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Sources of solutes to the proglacial Watson River (Akuliarusiarsuup Kuua) near Kangerlussuaq, West Greenland

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INTRODUCTION

Chemical weathering & climate

- Chemical weathering of silicates in glacial forelands may be either a sink or source of atmospheric CO_2 dependent on rock type[1], intensity of weathering[2], composition of melting ice[3], and the availability/fate of carbon in the region[4]
    - o As ice sheets recede, the chemical weathering of newly exposed regions could affect the long-term carbon cycle (Fig. 1)

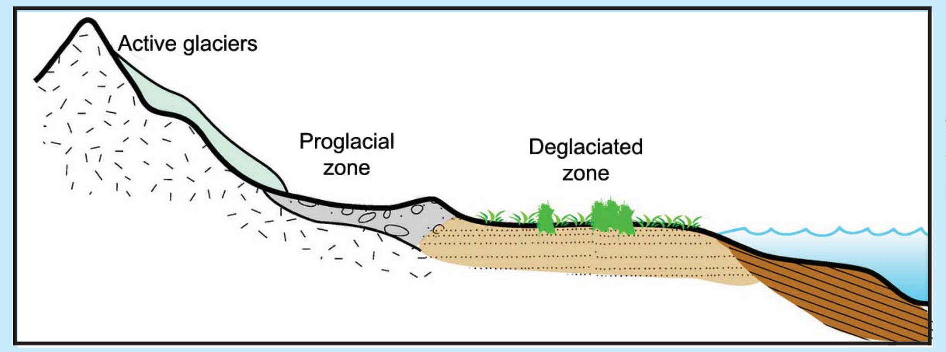

Figure 1. Idealized cross-section of glacial foreland showing depositional environments and watersheds. Figure modified from Anderson (2007)[5].

- Physical weathering of bedrock by *active glaciers* produces chemically reactive rock flour with high specific surface area that is exported to and weathered in the *proglacial zone* (Fig. 1)
    - o Rock flour enhances chemical weathering despite low temperatures
    - o Chemical weathering in cold environments proceeds at rates similar to temperate regions[6]

Sources of solutes to proglacial streams

1. *Weathering of suspended sediments (SS) and bedload* within the channel along the flow path of the stream (Fig. 2a, 2b)
2. *Weathering within the hyporheic zone* (HZ) when channel water exchanges with porewaters (PW) (Fig. 2b, 2c)

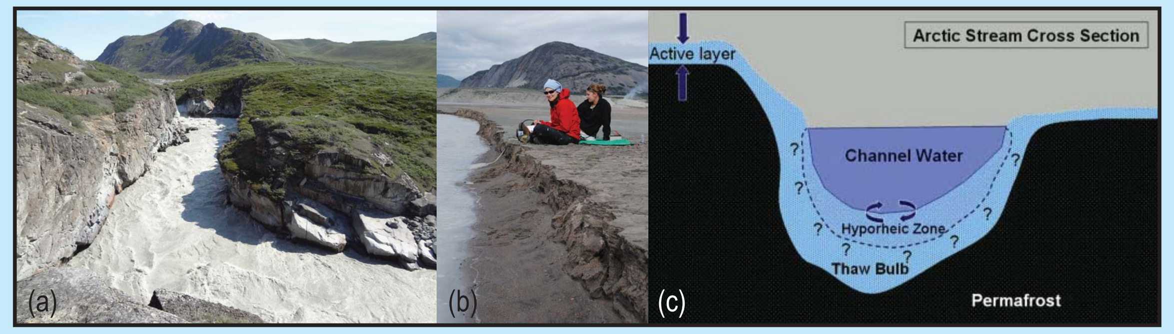

Figure 2. (a) Bedrock-channelized portion of Watson River. Notice grey color of water indicative of high SS load. (b) Sand flat portion of the Watson River showing SS load in the river and potential HZ. Photo credit: J. Martin. (c) Generalized cross-section of a stream impacted by permafrost showing thaw depth and HZ. Modified from Greenwald et al. (2008)[7]

RESEARCH QUESTIONS

1. *Where is chemical weathering predominantly occurring in proglacial streams?*
2. *How does chemical weathering affect downstream water composition?*

