2.8 Arctic Geomicrobiology and Climate Change (Arctic Geomicrobiology)

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**ABSTRACT**

Anthropocene is a time of extraordinary change in the Arctic. It has experienced unprecedented variability in both the rates and magnitudes of change in the cryosphere, atmosphere and lithosphere, dependent ecosystem function variability, increased industrial development, and concomitant globalization of local economies. These changes are challenging our ability to respond and to develop a coordinated and scientifically informed policy for the Arctic. The objectives of this project are aligned with the targeted achievements of the Canada Excellence Research Chair on “Arctic Geomicrobiology and Climate Change” to increase understanding on geomicrobial transformations as they occur in Arctic sea ice and sediments, including the regeneration of nutrients required by primary producers and thus the health of all other inhabitants of the Arctic marine system. The project will address 4 key research questions and 2 objectives: (1) What are the relative contributions of dynamic and thermodynamic forcing to the observed change in sea ice areal extent and thickness and how is this related to intra- and extra-Arctic climate processes, variability, and change? (2) What are the consequences of change in Question 1 on biogeochemical cycling, including carbon, nitrogen, sulphur, phosphorous, oxygen, and their stable isotopes? (3) What are the consequences of changes in Questions 1 and 2 on ecosystem function, examined throughout the complete trophic structure: beginning with microbial processes, primary and secondary production, through to apex predators; and on habitat structure: benthic, pelagic, epontic, and within the ocean–sea-ice–atmosphere (OSA) interface? (4) What are the consequences of change on release, transport, and biological impact of chemical contaminants, including both organic and inorganic contaminants, across Arctic biotic and abiotic environmental interfaces? Objective 1: To produce models of coupled physical-biological processes examined in Questions 1 through 4 as a means of making the project science predictive and able to inform future environmental conditions. Objective 2: To provide and communicate a knowledge base upon which public policy development can build to address the key issues facing the Canadian Arctic (e.g., sustainable development, globalization, socioeconomic stability, and environmental stewardship). Recent evidence suggests that microbial activity and chemical transformations within sea ice greatly influence inorganic carbonate chemistry, playing a far more important role in regulating carbon dioxide (CO₂) uptake by Arctic seas than previously anticipated. The objective of the program is to investigate and quantify the importance of these fundamental microbial activities using state-of-the-art assessment techniques in a comprehensive three-pronged approach of ice tank, in situ, and modelling studies. Combining experimental ice tank and in situ studies will provide important new insight into the regulation of these processes, their seasonal and geographical distribution, and how they are coupled between surface ocean and seafloor. Modelling activities will range from small-scale studies within the sea ice and sediment compartments to local coastal regions of strategic importance and the large-scale systems of the Arctic Ocean and neighbouring seas.

**KEY MESSAGES**

- Oxygen consumption in Canadian sediments was high and compared with sediments in Greenland and temperate locations.
- Oxygen penetration depths ranged from 0.8 to 2.3 cm at the investigated sites indicating well oxidized sediment conditions.
- Fresh organic matter caused high microbial activity in the surface sediment of most stations visited suggesting that summer primary production maintain a signal in the sediments all way through autumn.

**OBJECTIVES**

The objective of the Canada Excellence Research Chair (CERC) program is to investigate and quantify the importance of the fundamental microbial activities using...
state-of-the-art assessment techniques in a comprehensive three-pronged approach of ice tank, in situ, and modeling studies. Combining experimental ice tank and in situ studies will provide important new insight into the regulation of these processes, their seasonal and geographical distribution, and how they are coupled between surface ocean and seafloor.

The aim of this subcomponent of the CERC program is to understand:

- The importance of sea ice presence and timing on benthic processes.
- Benthic microbial aerobic and anaerobic degradation, including bacterial denitrification and anammox in arctic sediments.
- The control of sediment-water exchange rates of gases and nutrients.

