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Particle fluxes and geochemistry on the Canadian Beaufort Shelf: Implications for sediment transport and deposition

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Abstract

Biogeochemical data from four sequential sediment traps deployed for one full year (April 1987–March 1988) at the shelf edge (200 m isobath) of the Canadian Beaufort Sea are presented. In addition, multi-traps and Kenney traps, which collect material suspended near the bottom, provided data from the inner shelf for short intervals in spring and summer. A novel aspect of this work is the discrimination of biogenic and terrigenous contributions to the total carbon using a relationship between terrigenous carbon and aluminum (Al). The vertical flux in the Beaufort Sea derives primarily from three sources: marine biological production, the Mackenzie River Plume, and coastal and seabed erosion. The material trapped at all shelf edge sites was predominantly biogenic and the seasonal fluxes of both biogenic and terrigenous matter varied with geographical location. In open-water conditions, deposition of terrigenous material can be attributed at various times and places to (1) transport by the Mackenzie Plume to the shelf edge during freshet; (2) resuspension of sediment during north-westerly gales; and (3) erosion of steep coastlines during south-easterly gales followed by northward transport. On the west side of the shelf, the biogenic and terrigenous fluxes were highest in summer and were primarily influenced by the Mackenzie River freshet, increased solar flux, available nutrients, sea ice break-up, and water column stability. On the east side of the shelf, biogenic and terrigenous fluxes were highest in the fall and the most important controlling factors were the extensive open water, intense resuspension events accompanying storms from the northwest, and the flow of the fresh, warm, turbid waters of Mackenzie River to the northeast. There was strong evidence of sediment transport in mid-water and bottom layers, but the mechanisms involved cannot be inferred from this study. Stable isotopes of carbon and nitrogen, C/N ratios, biogenic silica, and chlorophyll *a* measurements help to distinguish between marine autotrophic production and heterotrophic production, of which the latter appears to dominate in the fall and continue beneath the ice into the polar night. Al and iron correlate strongly and are primarily associated with the terrigenous fraction whereas calcium and phosphorus have both terrestrial and biogenic associations.

Keywords: Beaufort; Mackenzie; Sediment; Transport; Trap; Fluxes; Carbon; Nitrogen; Aluminum; Iron; Calcium; Phosphorus; Silica; Isotope; Biogenic; Terrigenous

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1. Introduction

During the past decade dramatic change has been observed in the Arctic's ice climate, ocean circulation and storage of freshwater (McLaughlin et al., 1996; Cavalieri et al., 1997; Macdonald et al., 2002; ACIA, 2004). These primary changes are proposed to have dramatic consequences for thermohaline circulation, biogeochemical cycling, and contaminant transport (Aagaard and Carmack, 1989; Overland et al., 2004; Stein and Macdonald, 2004; Macdonald et al., 2005). However, there are virtually no data to evaluate the direction or magnitude of the response of these secondary processes to, for example, loss of ice cover. Continental shelves are regarded as important components of the global carbon cycle (Ruttenberg and Goñi, 1997; Liu et al., 1999, 2000; de Haas et al., 2002). In the Arctic, over 50% of the ocean is underlain by continental shelves which constitute ~20% of the world's continental shelves (Stein and Macdonald, 2004). These enormous continental shelves and slopes are likely to be in the vanguard of change (Carmack and Macdonald, 2002; Carmack and Chapman, 2003) and are, accordingly, crucial places to understand and monitor effects of climate variation.

The Arctic Ocean is exceptionally seasonal in its biogeochemical forcing by virtue of extreme ranges of air temperature, solar radiation and runoff and the accompanying consequences for ice cover (Carmack et al., 2004; Wassmann et al., 2004). Logistical constraints have largely limited biogeochemical studies in the Arctic to early spring, when ice-based operations are feasible, and summer when ships can access the shelves. This bimodal sampling pattern provides a restricted, and probably highly distorted, view of the Arctic Ocean. To overcome the difficulty of incomplete temporal and spatial coverage, instrumented moorings have been deployed and, in particular, the measurement of particle flux by sequential sediment traps has allowed observations throughout the year of biogeochemical coupling of the surface ocean with the deep ocean (Berelson, 2001). Despite the obvious advantage of sequential traps to study highly episodic systems, like those of the Arctic, very few long-term sediment trap deployments have been made (Wassmann et al., 2004). Published sets of long-term trap data with moored time series sediment traps from within the Arctic Ocean include one off Ellesmere Island (Hargrave et al., 1989, 1994), one over the Siberian end of the Lomonosov Ridge (Zernova et al., 2000; Wassmann et al., 2004), and one unpublished data set on the inner Kara Shelf (Wassmann et al., 2004).

Here we present biogeochemical data for samples collected by sediment traps deployed over the shelf and shelf edge of the Canadian Beaufort Sea during the period from April 1987–March 1988. These moorings included sequential sediment traps deployed for a complete year at the 200 m isobath, multi-traps moored over the inner shelf for short intervals in spring and summer, and Kenney traps moored at the seabed of the inner shelf in spring and summer (Fig. 1a). We examine the timing and composition of particle fluxes in these traps to infer the role of ice cover, river inflow, primary production, ocean currents, and winds in the production and transport of particles over the shelf. The sequential trap data provide the first opportunity to evaluate a complete year's record of biogeochemical cycling on an arctic shelf. It is important to note that the data reported here were collected prior to 1989 when the Arctic began to undergo large-scale changes associated with the Arctic Oscillation (Thompson and Wallace, 1998; Morison et al., 2000; Macdonald et al., 2005). Accordingly, these data provide a baseline for conditions prior to the large-scale changes in ice and ocean observed in the western Arctic over the past decade (Serreze et al., 2000).

2. Physical and biogeochemical setting of the Beaufort Shelf

The Canadian Beaufort Shelf (Fig. 1a–c) is relatively small (64,000 km^2 to the 200 m isobath), representing less than 2% of the Arctic Ocean's total shelf area (Stein and Macdonald, 2004), and is narrow (100 km) compared to the broad Eurasian shelves (400 km). The shelf is bordered on the west by the Mackenzie Trough and on the east by Amundsen Gulf. The central shelf is traversed by a number of smaller troughs (e.g. Kugmallit Trough) which may provide important conduits for transport on and off the shelf (Carmack and Macdonald, 2002).

Immense quantities of fresh water are delivered by the Mackenzie River making this the most estuarine of all Arctic shelves (Giovando and Herlinveaux, 1981; Macdonald, 2000). Indeed the annual inflow (333 km^3) evenly distributed on the shelf would produce a layer ~5 m thick. On average