

The Effect of a Temperature Rise on the Sulfate Reducing Rates in Cold Marine Sediments of Kongsfjorden (Svalbard, Arctic Ocean)

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Arctic Ocean is a useful sentinel for understanding the impact of climate change. Dramatic changes are occurring in this region, calling for monitoring of biogeochemical processes. The study site, Kongsfjorden is a unique marine coastal system located at the north-western coast of Spitsbergen island in Svalbard (78°55'N, 11°56'E, Norway). Since 90 per cent of the sea floor has temperatures less than 4°C, low environmental temperatures characterise the habitat of many bacteria living in the marine sediments. Sulfate reduction rates (SRR) in sediments of 4 sites in the Kongsfjorden area have been measured as a function of temperature using the ³⁵S radiotracer method. Experiments conducted with homogenised sediments amended with acetate and/or lactate at two different temperatures (0°C and 4°C) included suitable controls without amendments. SRR increased by almost 45 per cent with a 4°C rise in temperature. This increase in sulfate respiration could imply an increase in the CO₂ flux and subsequently global warming. The rate of carbon mineralised (CM) is proportional to the SRR, which in turn is influenced by salinity variations due to mixing of sea water with the fresh water from melting glaciers. Consequently, with a rise in temperature, the SRR actually tends to decrease with lowered salinities due to ice melting, thus offsetting the increase in CO₂ flux that could have occurred due to the warming effect. This work is a part of the 3rd Indian Arctic Expedition to Svalbard from 14 June to 18 July 2009.

Keywords: Kongsfjorden, lactate, organic carbon, polymers, salinity

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INTRODUCTION

Rising global temperatures are likely to increase the rate of organic matter decomposition resulting in substantial CO₂ release. The marine carbon cycle in Arctic regions currently occupies a prominent role in the study of climate warming effects as there is evidence from observational and modelling studies for strong seasonal temperature increases in northern high-latitude environments (Serreze *et al.* 2000). Further, biogeochemical processes react very sensitively to temperature changes (Denman *et al.* 2007; Anisimov *et al.* 2007). Since more than 90 per cent of the global sea floor is cold at 4°C (Levitus and Boyer 1994), sulfate reducers must be able to metabolise and grow at such low ambient temperatures.

Dissimilatory sulfate reduction is the most important bacterial process in anoxic marine sediments, accounting for up to half of the total organic carbon (TOC) remineralised (Canfield *et al.* 1993; Jorgensen 1982; Nedwell *et al.* 1993). Sulfate reduction rates (SRR) in polar sediments may be similar to those of temperate environments (Jorgensen *et al.* 1990; Nedwell *et al.* 1993; Sagemann *et al.* 1998; Thamdrup *et al.* 1994). Numerous factors have been shown to influence rates of bacterial sulfate reduction which include temperature, salinity, concentration of dissolved sulfate and quality and quantity of organic matter available for decomposition (Goldhaber and Kaplan 1975; Jorgensen 1983).

Kongsfjorden is a unique marine coastal system in the northwest coast of Svalbard, with a length of about 26 km surrounded by mountains and glaciers. Kongsfjorden itself consists of several zones from calving glacier fronts to rocky shores and soft bottom, caused by strong deposition of sediments from glaciers. Rivers and glaciers discharge high amounts of sediments and fresh water loaded with fine sediments resulting in high water turbidity and salinity stratification of the water body during the summer months (Hanelt *et al.* 2004). The inner fjord is generally free of ice cover during summer due to the mild climate influenced by the west Spitsbergen current. Thin pack ice is shifted out of the fjord by wind and the fjord surface maintains open water characteristics throughout the winter. The annual mean water temperature is generally slightly above 0°C (Ito and Kudoh 1997), which supports the abundance of psychrophilic bacteria. Among the most important is the capacity of these cold-adapted bacteria to catalyse biogeochemical processes at low temperatures (Feller and Gerday, 2003; Hoyoux *et al.* 2004).

