Seasonal evolution and spatial distribution of weathering in western Greenland

K.M. Deuerling (kdeuer@ufl.edu), J.B. Martin, E.E. Martin, C.A. Scribner, D.F. Collazo
Department of Geological Sciences, University of Florida, Gainesville, FL

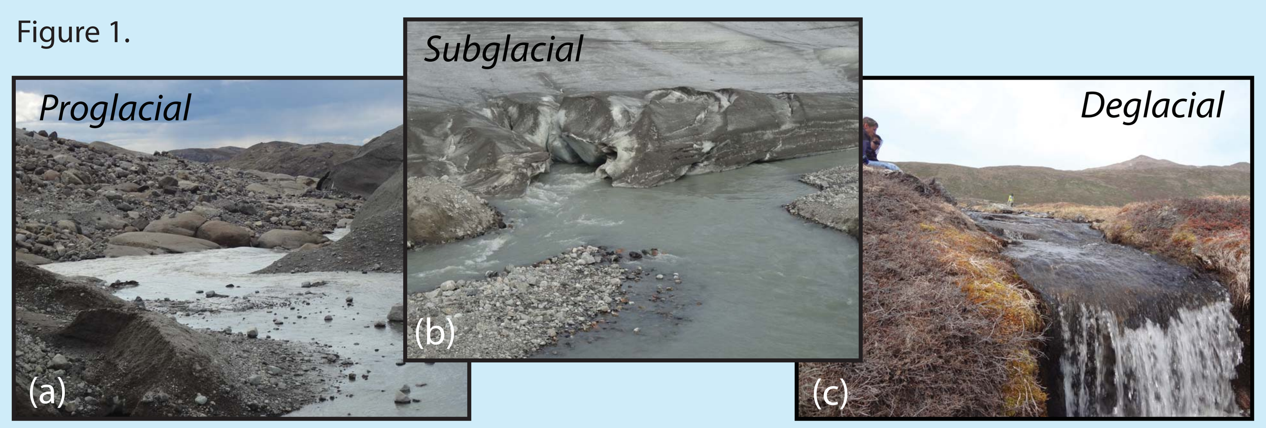
INTRODUCTION

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], the availability/fate of carbon in the region[3], and subglacial redox conditions[4,5]
- Previous studies indicate incongruent weathering of trace minerals (biotite, carbonate, sulfides) predominates in recently exposed land near alpine glaciers and proceeds to a more congruent/silicate weathering signature with age[2,6,7]
- Subglacial discharge from large ice bodies should record a more congruent/silicate weathering signature as isolated portions of the subglacial hydrological system are incorporated into flow to the proglacial system[5]

Types of periglacial watersheds

Figure 1.



Proglacial Watersheds
- Predominantly ice source
- ↑ discharge through the melt season
- High suspended sediment load
- Low vegetation

Subglacial Watersheds
- 2 types: distributed ("slow-flow") and channelized ("fast-flow") systems
- ↓distributed flow, ↑ channelized flow though melt season
- ↑ suspended sediment load

Deglacial Watersheds
- Precipitation/permafrost source
- ↓ discharge through the melt season
- Low suspended sediment load
- High vegetation

OBJECTIVES

1. Quantify solute sources in de-, pro-, and sub-glacial watersheds
2. Identify spatiotemporal changes in chemical weathering

METHODS

- Surface water samples from proglacial and deglacial watersheds analyzed for Na, K, Mg, Ca, Cl, SO_4, HCO_3, Si, and Sr
- Hydrochemical data applied to a stoichiometric mass balance scheme[2] modified for weathering conditions and minerals present in field area (e.g., plagioclase composition adjusted to 26% anorthite[8])

Mass balance steps:

1) Account for *seawater aerosol inputs* with element:Cl molar ratios. All Cl assumed to originate from aerosols. Na:Cl = 0.85, Mg:Cl = 0.095, K:Cl = Ca:Cl = 0.019, SO_4:Cl = 0.05

2) *Plagioclase ($An_{0.26}$) weathering to kaolinite*: $Na_{0.74}Ca_{0.26}Al_{1.26}Si_{1.48}O_8 + 1.26\ H_2CO_3 + 0.63\ H_2O = 0.74\ Na^+ + 0.26\ Ca^{2+} + 1.26\ HCO_3^- + 1.48\ SiO_2 + 0.63\ Al_2Si_2O_5(OH)_4$

