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Spatial variation in shallow sediment methane sources and cycling on the Alaskan Beaufort Sea Shelf/Slope

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ABSTRACT

The MITAS (Methane in the Arctic Shelf/Slope) expedition was conducted during September, 2009 onboard the U.S. Coast Guard Cutter (USCGC) *Polar Sea* (WAGB-11), on the Alaskan Shelf/Slope of the Beaufort Sea. Expedition goals were to investigate spatial variations in methane source(s), vertical methane flux in shallow sediments (<10 mbsf), and methane contributions to shallow sediment carbon cycling. Three nearshore to offshore transects were conducted across the slope at locations approximately 200 km apart in water column depths from 20 to 2100 m. Shallow sediments were collected by piston cores and vibracores and samples were analyzed for sediment headspace methane (CH_4), porewater sulfate (SO_4^{2-}), chloride (Cl^-), and dissolved inorganic carbon (DIC) concentrations, and CH_4 and DIC stable carbon isotope ratios ($\delta^{13}C$). Downward SO_4^{2-} diffusion rates estimated from sediment porewater SO_4^{2-} profiles were between −15.4 and −154.8 mmol m^{-2} a^{-1} and imply a large spatial variation in vertical CH_4 flux between transects in the study region. Lowest inferred CH_4 fluxes were estimated along the easternmost transect. Higher inferred CH_4 flux rates were observed in the western transects. Sediment headspace $\delta^{13}C_{CH_4}$ values ranged from −138 to −48‰, suggesting strong differences in shallow sediment CH_4 cycling within and among sample locations. Measured porewater DIC concentrations ranged from 2.53 mM to 79.39 mM with $\delta^{13}C_{DIC}$ values ranging from −36.4‰ to 5.1‰. Higher down-core DIC concentrations were observed to occur with lower $\delta^{13}C$ where an increase in $\delta^{13}C_{CH_4}$ was measured, indicating locations with active anaerobic oxidation of methane. Shallow core CH_4 production was inferred at the two western most transects (i.e. Thetis Island and Halkett) through observations of low $\delta^{13}C_{CH_4}$ coupled with elevated DIC concentrations. At the easternmost Hammerhead transect and offshore locations, $\delta^{13}C_{CH_4}$ and DIC concentrations were not coupled suggesting less rapid methane cycling. Results from the MITAS expedition represent one of the most comprehensive studies of methane source(s) and vertical methane flux in shallow sediments of the U.S. Alaskan Beaufort Shelf to date and show geospatially variable sediment methane flux that is highly influenced by the local geophysical environment.

1. Introduction

Global estimates of total methane (CH_4) content in coastal marine sediment hydrates vary greatly, with the most commonly-cited values ranging from 2600 to 210,000 Gt-C equivalent (Kvenvolden, 1999, 2002; Milkov and Sassen, 2003; Boswell and Collett, 2011). Though the Arctic Ocean is only 1% of the total Earth ocean volume, discrete high porosity and permeable lithologies often saturate coastal ocean and permafrost sediment with gas hydrate (Collett, 2009), making the Arctic Ocean a key region for CH_4-hydrate energy exploration and research on the role of CH_4-hydrate in global climate change. Past studies on climate change in the Arctic tend to

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assume that the land interface is the dominant CH_4 source to the atmosphere (Gorham, 1991; Oechel and Vourlitis, 1994; Frey and Smith, 2005). However, with many coastal regions showing active sediment CH_4 fluxes (i.e. Shakhova et al., 2010), there is a need to evaluate the contribution of Arctic Ocean sediment CH_4 flux to water column carbon cycling and the atmosphere (Isaksen et al., 2011).

Gas hydrate in coastal Arctic oceans occurs primarily in two different geologic settings. Nearshore, gas hydrate is expected to occur at high saturation in sand-rich units as an offshore extension of well-documented terrestrial permafrost-gas hydrate occurrences such as those along the North Slope of Alaska, northern Canada, and Siberia (Collett, 2009). A recent review of multichannel seismic data found the minimum expansion of subsea permafrost does not extend past the 20 m isobath along the Alaskan Shelf, Beaufort Sea (Brothers et al., 2012). Further offshore, gas hydrate exists in deep water settings as a result of higher pressures. In the Arctic Ocean, these conditions extend to somewhat shallower water (~300 m) due to typically lower bottom-water temperature. These deep water hydrates settings impinge on the slope but do not extend onto the shelf. Further evaluation of Arctic Ocean deep sediment hydrate distribution and stability is needed to determine potential changes in ecosystem carbon cycling, relative to tundra extensions of permafrost hydrates to coastal regions, during future warming (Biastoch et al., 2011).