METHODS

- Proglacial water collected at 6 sites along Watson River (WR) flow path near Kangerlussuaq, Greenland (Fig. 3a, 4)
- PW transects collected at 2 WR sites with vapor probe at various depths (~20, 45, 69, and 97 cm; Fig. 3b, 4) and distances from river channel (2.5, 6.5, 10.5 m)
- WR & PW collected with a GeoTech pump and Tygon tubing and filtered through a 0.45 um GeoTech trace metal grade high capacity capsule filter
- Installed well transect instrumented with CTD meters parallel to PW transect at site 4 (Fig. 4, 5)
- Alkalinity titrated within 48 hours in Kangerlussuaq, Greenland; aqueous elements preserved in field and shipped back to UF for major ion analysis.

Figure 3. Water sampling of (a) river sites (photo: C. Scribner) and (b) PW sites with vapor probe

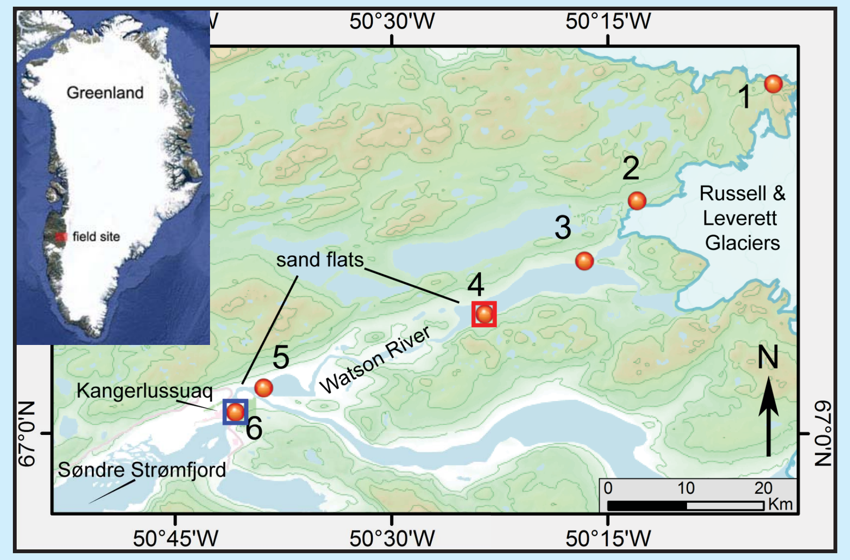

Figure 4. Map of field site near Kangerlussuaq indicating Watson River sample sites. Sites 4 and 6 are locations of PW transect samples. Color scheme remains constant in figures below. Inset image modified from Google Earth; Basemap available from opencyclemap.org.

FIELD SITE

- Watson River flows ~40 km from the Russell and Leverett glaciers through Kangerlussuaq into Søndre Strømfjord
- Water is derived from sub- and supra-glacial melt that flows overland due to continuous permafrost conditions[8]
- Negative water balance[8] in region -> high evaporation rates
- High SS load (up to 0.5 g L^{-1}) gives rise to sand flats where river flows over low gradient terrain (Fig. 4)
- Discharge ranges from no flow in winter to ~450 $m^3\ s^{-1}$ for short flooding events during high melt summers[9]