3) *Sulfide mineral oxidation*: $FeS_2 + 3.75\ O_2 + 2\ H_2O = 2\ SO_4^{2-} + 4\ H^+ + 0.5\ Fe_2O_3$

4) *Carbonate weathering by sulfuric acid* from step 3: $CaCO_3 + 2\ H^+ = Ca^{2+} + CO_2 + H_2O$

5) *K-feldspar weathering to kaolinite*:
$KAlSi_3O_8 + H_2CO_3 + 0.5\ H_2O = K^+ + HCO_3^- + 2\ SiO_2 + 0.5\ Al_2Si_2O_5(OH)_4$

6) *Biotite weathering to vermiculite*: $1\ K^+ : 1\ HCO_3^-$

7) *Carbonate weathering by carbonic acid*: $(Ca,Mg)CO_3 + H_2CO_3 = (Ca^{2+},Mg^{2+}) + 2\ HCO_3^-$

REFERENCES

1. Yde et al (2005) Glacier hydrochemistry, solute provenance, and chemical denudation at a surge-type glacier in Kuannersuit Kuussuat, Disko Island, West Greenland. J. Hydrol. 300, 172–187.
2. Anderson, S. P. et al (2000) Chemical weathering in the foreland of a retreating glacier. Geochim. Cosmochim. Acta 64, 1173–1189.
3. Bhatia et al. (2010) Molecular characterization of dissolved organic matter associated with the Greenland ice sheet. Geochim. Cosmochim. Acta 74, 3768–3784.
4. Tranter et al. (2002)Geochemical weathering at the bed of Haut Glacier d'Arolla, Switzerland: a new model. Hydrol. Process. 16, 959–993
5. Wadham et al. (2010) Biogeochemical weathering under ice: Size matters. Global Biogeochem. Cycles doi: 10.1029/2009GB003688.
6. Tranter (2002) "Geochemical Weathering in Glacial and Proglacial Environments" in Treatise on Geochemistry, Volume 5, p.189-205.
7. Scribner et al., (2015) Exposure age and climate controls on weathering in deglaciated watersheds of western Greenland. Geochim. Cosmochim. Acta 170, 157-172.
8. Hindshaw et al. (2014) Identifying weathering sources and processes in an outlet glacier of the Greenland Ice Sheet using Ca and Sr isotope ratios. Geochim. Cosmochim. Acta 145, 50–71.
9. Blum & Erel (2003) "Radiogenic Isotopes in Weathering and Hydrology" in Treatise on Geochemistry, Volume 5, p.365-392.

RESULTS & DISCUSSION

1. Average watershed values

Carbonate weathering:
Dominant form of chemical weathering in all watersheds, and decreases toward the coast (DG-C = 34 %TDS, DG-I = 57 %TDS, PG = 42 %TDS)

Aerosols:
Increased importance toward the coast (DG-C = 30 %TDS, DG-I = 25 %TDS, PG = 5 %TDS, SG = 9 %TDS)

Silicate weathering:
- Increases toward coast in deglacial watersheds (DG-I = 2 %TDS, DG-C = 13 %TDS)
- Enhanced silicate weathering in glacial watershed (PG = 18 %TDS, SG = 26 %TDS) indicates low water:rock ratios, long flowpaths, and/or the connection of isolated portions of the subglacial hydrological system

Biotite weathering:
Preferential weathering of biotite greatest in recently exposed watersheds (DG-I = 8 %TDS, PG = 16 %TDS) and decreases with increasing exposure age (DG-C = 2 %TDS)

Sulfide oxidation:
Highest in the subglacial and coastal watersheds indicating a secondary source of acid to weather carbonates and silicates

Excess solutes:
The majority of excess solutes in all watersheds consists of Na and HCO_3. Excess solutes are greatest in coastal and glacial watersheds, which have the most dilute waters. In dilute water, fine-grained sediments tend to retain divalent cations and release monovalent cations[6], potentially accounting for this signal.

