



Research papers

Hydrologic exchange and chemical weathering in a proglacial watershed near Kangerlussuaq, west Greenland



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ABSTRACT

The exchange of proglacial river water with active layer pore water could alter water chemical compositions in glacial outwash plains and oceanic solute fluxes. To evaluate effects of this exchange, we sampled Watson River and adjacent pore water during the 2013 melt season at two sandurs in western Greenland; one in Sandflugtdalen and the other near the confluence with Søndre Strømfjord. We measured temperature, specific conductivity, and head gradients between the river and bank over a week-long period at Sandflugtdalen, as well as sediment hydraulic conductivity and chemical compositions of waters from both sites. Specific conductivity of pore water is four to ten times greater than river water as solutes are concentrated from weathering reactions, cryoconcentration, and evaporation. Pore water compositions are predominantly altered by carbonate dissolution and sulfide mineral oxidation. High concentrations of HCO_3^- and SO_4^{2-} result from solute recycling and dissolution of secondary Ca-Mg carbonate/sulfate salts initially formed by near-surface evaporation in the summer and at depth by freeze-in of the active layer and cryoconcentration in the winter. High hydraulic conductivity (10^{-5} to 10^{-4} m/s) and diurnal fluctuations of river stage during our study caused exchange of river and pore water immediately adjacent to the river channel, with a net loss of river water to the bank. Pore water >6 m from the river continuously flowed away from the river. Approximately 1–8% of the river discharge through the Sandflugtdalen was lost to the river bank during our 6.75 day study based on calculations using Darcy's Law. Although not sampled, some of this water should discharge to the river during low river stage early and late in the melt season. Elevated pore water solute concentrations in sandurs and water exchange at diurnal and seasonal frequency should impact fluxes of solutes to the ocean, although understanding the magnitude of this effect will require long-term evaluation throughout the melt season.

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1. Introduction

High physical weathering rates in glacial terrains produce freshly eroded, fine-grained, reactive sediments that are commonly trapped in large outwash plains (sandurs) along glacial rivers. The reactive characteristics of the sediment result in chemical weathering rates in proglacial watersheds that are similar to those of temperate watersheds with similar specific discharge despite low temperatures (e.g., Anderson et al., 1997). Chemical weathering reactions are dominated by preferential weathering of trace reactive mineral phases (carbonate, biotite) and oxidation of sulfide minerals in subglacial and proglacial watersheds of alpine glaciers (e.g., Anderson, 2007; Tranter, 2003). Rates and magnitudes of weathering depend on which acid causes weathering and which minerals weather, and are important for nutrient and radiogenic

isotope fluxes to the ocean (Crocket et al., 2012; Hawkings et al., 2016, 2015; Kurzweil et al., 2010) as well as exchange with atmospheric CO_2 (Bernier et al., 1983; Martin, 2017; Spence and Telmer, 2005). Much of the weathering in proglacial rivers may occur in sandurs because they trap comminuted sediment and thereby extend the sediment residence times; however, the impact of weathering in sandurs depends on pore water residence times and thus the rate and direction of exchange between pore water and river water.

This exchange between sandur pore water and proglacial rivers depends on sediment permeability and head gradients between the river and its bank. It also may occur during flooding of the top of the sandur sediments and from percolation of precipitation (snow and/or rain into the exposed sandur). In this paper we refer to this exchange as “hydrologic exchange flow”, which describes all lateral and vertical exchange of river and subsurface waters rather than the more commonly used, but more restricted term, hyperheic exchange (Harvey and Gooseff, 2015). Head gradients of

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proglacial streams should vary at diurnal and seasonal timescales as their flow varies with alternating freeze and thaw (Graly et al., 2017; Koch et al., 2011; Malard et al., 1999). Permeability may also vary in permafrost-affected areas during freeze in of groundwater and restrict hydrologic exchange flow. However, streams in the Arctic tundra of Alaska were found to contribute bioreactive solutes at rates similar to temperate ecosystems (Edwardson et al., 2003). Altered pore water compositions, and their contributions to river compositions, should be enhanced by low water-rock ratios and long residence times compared to water in the river channel (Nezat et al., 2001) that produce steep gradients of biogeochemically reactive solutes (Boulton et al., 1998). For example, the proglacial discharge from Finsterwalderbreen, Svalbard, has elevated Ca, Mg, SO₄, and HCO₃ concentrations from sulfide oxidation and carbonate and gypsum dissolution in the river bank, which enhance in-stream solute concentrations by 30–50% (Cooper et al., 2002; Wadham et al., 2001). Delivery of these solutes from pore waters to the streams depends on flow conditions and the extent of subsurface exchange, which varies over diurnal to seasonal timescales during the ablation season (Koch et al., 2011; Malard et al., 1999).