This study presents a spatial overview of variation in the upward vertical CH_4 flux, estimated with a review of sediment CH_4, porewater sulfate (SO_4^{2-}), and dissolved inorganic carbon (DIC) concentrations and stable carbon isotope analyses (Borowski et al., 1996) across the Alaskan Beaufort Sea, during the September 2009 MITAS (Methane in the Arctic Shelf/Slope) expedition, conducted aboard USCGC *Polar Sea* (WAGB-11). At stable gas hydrate pressure-temperature conditions the shallow sediment CH_4 suggests locations with sediment hydrate loadings (Borowski et al., 1996, 1999; Coffin et al., 2006, 2008). Core samples were collected that cross between boundaries from permafrost to deep ocean hydrates (Brothers et al., 2012), and these results show geospatially variable sediment methane flux that is highly influenced by the unique, local geophysical environment. The MITAS expedition was one of the most ambitious and comprehensive research expeditions to date to investigate spatial variation in methane source(s), vertical methane flux in shallow sediments (<10 mbsf), and methane contributions to shallow sediment carbon cycling on the U.S. Alaskan Beaufort Shelf/Slope.

2. Methods

2.1. Study area overview

The Beaufort Sea (Fig. 1) extends to the northeast from Point Barrow, Alaska to Prince Patrick Island, southward toward Banks Island and westward to the Chukchi Sea, covering 476,000 km^2 with an average depth of 1004 m. The average shelf width on the U.S. Alaskan region of the Beaufort Sea is 75 km with a coastal westward current that is bordered by the Beaufort Gyre. This base-geology of the shelf plain is mantled with up to hundreds of meters of unconsolidated clastic materials sourced from the Gubik Formation (Engels et al., 2008). Surficial sediment deposits are highly heterogeneous (Naidu and Mowatt, 1983). Over consolidated silty-clay sediment is abundant through this region (Reimnitz and Barnes, 1974). Sediment characteristic in this region is controlled by dispersal and re-suspension of river-borne sediments, ice-scouring, and coastal erosion and retreat (reviewed in Carmack and MacDonald, 2002; Naidu and Mowatt, 1983). Ice-scouring during the last glaciation was dominated by the northwestern progression of the Laurentide ice sheet (Engels et al., 2008). Modern Holocene sediment supply on the shelf is primarily from the two major river systems, the Mackenzie and Colville Rivers. In the

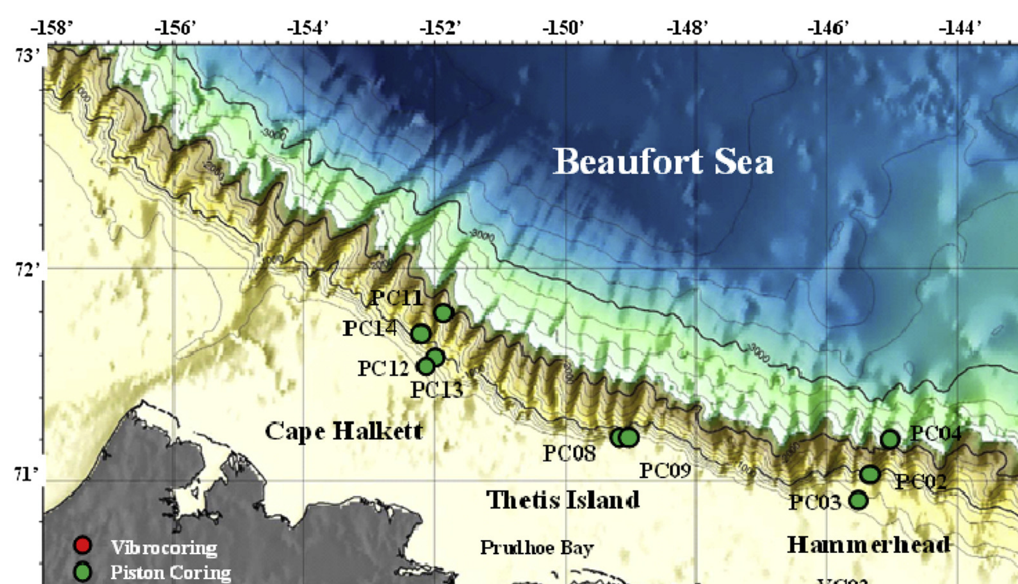

Figure 1. Location of piston core and vibracore sites through Coastal Beaufort Sea in the Arctic Ocean.