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ORIGINAL RESEARCH ARTICLE

Comparison of the burial rate estimation methods of organic and inorganic carbon and quantification of carbon burial in two high Arctic fjords

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Summary Quantifying the burial of organic carbon (OC) and inorganic carbon (IC) species in marine sediments contribute to a better understanding of carbon cycle. This is especially important in the Arctic, where carbon deposition is relatively high and expected to change with climate warming. This study aimed to quantify the burial rates of OC and IC in the sediments of two high-latitude fjords — Hornsund and Kongsfjorden (European Arctic). Comparison of the results from three methods quantifying carbon burial in marine sediments was carried out.

Sediment cores, pore water, and over-bottom water samples were analyzed for OC and IC. The burial rates were established by considering: carbon deposition to sediments minus carbon return flux, carbon deposited to sediments 80—100 years ago and carbon deposited to sediments recently. The radiolead method was employed for sediment dating. Carbon return flux was obtained using dissolved carbon species concentrations in pore water and over-bottom water.

Sediment linear and mass accumulation rates in the fjords were 0.12—0.20 cm y^{-1} and 1160—2330 g m^{-2} y^{-1}. The OC burial rates were 19.3—30.3 g OC m^{-2} y^{-1} in Hornsund and 5.7—10.0 g OC m^{-2} y^{-1} in Kongsfjorden. IC burial was taken as equal to IC deposition and ranged from 10.7 to 20.8 g IC m^{-2} y^{-1} in Hornsund and 19.4—45.7 g IC m^{-2} y^{-1} in Kongsfjorden. The "return flux" model seems most appropriate for carbon burial rate studies. The data demonstrated that OC burial dominates in Hornsund, while in Kongsfjorden, IC burial is more important.

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1. Introduction

Carbon dioxide is a trace component of the atmosphere that has a major role in the greenhouse effect (IPCC, 2013). As carbon dioxide is an important component of carbon cycling, the quantification of sinks, sources, and fluxes that influence its concentration in the atmosphere is important, especially in the context of future CO_2 concentrations in the atmosphere and predictions of future climate.

Marine sediments constitute the most important long-term sink of carbon worldwide, while Arctic sediments preserve much of the deposited carbon (Smith et al., 2015). This is apparently facilitated by large loads of carbon delivered from land (Smeaton et al., 2016) and integrated in a short time period primary production (Stein and Macdonald, 2004), which supports organic carbon (OC) and inorganic carbon (IC) deposition to sediments (Koziorowska et al., 2017). It has recently been postulated that the sediments of the high-latitude fjords serve as a sink of OC to an extent that greatly exceeds the fjords' contribution to the Arctic area (Smith et al., 2015). Moreover, recent reports indicate that high loads of IC (carbon in carbonates) are deposited in fjords sediments (Smeaton et al., 2016), while significant part of the loads can be attributed to biogenic carbonates (Koziorowska et al., 2017).

Both OC and IC species that originate either from primary production or are delivered from land are readily deposited to the bottom sediments (Teske et al., 2011). The former are intensively mineralized in the water column and at the sediment–water interface (Holding et al., 2017; Teske et al., 2011), where the redox conditions determine the efficiency of mineralization and biogenic element exchange between sediments and the overlying water (Ingall et al., 2005; Jorgensen et al., 2005). The load of biogenic carbonates originating from numerous carbonate-secreting organisms, such as coccolithophores, barnacles, echinoids, and bivalves, reaches the sediments and is largely unaffected when buried there (Andruleit et al., 1996; Freiwald, 1998).

Recently, a major effort has been directed toward establishing the rate of OC deposition and its burial in surface sediments (Smeaton et al., 2016; Smith et al., 2015). To calculate OC burial in sediments, most often, the product of the sediment mass accumulation rate (MAR) and the concentration of OC in sediments have been used. OC mineralization in sediments has been either neglected or estimated based on the difference between contemporary and preindustrial OC delivery to surface sediments (Kuliński et al., 2014; Zaborska et al., 2016); in practice, the OC load in a sediment layer deposited 80–100 years ago is taken as equal to the burial rate. The former approach (ignoring mineralization) is valid for short-term carbon preservation in sediments, while the latter is subject to uncertainties caused by the unspecified effects of glacier surges and the primary production changes caused by the recent warming of the Arctic. Due to the global warming, and, in the consequence, substantially increased primary production (Arrigo et al., 2008; Fernandez-Mendez et al., 2015), the surface sediments have been enriched with autochthonous labile OC that is eventually mineralized and/or decomposed, while the dissolved IC (DIC) and dissolved OC (DOC) species resulting from those processes return to the seawater overlying the sediments.

The problem concerning quantifying burial rates in view of the recent increase of OC in marine surface sediments has been resolved by measuring the return flux of OC and IC species from sediments to the overlying seawater (Arndt et al., 2013; Kuliński and Pempkowiak, 2012; Winogradow and Pempkowiak, 2018). The actual burial of carbon is obtained by subtracting the carbon return flux from the carbon deposition to sediments. Burial of carbonates is much easier to quantify, as they do not undergo any microbial processes in the surface sediments. The only way to reduce the concentration of carbonates in sediments would involve a significant pH decrease; pH, although low, is relatively constant in pore waters (Mucci et al., 2000). Despite the straightforward measurement technique, the sedimentary carbonate deposition and burial in sediments of the Arctic fjords have seldom been quantified (Freiwald, 1998; Koziorowska et al., 2017; Smeaton et al., 2016). Thus, the burial of both OC and IC in the fjords' sediments remains to be assessed.

The purpose of this study was to quantify the OC and IC burial rates in the subsurface sediments of the two high-latitude fjords — Hornsund and Kongsfjorden — localized on the western shores of Spitsbergen, the main island of the Svalbard archipelago, European Arctic. OC and IC concentrations were measured in the subsequent layers of sediment cores collected at two sampling stations along each fjord axis, in pore water separated from the surface core layers and seawater overlying sediments. Carbon deposition was equal to the product of the sediment MAR and carbon concentration in sediments. The sediment accumulation rate (SAR) and age of the sediment layers, required for assessing carbon deposition, were obtained using the ^{210}Pb method, which was validated with the distribution of ^{137}Cs. The return fluxes of both DOC and DIC were calculated as diffusion flows from pore water of the uppermost sediment layer to water overlying sediments using Fick's first law of diffusion. The carbon burial rates were calculated based on all three available approaches, as follows: (I) the difference between carbon deposition to sediments and the carbon return flux; (II) carbon deposited to sediments approximately 80–100 years ago, as this is considered enough time for mineralization of the labile OC in sediments (for further calculations, we took samples from about 1930 AD); and (III) carbon deposited to sediments recently.

2. Study area

The study was carried out in Hornsund and Kongsfjorden on the west coast of Spitsbergen. *Hornsund* is the southernmost fjord; it is a medium-sized fjord characterized by a complex coastline including 14 tidewater glaciers entering it directly. The fjord is influenced by two main current systems. The first, the coastal Sørkapp Current, carries less saline and cold Arctic-type waters, while the other, the West Spitsbergen Current (WSC), carries relatively warm and saline Atlantic water (Piechura et al., 2001; Swerpel, 1985). In Hornsund, however, the influence of WSC is less pronounced, due to strong pressure from waters of the Sørkapp Current. The SARs vary significantly, with a decreasing trend toward the mouth of the fjord. In the inner part (Brepollen), the rate is about 0.7 cm y^{-1} (Szczuciński et al., 2006; Zaborska et al., 2016); in the central part, it ranges from 0.2 cm y^{-1} (Pawłowska et al.,