (Sedwick and DiTullio, 1997; Goffart et al.,

* Corresponding author. Tel.: +32 2 6502246.
E-mail address: jdejong@ulb.ac.be (J. de Jong).

0304-4203/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.marchem.2013.07.001

2000) at the retreating ice edge or in polynyas (Arrigo and van Dijken, 2003).

In this paper we will discuss results from a survey in January 2003 of Fe concentrations in snow, sea ice and seawater in Erebus Bay (McMurdo Sound). We hypothesize that land-fast ice from McMurdo Sound is an important vector of natural Fe fertilization of the Ross Sea, thanks to atmospherically (McMurdo Ice Shelf, Dry Valleys, Ross Island, Erebus volcano) and sedimentary (sea floor sediment resuspension and ice shelf basal debris) derived Fe.

2. Geological, hydrographical and glaciological setting

2.1. Geology

McMurdo Sound is a small marginal basin surrounded by the Transantarctic Mountains of Victoria Land to the west, the McMurdo Ice Shelf (MIS) to the south, Ross Island to the east and the Ross Sea to the north (Fig. 1A). Ross Island is the site of the most active volcano in Antarctica: Mount Erebus (Del Carlo et al., 2009) (Fig. 1A and B). The bulk of exposed lava flows on the Erebus volcano cone is distinctively phonolitic, contrasting with the surrounding areas on Ross Island forming the broad platform shield of the Mount Erebus edifice and consisting predominantly of basanitic lavas (Kyle, 1976). The volcanic bedrock to the south and the west of McMurdo Sound is also basanitic in nature (Kyle, 1976). Phonolitic and basanitic lavas exhibit characteristic Fe/Al ratios, which can be useful to trace sources of Fe, e.g., basanite median molar Fe/Al $= 0.60 \pm 0.03$ ($n = 91$) (Table 1) and phonolite median molar Fe/Al $= 0.18 \pm 0.02$ ($n = 55$) (Table 1).

Victoria Land is the scene of one of the world's most extreme deserts, the McMurdo Dry Valleys, a large 4000 km^2 ice-free area (Bockheim, 2002) with very low humidity and precipitation. High katabatic winds blow dust and gravel into the coastal zone (Ayling and McGowan, 2006) with intermediate molar Fe/Al compositions (median 0.41 ± 0.06, $n = 269$, Table 1).

On the MIS, glacial debris bands lie openly exposed on the ice shelf surface (Atkins and Dunbar, 2009; Dunbar et al., 2009), which with the prevailing southerly wind direction are subject to wind erosion and transport of wind-blown dust into McMurdo Sound. This wind-blown dust has a median Fe/Al of 0.45 ± 0.03 ($n = 24$) (Table 1).

2.2. Hydrography

The western shelf of McMurdo Sound has water depths of about 200 m, which slowly increases towards the east to 900 m depth near-shore of Ross Island, where the shelf slope is very steep (Fig. 1C). A cyclonic oceanic circulation pattern brings relatively warm and salty Antarctic Surface Water (AASW) from the Ross Sea along the west coast of Ross Island in southerly direction where it returns north along the coast of Victoria Land and by doing so entrains Ice Shelf Water (ISW) from underneath the MIS (Barry and Dayton, 1988).

2.3. Glaciology

Land-fast ice is formed in the Sound during winter, between late March and early December (Jeffries et al., 1993), and reaches an average

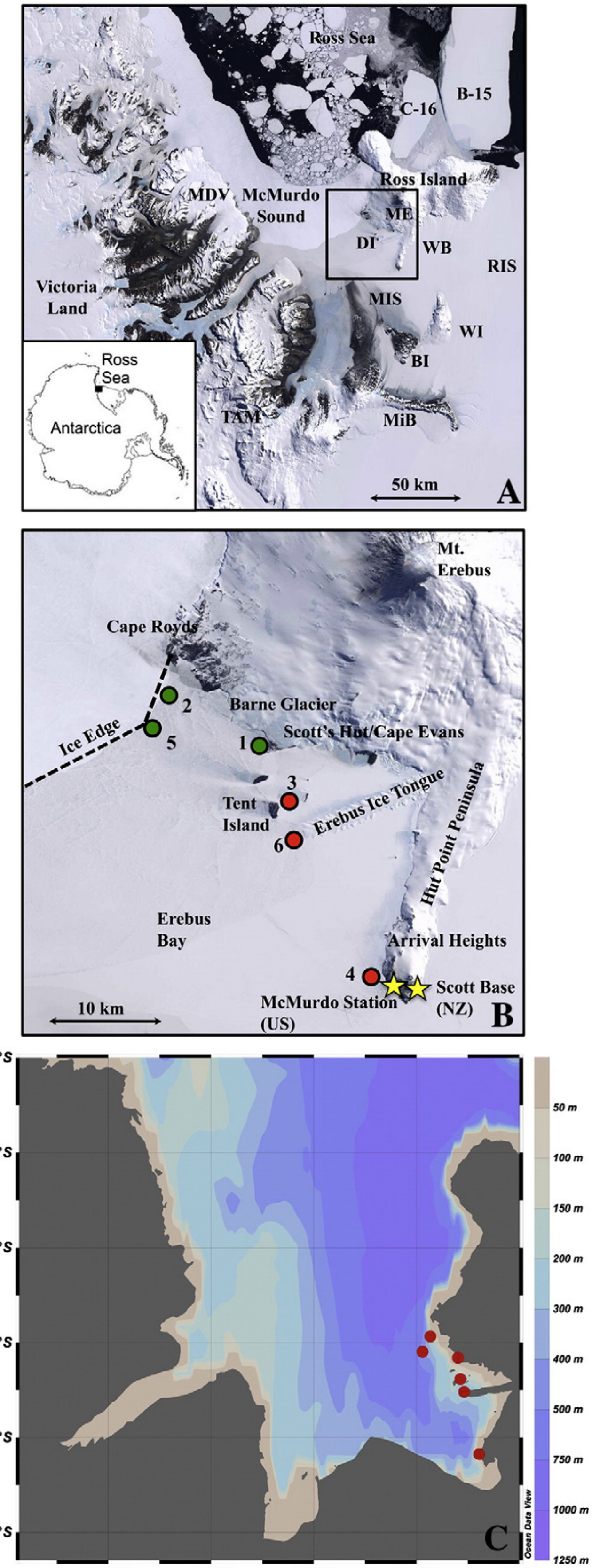

Fig. 1. (A) Composite of satellite images of Ross Island, McMurdo Sound and Victoria Land with geographic abbreviations: BI (Black Island), DI (Dellbridge Islands), MiB (Minna Bluff), MDV (McMurdo Dry Valleys), ME (Mount Erebus), MIS (McMurdo Ice Shelf), RIS (Ross Ice Shelf), TAM (Transantarctic Mountains), WB (Windless Bight), WI (White Island). Also indicated are giant iceberg B-15 and smaller iceberg C-16. Giant iceberg C-19 was further to the north (see Arrigo and van Dijken, 2003). (B) Blown up section of research area comprising Erebus Bay and western Ross Island with station positions. Green circles represent stations with first-year sea ice, while red circles are stations with multi-year sea ice. Satellite imagery (Terra-MODIS) is courtesy of NASA. (C) General bathymetry of McMurdo Sound, with the ice stations represented as red dots (see also B). Courtesy of Ocean Data View.