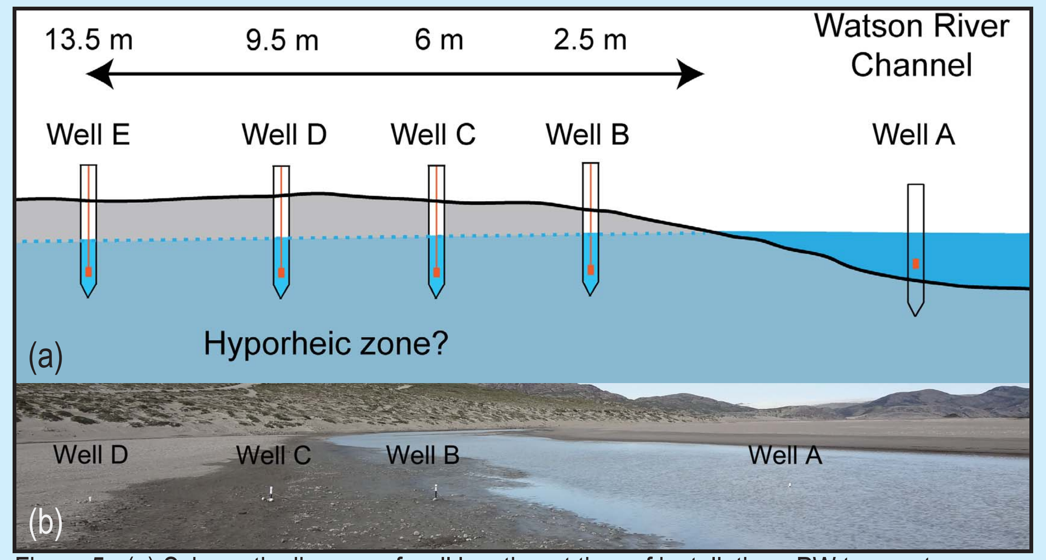

Figure 5. (a) Schematic diagram of well location at time of installation. PW transects were taken parallel to Wells C, D, and E (then 2.5 after the river had risen past location of Well B. (b) Photo of well transect at time of installation.

RESULTS & DISCUSSION

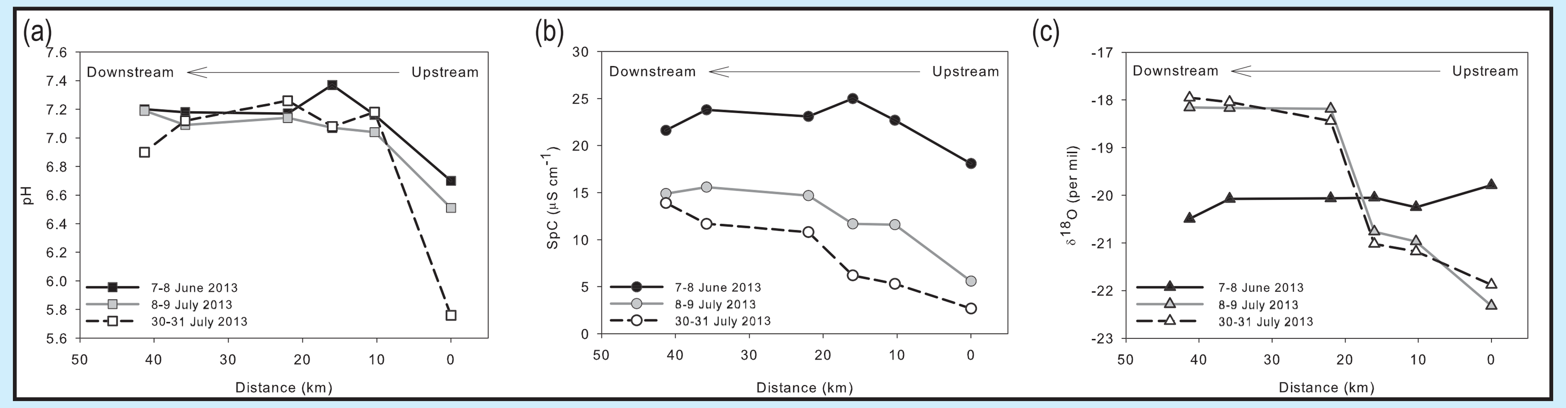

Figure 6. Plots of (a) pH, (b) specific conductivity (SpC), and (c) $\delta^{18}O$ with distance downstream in the Watson River. Note that distance axis is plotted to be consistent with geographic location of sites (Fig. 4). SpC and pH generally increase with distance downstream indicating in-stream weathering is occurring.