In the present study, we therefore address the question whether an increase in temperature by 4°C has an impact on sulfate reduction (a dominant process in marine sediments) in cold sediments of Kongsfjord in Svalbard. We have also evaluated the substrate utilisation and the importance of salinity variations on the SRR with temperature increase and in turn the CM.

MATERIALS AND METHODS

Site Description

Kongsfjorden is a glacial fjord in the Svalbard, Arctic, about 40 km long and 5 to 10 km wide in the northwest coast of Spitsbergen. The main island of Svalbard, it is a site where the warmer waters of the Atlantic meet the colder waters of the Arctic. The melt water during summer not only stratifies the upper water column but significantly alters the turbidity. The locations of the 4 sampling sites are depicted in Figure 1.

Sediment samples were collected on the 4 July 2009 from Kongsfjorden, Svalbard, Arctic Ocean (Station 1; 79°02.126' N, 11°17.014' E), (Station 2; 79°0.594' N, 11°25.471' E), (Station 3; 78°57.216' N, 12°10.527' E) and (Station 4; 78°58.530' N, 11°41.487' E). Station 2 and 3 lie in the vicinity of glacier water inflow, while at Station 1 mixing of warm Atlantic water takes place with Arctic cold waters. The sediment temperature was on an average 0°C, while the surface water temperature was ca. 5°C. Sediment samples, collected with a grab from various depths (Table 1) were sub sampled and kept at in-situ temperature during transport. The pH was measured immediately, (Thermo Orion model 420A, USA) as per the standard



Fig 1. Study area showing sampling sites at Kongsfjord, Arctic Ocean during summer 2009.

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Table 1. Parameters of the four sampling sites of Kongsfjorden

Kongsfjorden		Depth in (m)	TOC (%)	SRR (nMg ⁻¹ d ⁻¹)		% variation in carbon mineralisation
				At 0 °C	At 4 °C	
S1	Outer zone	340	1.28	3.69	6.12	+39.76
S2	Middle zone	235	1.04	4.07	3.10	-31.07
S4	Transition zone	75	0.45	1.54	3.29	+20.33
S3	Inner zone	29	0.21	1.38	1.73	+53.19

Note: TOC - Total organic carbon; SRR - sulphate reduction rates; CM - carbon mineralisation

procedure. TOC was estimated by titrimetry with a precision of 0.01 per cent (Allen *et al.*, 1976) that involves complete wet oxidation of organic matter in the sample with chromic acid. The TOC was expressed as a percentage. Glucose was used as the standard.

Pore water analysis

Sediment was centrifuged at 5000 rpm for 10 minutes. The supernatant- pore water was collected with a 5 ml syringe and salinity was measured using a hand refractrometer (S/MILLE, ATAGO, Co. Ltd, Japan).

Sulfate reduction rates

SRR was measured using King's assay (King GM, 2001). Sodium sulfate 10 µl (74KBq) from Sigma Aldrich (USA) was injected into the section to distribute the label evenly, incubated at 5°C and the activity was arrested at the end of 10 hours by adding 5 ml (5 per cent wt/vol) zinc acetate and frozen at -20°C till the analysis. Radiotracer assay of the sediment was carried out using single step chromium reduction assay (King GM, 2001) using Packard 1600 CA Tri Carb (USA) liquid scintillation counter.

SRR were calculated using the equation:

$$SRR = (H_2^{35}S/^{35}SO_4^{2-}) \times ^{32}SO_4^{2-} \times IDF/T$$

$H_2^{35}S$ = radioactivity of reduced sulfur (DPM),

$^{35}SO_4^{2-}$ = radioactivity of sulfate at the beginning of incubation,

$^{32}SO_4^{2-}$ = Pore water sulfate concentration ($\mu M SO_4^{2-} cm^{-3}$),

Where IDF (isotopic discrimination factor) = 1.06,

T = time of incubation in hours.

