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Mesoscale variability of the summer bloom over the northern Ross Sea shelf: A tale of two banks

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ABSTRACT

Multi-year satellite records indicate an asymmetric spatial pattern in the summer bloom in the Northern Ross Sea, with the largest blooms over the shallows of Pennell Bank compared to Mawson Bank. In 2010–2011, high-resolution spatiotemporal in situ sampling focused on these two banks to better understand factors contributing to this pattern. Dissolved and particulate Fe profiles suggested similar surface water depletion of dissolved Fe on both banks. The surface sediments and velocity observations indicate a more energetic water column over Mawson Bank. Consequently, the surface mixed layer over Pennell Bank was more homogeneous and shallower. Over Mawson Bank we observed a thicker more homogeneous bottom boundary layer resulting from stronger tidal and sub-tidal currents. These stronger currents scour the seafloor resulting in sediments less likely to release additional sedimentary iron. Estimates of the quantum yield of photosynthesis and the initial slope of the photosynthesis-irradiance response were lower over Mawson Bank, indicating higher iron stress over Mawson Bank. Overall, the apparent additional sedimentary source of iron to, and longer surface residence time over Pennell Bank, as well as the reduced fluxes from the more isolated bottom mixed layer over Mawson Bank, sustain the observed asymmetric pattern across both banks.

1. Introduction

Phytoplankton blooms in the Ross Sea are extensive (Arrigo and Van Dijken, 2004), high productivity events (Arrigo and McClain, 1994) that are responsible for large quantities of carbon export (Asper and Smith, 1999). The Ross Sea continental shelf has the highest rates of net primary productivity in Antarctica (Arrigo et al., 2008a, Smith and Comiso, 2008), is a major regional CO_2 sink (Arrigo et al., 2008b) and supports a robust food web containing more than a dozen upper trophic level predators such as penguins, cetaceans and seals (Ballard et al., 2012; Smith et al., 2014). Over continental shelf systems, physical features have suggested that the spatial distribution of phytoplankton blooms and grazers may be linked to local bathymetry and/or tides (Hunt et al., 1998; Cotté and Simard, 2005; Vlietstra et al., 2005). In the Ross Sea, Reddy and Arrigo (2006) show that the extent of the spring bloom is linked to the underlying bank and trough bathymetry of the outer shelf (Fig. 1).

The phytoplankton composition in the Ross Sea has a temporal progression that is potentially driven by varying physical controls on light regime and/or iron supply, although the exact contribution of each factor is debated. In the spring, strong katabatic winds push sea ice offshore and create relatively deep mixed layers. Communities in these waters are often dominated by the haptophyte *Phaeocystis antarctica*, but by early summer the polynya assemblage becomes increasingly dominated by diatoms (Arrigo et al., 1999). The springtime dominance of *P. antarctica* is consistent with its photo-physiology, which is well suited for irradiance conditions resembling those of a deep mixed layer with a

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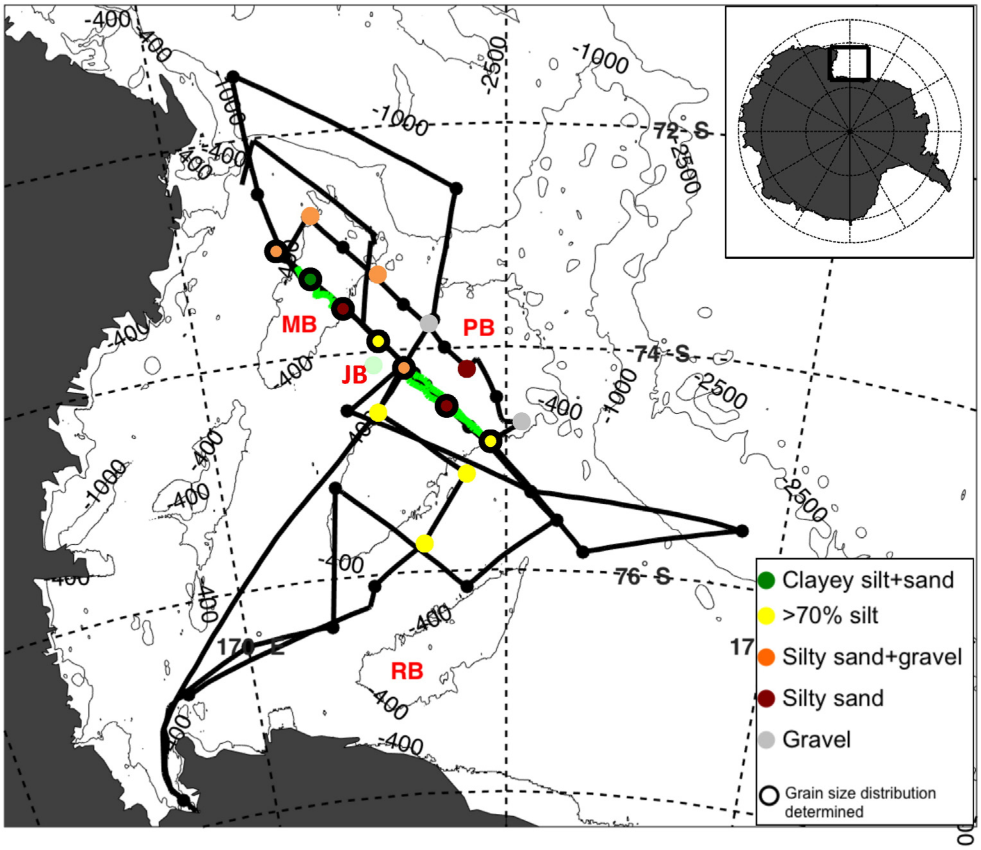