To assess the potential contributions from hydrologic exchange flow to a proglacial river draining a continental ice sheet, we evaluate chemical alteration in pore waters and hydrologic exchange between proglacial surface and pore waters at two locations along the Watson River near Kangerlussuaq, west Greenland. We also calculate temporary bank storage (proximal exchange) immediately adjacent to the river channel due to diurnal river stage fluctuations. We use these observations to speculate on distal exchange caused by seasonal changes in river stage (e.g., Gooseff et al., 2003). Our data include hydrologic parameters, major ion, and minor element hydrochemistry that provide an assessment of weathering reactions and how proglacial hydrologic exchange flows may affect river water chemical composition and potential oceanic solute fluxes. These data should be considered a reconnaissance study serving to expand our knowledge of hydrologic exchange flows in proglacial watersheds draining ice sheets. To our knowledge, this work represents the first study of hydrologic exchange flows and pore water chemistry conducted in a proglacial watershed draining the Greenland Ice Sheet, an actively retreating continental ice sheet. Our results could be important for understanding mechanisms for ocean and atmospheric fluxes during retreat of the northern hemisphere ice sheets since the last glacial maximum, and for making predications of changes in fluxes as glaciers continue to retreat in a warming world.

2. Methods

2.1. Site description

The Watson River flows ~40 km from the convergence of Isunguata Sermia and Russell Glacier at the western margin of the Greenland Ice Sheet into Søndre Strømfjord (Fig. 1A), draining a proglacial area of ~600 km². Average summer discharge to Søndre Strømfjord was 117 m³/s between 2007 and 2010 (Hasholt et al., 2013), correlating with increased ice melt and evolution of an efficient subglacial drainage system (Bartholomew et al., 2010; Chandler et al., 2013). We investigated two portions of the outwash plain: Sandflugtdalen (67.06°N, 50.39°W) and a smaller sandur across the Watson River from the Kangerlussuaq International Science Support (KISS) facility (67.00°N, 50.68°W), hereafter referred to as WR6 and WRK, respectively. Sampling locations at WR6 were located near the middle of the valley, while the sampled sandur at WRK abuts a hill. Near the river bank, glaciofluvial fine to coarse sands with intermittent gravel lenses predominate and give

way to eolian sands with increasing vegetation and peat content with distance from the channel (Willemse et al., 2003). The downstream site, WRK, consists of finer, better-sorted sands than WR6 within the depths sampled. The sampling regions in this study have longitudinal gradients of ~1.4 m/km at Sandflugtdalen (WR6), while transverse gradients are ~100 m/km (Howat et al., 2014). These gradients suggest lateral hydrologic exchange flows are likely larger than longitudinal hydrologic exchange flows and therefore we focus this study on lateral exchange.

Long-term (1958–1999) mean annual air temperature is –5.7 °C in the Kangerlussuaq region. Mean annual precipitation is ~150 mm (Cappelen et al., 2001), while ~300 mm of evapotranspiration produces a negative water balance (Hasholt and Sogaard, 1978). Continuous permafrost has a seasonal active layer thickness of up to 1.7 m on non-vegetated portions of the proglacial outwash area (Dijkmans and Tornqvist, 1991; van Tatenhove and Olesen, 1994).

Local bedrock consists of metamorphosed Archean gneisses of the Nagssugtoqidian mobile belt (NMB) (Escher and Watt, 1976). Major mineralogy includes quartz, potassium feldspars, and plagioclase along with minor amounts of biotite, muscovite, sphene, garnet, epidote, magnetite, amphibole, apatite, zircon, pyrite, chlorite, and calcite (Hindshaw et al., 2014; Mowatt and Naidu, 1994; Souchez et al., 1990; Yde et al., 2010). Trace calcite (average = 0.6 g/kg CaCO₃, n = 2) is also present in bedload sediments from the Watson River based on coulometric titration, consistent with carbonate concentrations in felsic rocks collected near Nuuk, Greenland (White et al., 2005). Primary carbonate rocks do not occur in the field region, thus any calcite present must be disseminated in the bedrock as a minor mineral phase (Killawee et al., 1998; White et al., 2005).

2.2. Field methods

2.2.1. Water chemistry

Pore water samples were collected from WR6 (14–15 July) and WRK (16 July) during the 2013 melt season (Fig. 1A); Watson River water samples were collected at both sites on 8 July. Pore water samples were collected using an AMS vapor probe (Charette and Allen, 2006) at discrete depths 20–96 cm below the water table (cmbwt). The vapor probe was installed in river bank sediments in a transect perpendicular to one of the larger braids in the river channel (Fig. 1B). During sampling, the channel remained straight and stable, although it widened with increased discharge during our sampling period. Both pore and river water were pumped into an overflow cup using a peristaltic pump fitted with tygon tubing. Temperature, pH, specific conductivity (SpC) corrected to 25 °C, and dissolved oxygen (DO) were measured with a YSI ProPlus handheld unit with the sonde installed in the overflow cup. Once readings stabilized, sample water was filtered through a 0.45 µm trace metal grade canister filter into labeled bottles and preserved as required for each solute. Cation and dissolved metal samples were collected in acid-washed 20 mL HDPE bottles and preserved with Optima HNO₃ to pH < 2. Dissolved inorganic carbon (DIC) samples were collected in 20 mL glass vials and preserved with a saturated solution of mercuric chloride. Anion and silica samples were collected in DI-washed 20 mL HDPE bottles with no preservative. Stable isotope samples were collected in 2 mL borosilicate glass vials with no preservative. All bottles were triple rinsed with filtered site water before collecting the sample for analysis. Water isotope and DIC samples were collected to minimize headspace in vials. Silica was analyzed within thirty days of collection at the laboratory facilities at KISS. All other samples were stored at KISS in 4 °C refrigerators. Samples were shipped chilled to the University of Florida and stored at 4 °C until analysis.

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