SRR was expressed as nM.g⁻¹.d⁻¹.

Effect of carbon source and temperature on SRR: slurry experiment

Sediment samples for the preparation of slurries were collected. Aliquots were prepared by taking approximately 2 g of sediment slurry into 5 mL vials. These samples (in triplicates) were then amended separately with lactate (5mM), acetate (5mM) and a combination of lactate and acetate to a final concentration of 5mM. Incubation was carried out in two separate sets at 0°C and 4°C, respectively. All the vials were flushed with oxygen free nitrogen gas. The resulting slurry samples were acclimatised for 10 minutes and supplemented with 10 µL sodium sulfate (74KBq) and incubated at room temperature for 10 hours. Samples were fixed and analysed by the radiotracer using single step chromium reduction King's assay (2001) as described previously.

Results

The TOC content in the sediments showed an increasing trend from the inner zone (0.21 per cent) to the outer zone (1.28 per cent) at a depth of 75 m and 340 m, respectively—the highest amount of organic carbon being in the outer zone (Table 1). SRR generally increased with an increase in the TOC at S1, S3 and S4.

Similarly the SRR increased by 45 per cent with a 4°C rise in temperature. The percentage increase in the CM was calculated and found to increase with a 4°C rise in temperature. However, there was a substantial decrease in the CM in the middle zone S2 of the Kongsfjorden. Addition of substrates to the slurries resulted in a marked increase in the SRR at 4°C than at 0°C. Lactate when supplemented as a sole carbon source was more preferred as compared to acetate at station S1, S2 and S3. Acetate was the most preferred at station S4. However when both substrates were supplemented together, the SRR was lower than the control at 0°C (Figure 2). At 4°C, the SRR were almost two times higher than the values at 0°C when supplemented with carbon substrates. Lactate was preferred to acetate at 4°C. A combination of

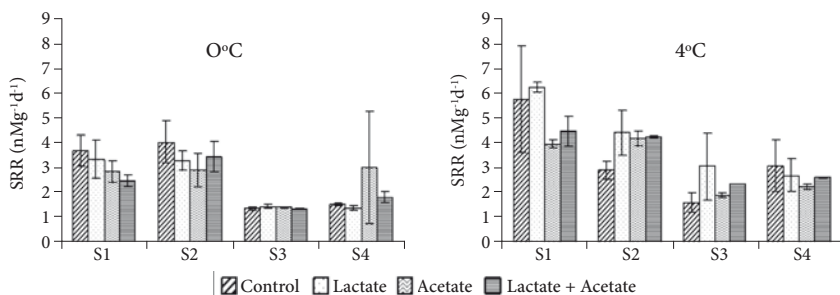


Fig 2. Sulfate reducing rates (SRR) at 0°C and 4°C

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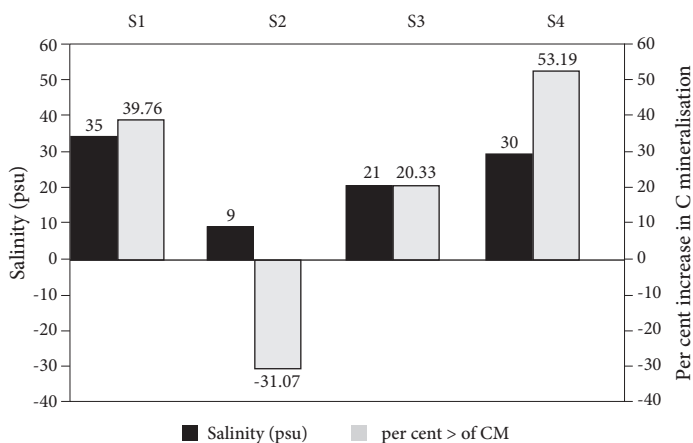


Fig 3. Percentage increase in carbon mineralisation (CM) with respect to salinity at four locations in Kongsfjorden.

lactate and acetate amended, elicited lower SRR in most of the stations.