INTRODUCTION

An important nutrient source for primary producers is provided by microbial degradation of dead organic matter. In general, a large fraction of the primary production in shelf areas is deposited on the sea floor, where various microbes and pathways degrade it. In addition, terrigenous organic material in coastal regions of the Arctic account for a substantial input to the sediments (Goñi et al. 2005, Rysgaard and Sejr 2007). At the sediment surface, degradation of organic matter is aerobic, through the activity of benthic microbes and animals. These organisms constitute an oxygen-consuming detritus-based food chain through which organic compounds are degraded to CO$_2$, NH$_4^+$, and PO$_4^{3-}$. Thus, in shelf areas, the oxidized zone is restricted to a thin surface layer, below which further degradation takes place anaerobically. Sedimenting organic material may be transported to deeper anoxic sediment layers through the activity of benthic animals or buried by deposition of fresh sediment. Further degradation of organic matter releases organic molecules, which serve as substrate for other microbes that carry out denitrification, anamnmox, iron and manganese reduction, sulphate reduction, and methane production. Through these processes, organic molecules are likewise metabolized to CO$_2$, NH$_4^+$, and PO$_4^{3-}$ in the anoxic sediment layer. In addition, anaerobic degradation results in the formation of N$_2$, Mn$^{2+}$, Fe$^{2+}$, HS$^-$, and CH$_4$. These accumulate in the pore water and may subsequently diffuse upwards to the oxic surface layer and, except for N$_2$, undergo oxidation. Furthermore, NH$_4^+$ may be oxidized to NO$_3^-$ in the oxic zones by nitrifying bacteria. The nitrogen gases N$_2$O and NO are also produced as intermediates through denitrification or nitrification and although they are typically minor products, they are of interest as possible sources of atmospheric greenhouse gases. As a result of these benthic degradation processes, the products from both aerobic and anaerobic degradation will be released to the overlying water and re-assimilated by primary producers, thereby completing the nutrient cycle.

ACTIVITIES

The upper sediment layers were used to describe present-day carbon and nutrient cycling in Canadian Arctic sediments during the leg3b expedition of the Amundsen 4-29 October 2011. Rate measurements covered oxygen respiration, denitrification, and carbon mineralization as well as fluxes of nutrients across the sediment-water interface. Furthermore, sampling in the upper sediment layers for identification and activity measurements of benthic foraminifera was made on various stations. In addition, the depth distribution of O$_2$, organic carbon and nitrogen, chlorophyll as well as 13C and 15N in the sediment will form basis for interpretation and modeling biogeochemical transformations in the sediment (Rysgaard et al. 1998, Berg et al. 1998, Berg et al. 2003).

Material for completion of six tasks was collected during the cruise:

- Investigation of the sediment-water exchange rates.
b. Investigation of the vertical distribution of the oxygen in the sediment.

c. Investigation of nitrification and denitrification.

d. Investigation of nitrate accumulation and nitrate respiration in Arctic foraminifers.

e. Investigation of temperature adaptation of aerobic Arctic bacteria.

f. Assessment of the microbial community structure in Arctic sediments.

a) Exchange rates of O₂ and nutrients between the water column and sediment were measured in 6 intact cores (subsamples within a box corer) from each station. The sediment height was adjusted to a sediment and water column of c. 12 and c. 20 cm, respectively. The water column was continuously stirred during the flux rate experiments. Blank cores containing only bottom water were incubated in parallel to the sediment cores to correct for water column activity. All cores were incubated in darkness at 0-2°C. Flux measurements were initiated by sealing the cores with rubber stoppers and incubated as described by Risgaard-Petersen and Rysgaard (1995). Initial samples were collected from the tank immediately after sealing of the cores and from individual cores after incubation of 0.5 to 1 d. During incubation, O₂ concentrations in the water column did not decrease by more than 25%. The water samples were analyzed for O₂ concentration by Winkler titration within 12 h of sampling. Water samples for nutrients were frozen for later analysis.

b) Oxygen conditions. At each station, 6–10 vertical O₂ concentration profiles were measured at a resolution of 200–500 μm using a Clark-type O₂ micro-electrode (Revsbech 1989). The microsensors had a measuring tip diameter of 10–20 μm and a low stirring sensitivity of 1–2%. The sensors were positioned by a motor-driven micromanipulator, and the sensor current was measured with a pico-ammeter connected to an A/D converter, which transferred the signal to a computer. Measurements were performed in three selected cores, which were kept in darkness at in situ temperature while the overlying water column of 2 cm was aerated by a flow of atmospheric air to ensure sufficient stirring and fully airsaturated water.