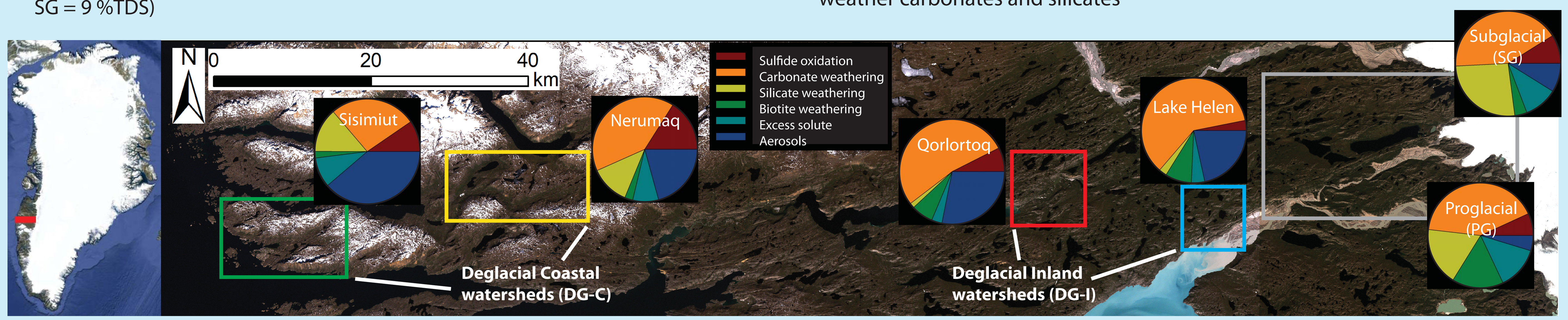


Figure 2. a) Google Earth image of Greenland with transect area highlighted in red; b) USGS Landsat images of transect area with watershed locations outlined (Sisimiut = green, Nerumaq = yellow, Qorlortoq = red, Lake Helen = blue, Watson River/proglacial = gray). Pie charts graphically represent the percentage of solutes attributed to each type of weathering as an average for the watershed.

2. Spatial distribution of weathering signatures

Carbonate (Fig. 3) and biotite (Fig. 4) weathering generally decrease while silicate weathering increases downstream (Fig. 5) from inland to the coast and downstream in individual watersheds, consistent with increasing exposure age and removal of preferentially weathered minerals from the ice sheet to the coast[7]

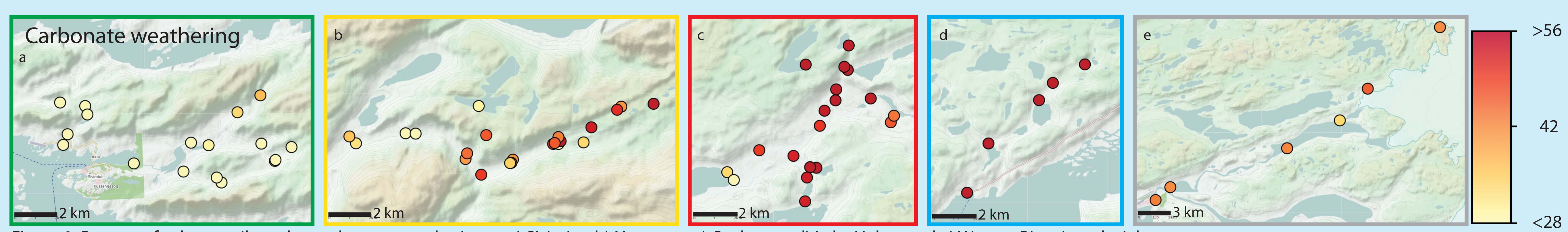


Figure 3. Percent of solute attributed to carbonate weathering at a) Sisimiut, b) Nerumaq, c) Qorlortoq, d) Lake Helen, and e) Watson River/proglacial

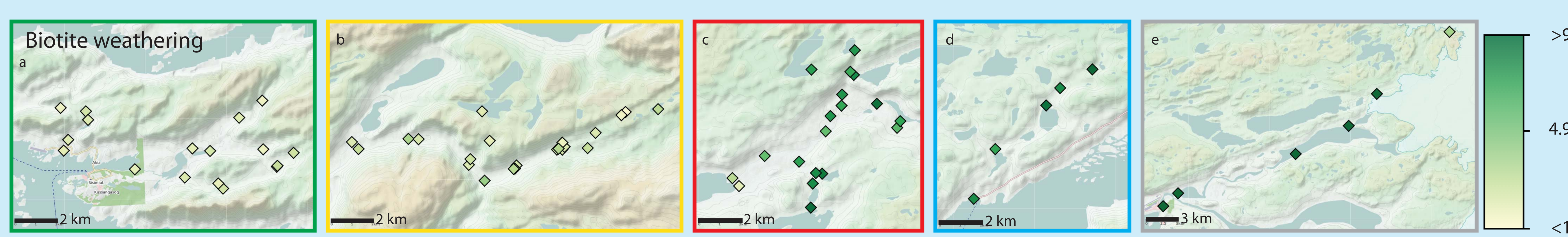


Figure 4. Percent of solute attributed to biotite weathering to vermiculite at a) Sisimiut, b) Nerumaq, c) Qorlortoq, d) Lake Helen, and e) Watson River/proglacial