Figure 3 shows the effect of salinity on the SRR and in turn on the CM rates. CM was calculated as increased rates subsequent to a 4°C rise in temperature which is expressed as per cent increase of the value at 0°C. The increase in CM rates through SRR at 30 psu was 53 per cent at station S4. It was observed that with a decrease in salinity, the rate of CM decreased and was negative at station S2 which coincided with the minimum salinity recorded.

DISCUSSION

Coastal and estuarine sediments are important sites for the mineralisation of biomass produced in the photic zone (Jorgensen, 1983). Anaerobic sulfate reduction is an important process in the degradation of organic matter in these sediments. SRA in marine ecosystems, especially the coastal regions contributes as much as 50 per cent organic carbon turnover (Jorgensen, 1982). Organic carbon levels also influence SRR which is an important reaction for the production of reactive byproducts and the regeneration of nutrients. Naturally occurring organic polymers are stated to have vastly different susceptibilities to bacterial attack. In the present study we have used two volatile fatty acids viz. acetate and lactate which are the normally preferred substrates by sulphate reducing bacteria (SRB) in marine

sediments. It is widely accepted that acetate is one of the important substrates for sulfate reduction in Smeerenburgfjorden, Svalbard sediments (Finke *et al.* 2007) and intertidal sediments (Taylor and Parks, 1985) accounting for 70 per cent of the total sulfate reduced in marine sediments and lactate is a widely utilised substrate by most SRB (Kerkar and Bharathi, 2007), hence chosen for the present study. We have observed that although a range of different substrates are used by SRB, the individual substrates utilised in different environments and SRB populations vary as seen in the above four stations which are located in Kongsfjorden within an approximately 26 km length. Kongsfjorden is a fjord with several zones from calving glaciers to rocky shores and soft bottom habitats. We suggest that the susceptibility of organic substrates to metabolic attack exerts an important control on the temperature dependence of sulfate reduction. Thus seasonal variations need to be considered in quantifying annual rates of sulfate reduction in these polar regions. From our observations, we infer that deeper sediments have smaller thermal fluctuations than the surface sediments. However depth may also be an important factor influencing SRR. The SRR in the Kongsfjorden at 0°C were in the range of 1.73 to 6.12 nM.g⁻¹.d⁻¹ which are much lower than the rates observed in the Smeerenburgfjorden in Svalbard which varied from 48 to 70 nM.cm⁻³.d⁻¹ where incubation temperatures have not been mentioned. Interestingly SRR in the Kongsfjorden increased by 45 per cent with a 4°C rise in temperature. Relatively higher activities in SRR were observed with higher TOC and increasing salinities. Jorgensen (1977) has stated that on an average 2 moles of organic carbon (C) are oxidised for every mole of sulphate reduced. Redfield's stoichiometry for organic matter oxidation by sulphate reduction C_{org}: SO₄⁻² = 2.1 (Volkov *et al.* 1998). Thus SRB contribute to the CO₂ flux. Based on this relationship, the annual CM rate estimated by SRR in sediments ranged from 3.46 to 12.2 g. C d⁻¹ which amounts to a 20.3 to 53.19 per cent increase in the CM. When the salinity decreases to 9 psu, due to the melting glaciers at S2, the per cent CM was below the value at 0 degrees by 31 per cent. This change could be attributed to the decrease in salinity having a negative impact on the SRR and thus the CM. Consequently, a temperature rise would mean that the SRB would contribute to an increase in CO₂ flux and thus contribute to global warming. However, due to mixing of sea water with fresh water by ice and glaciers melting, the SRR decreases neutralising the above effect.

CONCLUSION

The present work suggests that the temperature dependence of sulfate reduction may have predictable substrate dependence. Salinity variations also play an important role in the SRR and in turn the CM. However there is a need to determine the

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seasonally averaged rates of sulfate reduction in these polar marine environments with reference to the variations in temperature, salinity and organic matter.

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