Impacts of collapsing permafrost coasts: the fate of carbon, nutrients and sediments in the Arctic nearshore zone

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Abstract

We need to consider permafrost coastal erosion as a major source of sediments, carbon and nutrients in the Arctic Ocean, especially in the nearshore zone. Marine sediments along permafrost coasts are dominated by erosion-derived terrestrial organic matter. A significant increase in matter fluxes would result in drastic impacts on global carbon cycling and related climate feedbacks, on nearshore food webs and on local communities, whose survival still relies on marine biological resources.

Keywords: coastal erosion; lateral material transport; socio-economic impact; biogeochemical cycling; Arctic Ocean; permafrost organic matter; lipid biomarkers

Introduction

Global warming is exposing permafrost along the extensive Arctic coastlines, which account for 34% of the Earth's coasts, to rapid thaw and erosion. Coastal erosion rates as high as 25 m yr^{-1} and the large organic-matter pool frozen in permafrost result in an annual release of 14.0 Tg (10^{12} gram) particulate organic carbon into the nearshore zone. This zone is the primary recipient of increasing fluxes of carbon and nutrients from thawing permafrost. We highlight the crucial role of the nearshore zone in Arctic biogeochemical cycling, as here the fate of the released material is determined to: (1) degrade into greenhouse gases, (2) fuel marine primary production, (3) be buried in nearshore sediments or (4) be transported offshore. With Arctic warming, coastal erosion fluxes have the potential to increase by an order of magnitude until 2100. Such increases would result in drastic impacts on global carbon fluxes and their climate feedbacks, on nearshore food webs and on local communities, whose survival still relies on marine biological resources (Fritz *et al.*, 2017). Determining the potential impacts of increasing erosion on coastal ecosystems is crucial for food security of northern residents living in Arctic coastal communities. Quantifying fluxes of organic carbon and nutrients is required, both in nearshore deposits and in the water column by sediment coring and systematic oceanographic monitoring. Ultimately, this will allow us to assess the transport and degradation pathways of sediment and organic matter derived from erosion.

Material and Methods

We present multi-year dissolved organic matter (DOM) fluxes from coastal erosion into the nearshore zone of the southern Canadian Beaufort Sea (Fig. 1). We further explore removal and degradation patterns of DOM based on oceanographic monitoring of coastal waters. Finally, we present accumulation rates and biogeochemical properties (e.g. carbon, nitrogen, stable isotopes) of marine sediment sequences drilled off the Yukon coast to track the pathways of the eroded material. This also involves ^{14}C radiocarbon dating of bulk carbon and marine macrofossils. It further includes biomarker analyses and carbon budget calculations based on estimating coastal, riverine, and marine endmembers.

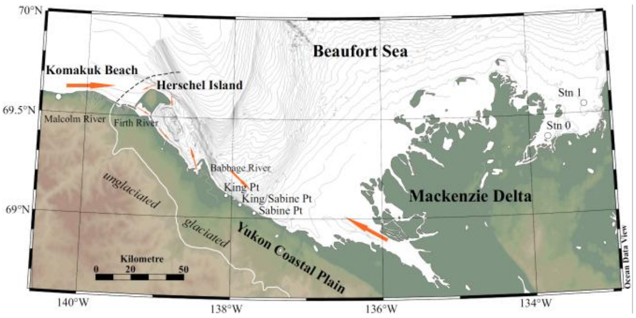

Figure 1. Overview of the study area with major currents and sediment inflows, indicated by orange arrows. The white line indicates the farthest extent of the Wisconsin glaciation.

Results and Discussion

Dissolved organic matter

Low salinity and high DOC concentrations are caused by sea-ice melt, surface runoff and material input from coastal erosion. Salinities remain mostly below 25 and DOC concentrations at or above 200 µmol L^{-1}. Elevated concentrations in the early part of the open-water season indicate the inflow of relatively DOC-rich Mackenzie River water from the east. Turbulent mixing and a stronger oceanic dominance lead to DOC concentrations mostly below 200 µmol L^{-1} in the later part of the season. Fluorescence EEMs and fluorescent components derived from PARAFAC modeling indicate that more than 70 % of the DOM is derived from terrestrial sources. CDOM indices suggest strong degradation of terrestrial DOC proximal to the coast.