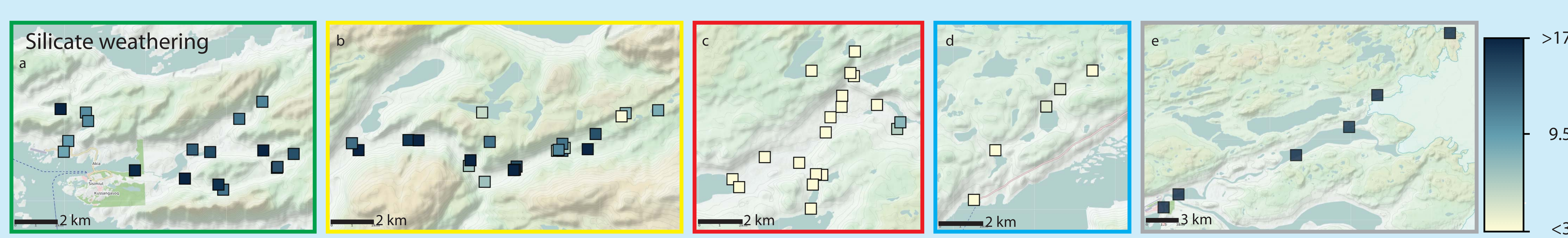


Figure 5. Percent of solute attributed to silicate minerals (feldspars) weathering to kaolinite at a) Sisimiut, b) Nerumaq, c) Qorlortoq, d) Lake Helen, and e) Watson River/proglacial

RESULTS & DISCUSSION (continued)

3. Seasonal variation of chemical weathering

- Lake Helen deglacial watershed shows little variation in dominant minerals being weathered downstream or through melt season (Fig. 6) carbonate > aerosol influence > biotite > silicate = sulfide oxidation
- Overall importance of carbonate weathering decreases through the season and silicate weathering influences increases through the melt season at the Watson River (Fig. 7).
- Peaks in silicate weathering and minima in biotite and carbonate weathering at proglacial headwaters (Fig. 7) are consistent with the connection of isolated portions of the subglacial hydrological system that records a more extensive weathering signature at high discharge