c) The rate of nitrification and denitrification was determined using the isotope pairing technique as described by Rysgaard et al. (2004). In short, 15NO₃⁻ was added to the overlying water (50 μM final concentration) to initiate incubation and cores were closed leaving no head space. In all, six sediment cores were processed during the 0.5 to 1 d. incubation period. After incubation, subsamples of the water column and sediment were collected for analysis of the 15N-labelling of N₂ and NO₃⁻. The samples for 15N-abundance in the NO₃⁻ were frozen (-18°C) until further analysis, and samples for 15N-N₂ analysis were preserved in glass vials containing 2% (vol.) of a ZnCl₂ solution (50% w/v). The abundance and concentration of 14N15N and 15N15N will be analyzed by mass spectrometry upon arrival to the GCRC laboratory in Greenland.

d) We have recently discovered that some foraminifers, with preference for anoxic environments accumulate nitrate intracellular, which is subsequently respired to dinitrogen gas (Risgaard-Petersen et al. 2006, Piña-Ochoa et al. 2010). During the cruise we collected foraminifers and transferred individuals to PCR-tubes. The foraminifers will be analysed for presence of intracellular NO₃⁻ as described in Risgaard-Petersen et al. (2006) on return to the laboratory. On board the ability to respire with NO₃⁻ was tested using 15N isotopes and micro sensors (Risgaard-Petersen et al. 2006).

e) Bacterial oxygen consumption in intact sediments has been measured using O₂ microsensors on several stations. In addition material for determination of organic carbon in these sediments has been collected. The relationship between organic carbon and bacterial respiration will be compared with data derived from Greenland arctic marine sediments as well as with temperate marine sediments. Depending on the outcome further studies focusing specifically on temperature regulation of bacterial activity will be performed in the laboratory.
f) Sediment samples from the leg3b to the Canadian Arctic have been collected for microbiology and microbial diversity studies. This work will be approached in an interdisciplinary way, through both enrichment culturing by inoculating sediments (stored at 4°C after sampling) into defined microbial growth media, and also through molecular biological approaches (eg, high throughput sequencing, quantitative PCR, etc.) that will be applied to sediments from the same locations that are frozen immediately after collection. The microbial community structure in Arctic sediments will be assessed both by looking at the dominant taxa and specific low abundance taxa. Dominant taxa will be identified and considered in light of major biogeochemical processes occurring in sediments (e.g., oxygen respiration, fermentation, nitrate reduction and sulfate reduction) in order to reveal insight into benthic ecosystem functioning. Rare taxa of interest include thermophilic Fimicutes that have been detected in other Arctic sediments (e.g., Svalbard fjords) and that may be useful indicator organisms for understanding the biogeography of marine microorganisms and how cell dispersal mechanisms operate in the Arctic seas.

RESULTS

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DISCUSSION

Analysis of samples is still in progress, but data on sediment-water fluxes of O2 at various stations were completed onboard. In addition, the vertical O2 concentration profiles as measured by microsensor techniques as well as model calculations of the vertical distribution of the O2 consumption in the sediment were accomplished during the leg.

Sediment-water fluxes at the investigated stations ranged from 3.7 to 9.5 mmol O2 m-2 d-1 and are comparable with sediment activities at other high-arctic Greenlandic sites, Table 1 (Rysgaard et al. 2004). Oxygen penetration depths ranged from 0.8 to 2.3 cm at the investigated sites, and little variation was observed between the 6-10 profiles measured at each site. Oxygen consumption as a function of sediment depth was calculated using the numerical procedure for interpretation of O2 concentration profiles described by Berg et al. (1998). The diffusive O2 uptake calculated from the mean profiles ranged from 2.1 mmol O2 m-2 d-1 to 6.2 mmol O2 m-2 d-1. At stations 314, 312, 308, and 304, the highest O2 consumption was observed near the sediment–water interface due to recent inputs of fresh organic material. At stations 301, 323, 115, a high O2 consumption was observed deeper in the oxic zone, presumably due to the reoxidation of reduced products being transported upward to the oxic zone from deeper sediment layers. The ratio between total O2 uptake and diffusive O2 uptake ranged from 1.3 to 4.4 at the investigated sites. The difference between total and diffusive O2 uptake rates has previously been used as a measure of the benthos-mediated solute exchange (Archer and Devol 1992, Rysgaard et al. 2004). The difference found in the present study was most likely related to the density of benthos in the different sediments studied and our results will be compared with the data from the benthos teams working at the same leg and stations.

ACKNOWLEDGEMENTS

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REFERENCES


2011-12 PUBLICATIONS

All ArcticNet refereed publications are available on the ASTIS website (http://www.aina.ucalgary.ca/arcticnet).