Marine sediments from the surface and at depth

Organic carbon in surface sediments from the nearshore zone have been radiocarbon dated. We observe high amounts of "old" organic carbon (between 9 and 14 ka), which is much older than Mackenzie River particulate organic carbon, confirming our hypothesis that the organic carbon is mainly derived from coastal erosion. Bulk ^{14}C ages of a 12.5 m long sediment core from Herschel Basin (Fig. 1) display an overall increase from top to bottom, ranging from 6.7 ka BP to 16.1 ka BP. To distinguish between various sediment sources into Herschel Basin, an endmember model was established (Fig. 2). The model combines our ^{14}C data from marine sediments and terrestrial samples taken from Herschel Island with literature data on suspended matter from the Mackenzie River in combination with peat samples from the Yukon coast. Relative contributions from Herschel Island and the Mackenzie River were also calculated for all samples by defining endmember compositions based on the mean ratio of diploptene versus C29aß and C30aß hopanes (diploptene/(diploptene + C29aß + C30aß)). Biomarker analyses and bulk radiocarbon data show that sediments in Herschel Basin are mainly of terrigenous origin. Approximately 60 % of the organic matter in the surface sediments of Herschel Basin and the adjacent nearshore area can be assigned to eroded material from the coast. This is also based on C/N ratios and δ^{13}C signatures. Sedimentation rates are extremely high with up to 4 mm per year. Based on radiocarbon dates of marine mollusks from the core, which has a length of 12.5 m, covers the last ~5,000 years. Simple sediment budget calculations suggest that Herschel Basin receives about 720,000 metric tons of sediment and about 13,200 tons (13.2 * 10^{9} g) of organic carbon each year.

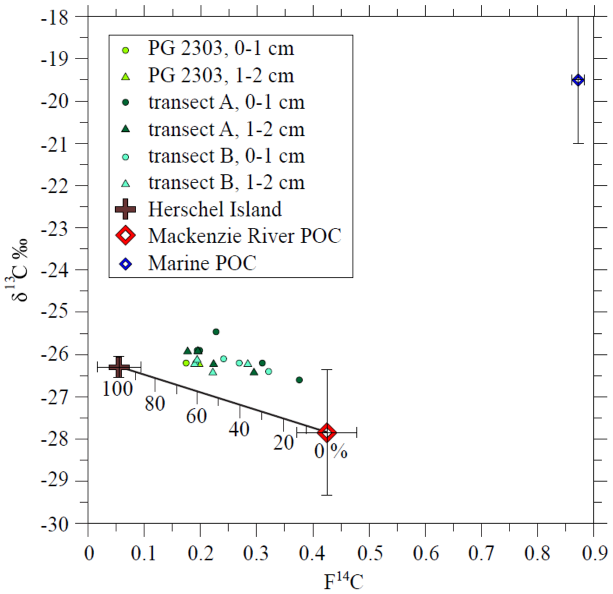

Figure 2. F^{14}C endmember model. The marine POC endmember (blue diamond) and the F^{14}C Mackenzie endmember (red diamond) combine data from the literature (Yunker *et al.*, 1992; Lamb *et al.*, 2006; Guo *et al.*, 2007). F14C endmember results of the surface sediments are based on the linear regression between the F^{14}C Mackenzie and the F^{14}C Herschel Island endmember.

We conclude that: 1) High loads of DOM in the nearshore zone are derived from surface runoff and coastal erosion. Degradation and biogeochemical cycling of DOC is particularly effective proximal to the coast; 2) Coastal erosion releases huge amounts of sediment and organic matter into the nearshore zone. Rapid burial removes large amounts of carbon from the carbon cycle in depositional settings. Flux and burial rates on the Beaufort Sea shelf seem to be significantly underestimated so far.

References

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