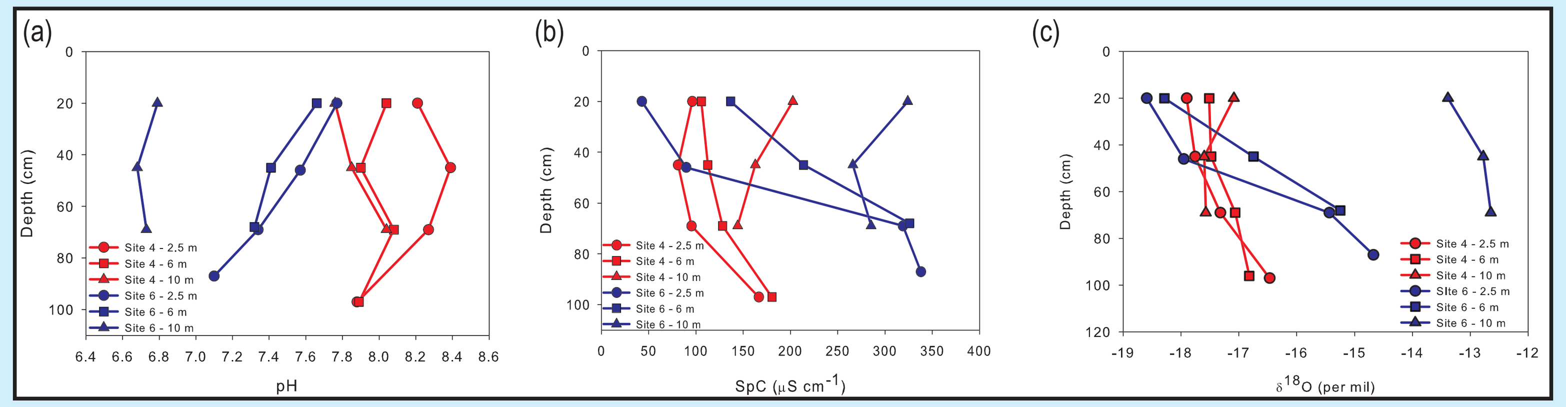

Figure 7. Plots of (a) pH, (b) SpC and (c) $\delta^{18}O$ with depth in PW transects. SpC generally increases with depth indicating that weathering is occurring within the PW at sites 2.5 and 6.5 m from the river channel. The 10.5 m sites decrease in SpC with depth indicating evaporation, which is supported by the relative enrichment in $\delta^{18}O$ at the far site. The decrease in pH with depth may be due to the production of acid during sulfide oxidation.

