

Nitrate production beneath a High Arctic glacier, Svalbard

P.M. Wynn ^{a,*}, A.J. Hodson ^a, T.H.E. Heaton ^b, S.R. Chenery ^b

^a *Department of Geography, University of Sheffield, Winter St., Sheffield S10 2TN, UK*

^b *British Geological Survey, Keyworth, Nottingham NG12 5GG, UK*

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Abstract

Natural environmental isotopes of nitrate and ammonium are used in conjunction with major ion chemistry and hydrological data to establish controls upon the biogeochemical cycling of nitrogen beneath a High Arctic polythermal glacier (Midtre Lovénbreen). Here, high nitrate concentrations in subglacial meltwaters suggest that the subglacial environment may be furnishing nitrate in excess of that released from the snowpack and glacier ice. Isotopic values of $\delta^{18}\text{O}_{\text{NO}_3}$ suggest the provenance of such excess nitrate to be microbial in origin and $\delta^{15}\text{N}_{\text{NO}_3}$ indicates the source nitrogen compounds to have high $\delta^{15}\text{N}$ values relative to supraglacial runoff. We address the nitrification of supraglacial ammonium, the mineralization of organic nitrogen and the oxidation of geologic ammonium as potential sources of this additional nitrate. Mass fluxes of N compounds in a subglacial river and their $\delta^{15}\text{N}$ ratios indicate that the nitrification of supraglacial ammonium delivered to the glacier bed can account for much, but not all, of the excess nitrate. The additional source most likely involves the mineralization of organic nitrogen, although $\delta^{15}\text{N}$ values in rock samples suggest that the dissolution of rock-derived ammonium cannot be discounted if large fractionation effects occur during dissolution. Our results therefore agree with previous catchment scale mass balance studies at the site, which report a major internal loss of NH_4^+ from the snowpack following melt. However, at the catchment scale, the NH_4^+ loss is greater than the excess of NO_3^- observed in runoff, indicating that microbial assimilation of ammonia into organic matter in a range of other habitats is also likely. The identification of NH_4^+ assimilation and nitrification further highlights the non-conservative behaviour of nitrogen in glacial environments and testifies to the importance of microbially-mediated reactions in the biogeochemical cycling of nitrogen in an environment that has, until recently, been regarded as biologically inert.

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1. Introduction

Solute acquisition by glacial meltwaters takes place at the bed of glaciers during transit through distributed and channelised drainage systems (eg. Raiswell, 1984;

Tranter et al., 1993, 1996, 1997). The distributed system pertains to hydrological flowpaths conveying water under high pressure with long residence times and high rock/water contact ratios. Channelised drainage networks however follow discrete flowpaths, represent low pressure hydrological systems and evacuate large volumes of water rapidly from beneath the glacier. The spatial and temporal evolution between the two systems depends upon the flux of meltwater to the glacier bed, whereby high inputs of supraglacial meltwater raise the

* Corresponding author. School of Geography, Earth and Environmental Sciences, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK. Tel.: +44 121 414 5544; fax: +44 121 414 5528.

E-mail address: p.m.wynn@bham.ac.uk (P.M. Wynn).