Fig. 1. Map of the study site in the Western Ross Sea showing the ship track (black line), ship stations (black dots), and glider tracks (green). Isobaths highlight the relevant topographic features including Ross Bank (RB), Pennell Bank (PB), Joides Basin (JB), and Mawson Bank (MB). The colored circles indicate the broad sediment characteristics of surface sediments. The repeat ship section is the southernmost line across the two banks coincident with the glider deployments. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

dynamic light regime (Kropuenske et al., 2009; Alderkamp et al. 2012). As the season progresses, the water column becomes more stratified, leading to irradiance conditions suitable for diatoms such as *Fragilariopsis cylindricus* (Kropuenske et al., 2009; Alderkamp et al. 2012). Therefore, the spring to summer shifts in community assemblage from *P. antarctica* to diatoms may be related to changes in Mixed Layer Depth (MLD) and light regime. However, concurrent changes in dissolved iron (Fe) potentially confound this relationship. As the polynya first opens, dissolved Fe concentrations in surface waters can be as high as 4 nM (Sedwick et al., 2000). These springtime dissolved Fe concentrations are rapidly drawn down by *P. antarctica* blooms (Sedwick et al., 2011), leading to concentrations that typically remain low throughout the summer. The extent to which these lower Fe concentrations lead to preferential growth of diatoms is not clear. On one hand, some *P. antarctica* populations in the Antarctic Circumpolar Current require higher dissolved Fe concentrations for growth compared to co-occurring diatoms (Coale et al., 2003), and incubation experiments in the Ross Sea have revealed a preferential stimulation of *P. antarctica* by added Fe (Bertrand et al., 2007). However, other field observations and deck incubation results suggest low Fe conditions tend to favor *P. antarctica* over diatoms (Sedwick et al., 2000). Culture experiments demonstrated that species grown under low light have elevated Fe requirements, presumably due to the increased need for Fe-expensive photosynthetic units (Sunda and Huntsman, 1997), which may further complicate our understanding of iron and light limitation in the Southern Ocean.

The interplay between micronutrient sources, water column structure, shelf circulation, and local topographic features drives a persistent response in the summer bloom over the northern Ross Sea shelf. This is a critical region for both the exchange of dense bottom water masses that move down the slope and eventually form Antarctic Bottom Water (AABW, Gordon et al., 2009) and the injection of warm Circumpolar Deep Water (CDW) that comes from the mid-depths of the Southern Ocean (Orsi and Wiederwohl, 2009). The most energetic process that likely contributes to the mixing and advection of these water masses is tides. The tides of the Ross Sea are predominantly diurnal with higher amplitudes over the shallow banks and along the shelf break (Robertson, 2005; Whitworth and Orsi, 2006; Padman et al., 2009). The tides interact with the varying topography and the background flow over the northern Ross Shelf to mix and modify the water masses, likely influencing phytoplankton production in the summer bloom through varying water column stability and delivery of micronutrients to the euphotic zone (Gordon et al., 2009).

Using a long-term satellite record, Reddy and Arrigo (2006) describe a persistent spatial pattern in the spring bloom over the Ross Sea Shelf. They show that, on average, the bloom is constrained to the shallows of the banks with much lower biomass levels observed in the basins between the banks. The preferential advection of low biomass water from the north into the basins drives this observed pattern. However, a closer look at the blooms over Pennell and Mawson Banks reveals a persistent asymmetry. The satellite climatology indicates that there is typically more biomass over Pennell Bank (PB) compared to Mawson Bank (MB) and that the largest seasonal blooms occur over PB (Fig. 2). Through a multiplatform sampling strategy focused on the two banks, we describe and differentiate the characteristics related to the water column structure over each bank as they relate to the observed asymmetry in the blooms across the banks. We integrate in situ physical and biogeochemical measurements sampled across coincident ship and AUV based surveys to determine the conditions that support the observed spatial pattern across the two banks.