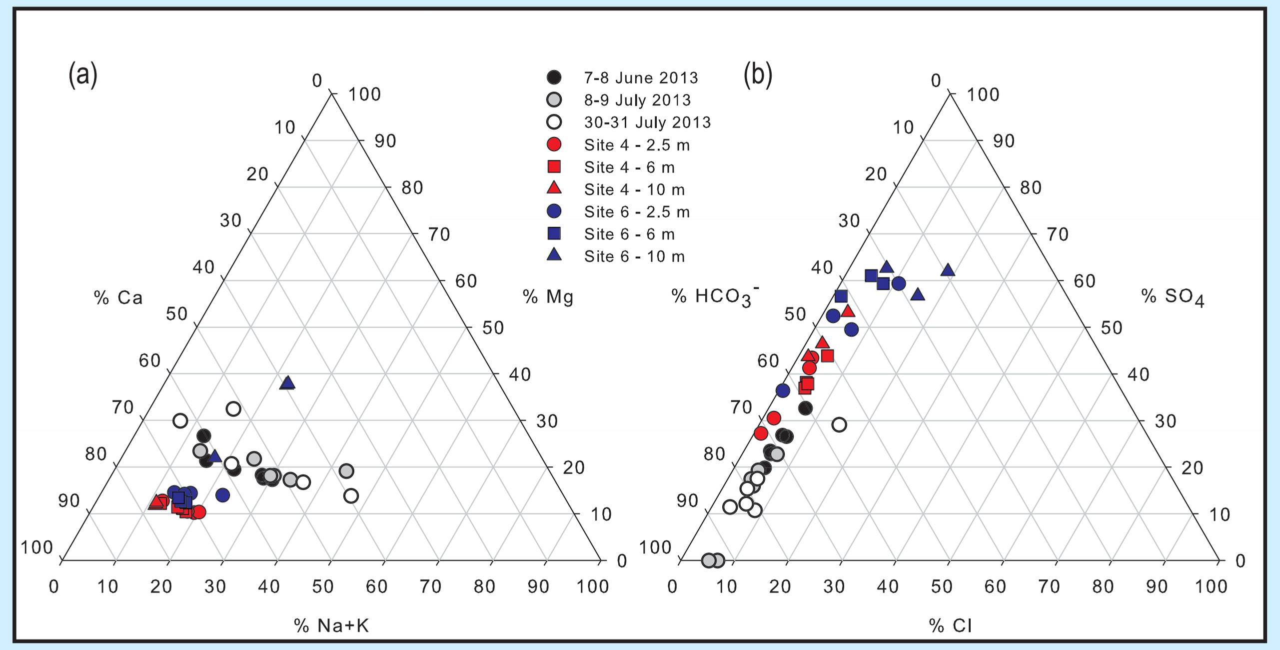

Figure 8. Ternary plots of relative (a) cation and (b) anion concentrations. WR & PW have different compositions: PW are enriched in Ca^{2+} & SO_4^{2-} relative to the Mg^{2+}-, alkali metal-, and HCO_3^--enriched WR. This indicates different styles of weathering may be occurring in the HZ relative to the stream channel itself. The enrichment of SO_4^{2-} in the PW also supports the possibility of sulfide oxidation occurring in the HZ.

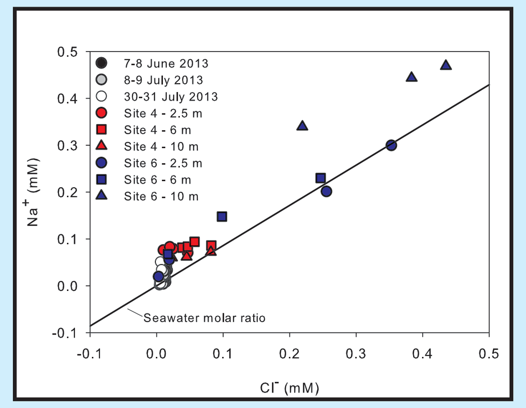

Figure 9. Cross plot of [Na^+] vs [Cl^-] with the seawater molar Na:Cl ratio (~0.85) for reference. There is excess Na^+ in most of the waters that is not accounted for by marine aerosols, indicating weathering is occurring within the proglacial zone.

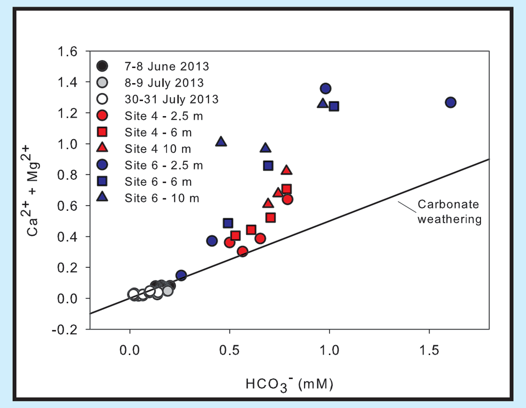

Figure 10. Cross plot of [Ca^{2+}+Mg^{2+}] vs [HCO_3^-] with the carbonate weathering ratio for reference. WR samples plot along the weathering ratio indicating carbonate dissolution; PWs contain excess Ca^{2+} & Mg^{2+} indicating silicate weathering.

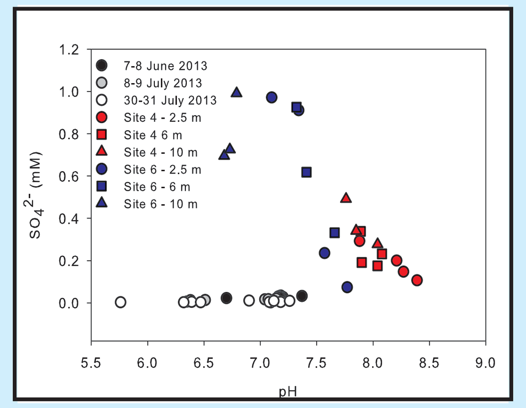

Figure 11. [SO_4^{2-}] vs pH for both WR & PW samples. No relationship exists in WR samples; a negative relationship exists in PW indicating potential oxidation of S-bearing minerals.