basal water pressure and encourage a spatial re-organisation of the drainage system such that the channelised system evolves at the expense of the distributed configuration (e.g. Richards et al., 1996; Nienow et al., 1998). Such hydrological forcing of subglacial drainage evolution at predominantly cold, polythermal glaciers can be rapid and closely coupled to the dynamics of glacier movement (Copland et al., 2003; Nutall and Hodgkins, 2005; Rippin et al., 2005; Bingham et al., 2006). A concomitant change in the hydrochemistry of subglacial runoff accompanies this transition and can be manifest as a rapid switch in the chemical properties of the melt water (Copland et al., 2003; Wynn et al., 2006). Due to extensive rock/water contact and weathering reactions, high pressure distributed drainage configurations encourage high total dissolved ion loads and low concentrations of atmospheric gases in solution. However, during the hydrological evolution of the subglacial drainage system, the development of channelised flow paths conveying large volumes of meltwater subjected to only limited rock/water contact means that waters are more dilute and dissolved gases in solution exceed the capacity of oxygen consuming reactions at the glacier bed (e.g. Tranter et al., 2002). However, since the presence of microbiological activity within ice and subglacial sediments is now widely acknowledged (Sharp et al., 1999; Skidmore et al., 2000; Welker et al., 2002; Tranter et al., 2005; Foght et al., 2004; Mader et al., 2006; Bhatia et al., 2006), researchers are increasingly aware that acquisition of solute in sediments at distance from such channels may be effectively decoupled from inorganic controls of gas supply and rock/water contact ratios. Atmospheric gas supplies thus become depleted in the distributed drainage system, and so the use of alternative oxidising agents by microbial populations is required to drive further solute acquisition under anoxic conditions (Bottrell and Tranter, 2002; Wadham et al., 2004; Wynn et al., 2006). Despite this increased understanding, the degree to which such biotic solute acquisition is governed by the evolution of the subglacial hydrological system remains largely unknown (Tranter et al., 2005; Wynn et al., 2006; Hodson et al., in press).

The NO_3^- ion represents one of the more readily available electron donors under reducing conditions, and so should be highly sensitive to the redox evolution of the subglacial hydrological system (Tranter et al., 1994; Wynn et al., 2006; Hodson et al., in press). Thus, during the early stages of summer ablation, subglacial meltwater in the distributed drainage configuration includes pockets of local anoxia that are characterised by nitrogen isotopic values that are diagnostic of microbial

denitrification (Wynn et al., 2006). However, later in the summer, when most meltwaters are conveyed through the aerated low pressure channelised system, concentrations of nitrate and $\text{NO}_3^-/\text{Cl}^-$ ratios in the subglacial meltwaters increase significantly, implying the presence of an additional source of nitrate to the subglacial drainage system. Hodson et al. (2005a) and Hodson (2006), show that some form of NO_3^- production must take place, because annual NO_3^- yields exceed inputs in a number of glacial environments, (including Midtre Lovénbreen). Such “excess NO_3^- ” is also implicit in meltwater hydrochemical studies of temperate glacier basins in the European Alps (Tockner et al., 2002) and cold-based glaciers of the maritime Antarctic (Caulkett and Ellis-Evans, 1997; Hodson, 2006) although its precise source has yet to be identified.

An appreciation of the manner in which glaciers regulate the biogeochemical cycling of nutrients and thereby impact upon the productivity of neighbouring freshwater and marine ecosystems demands a better understanding of the non-conservative behaviour of nitrogen and other nutrients in glacial environments on a sub-annual basis. Here, we build upon earlier annual mass balance studies of nitrogen and trace the provenance and dynamics of ‘excess’ NO_3^- production in the subglacial environment of a high Arctic glacier at a seasonal time scale. In so doing, major ion chemistry (NO_3^- , NH_4^+ and Cl^-) and environmental isotopes of $\delta^{15}\text{N}_{\text{NO}_3}$, $\delta^{18}\text{O}_{\text{NO}_3}$ and $\delta^{15}\text{N}_{\text{NH}_4}$ in pre-melt snow, meltwater, organic matter and whole rock samples are presented from Midtre Lovénbreen, Svalbard.

2. Methodology

2.1. Field site and sampling

Midtre Lovénbreen is a high Arctic polythermal glacier situated on the Brøggerhalvøya peninsula in North West Spitsbergen (78.53° N and 12.04° E). The geology of the peninsula includes basement rocks belonging to the Lower, Middle and Upper Proterozoic that are situated beneath the glacier and predominantly composed of phyllites and beds of quartzite (Hjelle, 1993). To the south of the phyllites are more strongly metamorphosed rocks that include mica schists and beds of marble beneath the accumulation area of the glacier (Hjelle, 1993).

The glacier is up to 180 m thick and two thirds of the ice is at the pressure melting point, thereby supporting an extensive subglacial drainage system (Rippin et al., 2003). Bulk meltwater runoff is conveyed towards the adjacent fjord of Kongsfjorden via two main proglacial

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