Interpretation

- PW are chemically distinct from WR water (Figs. 6-8) indicating that different types of weathering are occurring in the different systems.
- Decreases in pH, SpC and $\delta^{18}O$ values (Fig. 6) through the melt season indicate a changing source of water. Early in the melt season, WR water is derived from deglaciated watersheds and precipitation. Signal is swamped later in the melt season by the onset of supraglacial melt
- River water appears to be infiltrating top portion of PW as indicated by low SpC and $\delta^{18}O$ values at 20 cm below the water table (Fig. 7b, 7c).
- **Silicate weathering:** Excess Na^+ compared to that available due to marine aerosols (Fig. 9) indicate the weathering of a Na-bearing mineral (alkali feldspar) is occurring in both the PW and WR. Excess Ca^{2+} and Mg^{2+} concentrations compared to HCO_3^- concentration (Fig. 10) in the PW indicates the weathering of a Ca- and/or Mg-bearing silicate (plagioclase, hornblende, etc).
- **Carbonate weathering:** WR samples contain Ca^{2+}, Mg^{2+}, and HCO_3^- at concentrations proportional to carbonate weathering (Fig. 10).
- **Sulfide oxidation:** The general decrease in pH with depth (Fig. 7a) and predominance of SO_4^{2-} (Fig. 8) at PW sites indicate sulfide oxidation is occurring. Fig. 11 confirms this relationship for all PW sites, and may be due to oxidation of sulfide-bearing minerals such as pyrite (FeS_2)

Hyporheic zone exchange?

- PW must exchange with river channel to have any appreciable effect on downstream water composition
    - o Pressure data with atmospheric effects removed (Fig. 12a) indicates WR water is flowing into HZ sediments at Wells C, D, & E.
    - o Well B (~3 m from WR at installation) flows from HZ to the river (Fig. 12a values >0) on a diurnal basis following high flow in the WR
    - o Abrupt changes in stage (e.g. 7/12) lead to concurrent changes in the gradient ~6 hours later
- Weathering in the HZ is more intense than in the WR as shown by the elevated concentrations in solution and changes in composition because of two factors: (1) the residence time is longer and (2) the water:rock ratio is larger

Bank storage occurs within the HZ near the river channel and depends on flow conditions in the river. Seasonal melting of the ice sheet leading to rise in river stage causes flow of WR water into pore spaces, but as the river level drops, PW should flow back to the river.

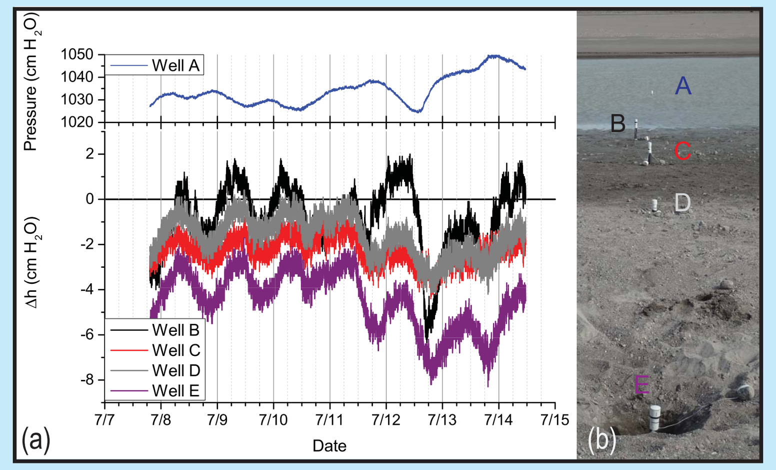

Figure 12. (a)Time-series of relative pressure difference between wells and the river channel. Well pressure data was normalized to a benchmark and the river data subtracted. Values greater than 0 indicate flow from the HZ toward the stream. Raw pressure data from the river is shown to give an idea of river stage. (b) Photo of well sites showing well locations in the sand flat.

CONCLUSIONS

Chemical weathering is occurring within the WR and within the HZ as represented by PW concentrations. However, the downstream composition of the WR does not appear to be influenced by exchange with the HZ. *Thus, the predominant source of solutes to the WR during the initiation of summer flooding must be through in-channel weathering of suspended sediments and bedload.* Pressure data in wells indicate that at the time of the sample collection, WR water was flowing into the HZ. These gradients may change on a seasonal timescale based on the stage of the WR. High concentrations present in PW relative to the WR are due to long storage times of channel water in the HZ.

FUTURE WORK

Radiogenic isotopic studies of water, suspended load, and bedload are ongoing as well as mineralogical analysis of bedload.

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