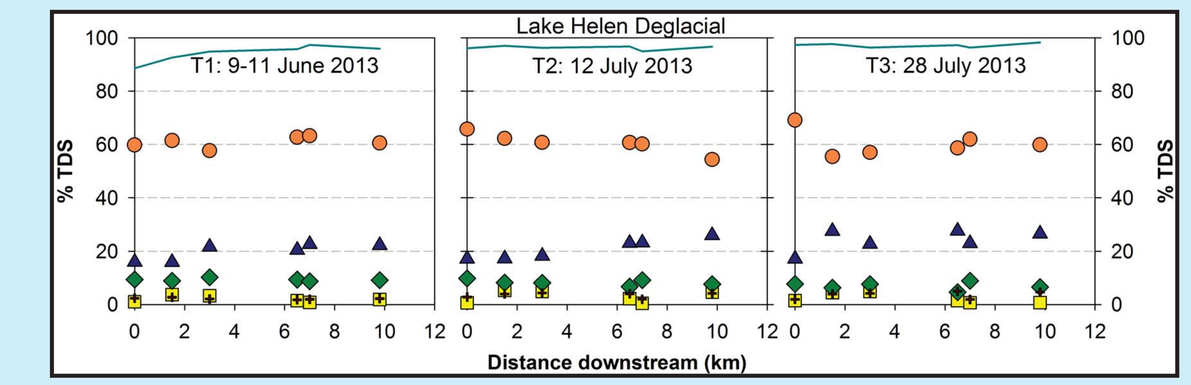


Figure 6. Variation through melt season at Lake Helen deglacial watershed

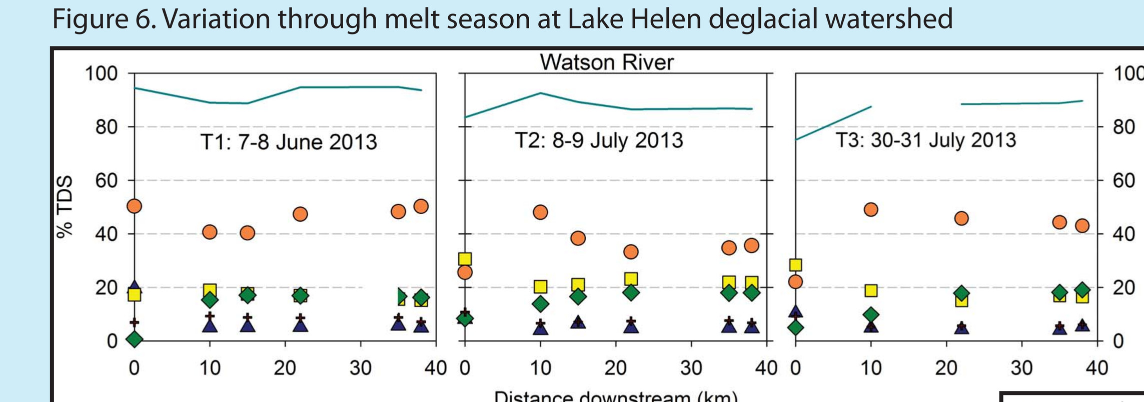
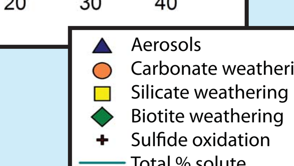


Figure 7. Variation through melt season at the Watson River/proglacial



4. Sr isotopic composition of waters

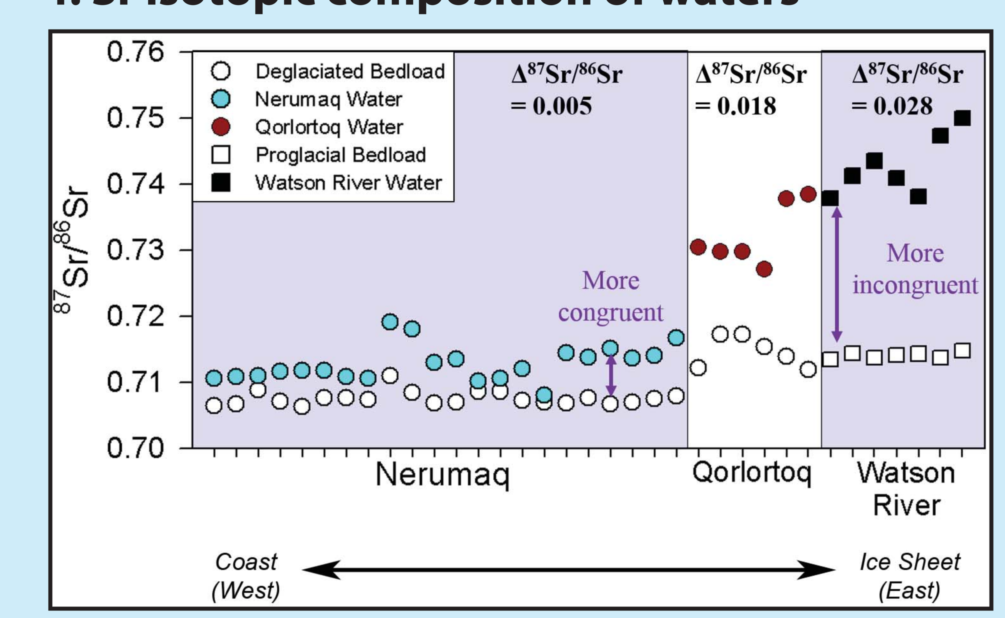


Figure 8. Sr isotopic composition of water and bedload. Larger differences between $^{87}Sr/^{86}Sr$ of water and solid are correlated to less extensive weathering. High $^{87}Sr/^{86}Sr$ values are attributed to the preferential weathering of biotite, which has weathered away in older terrains[9].

CONCLUSIONS

As the Greenland Ice Sheet recedes, the deglacial land area characterized by a greater extent of silicate weathering will increase. Intensified ice melt will potentially connect isolated portions of the subglacial hydrologic system, imparting an extensive silicate weathering signature on the proglacial watershed. Preferential biotite and carbonate weathering will still prevail in areas of active sediment production, but the overall weathering signature should shift toward silicate weathering and affect the global carbon cycle through the drawdown of atmospheric CO_2. The extent of this signal and the overall land area available for weathering will be modified by sea level changes.

ACKNOWLEDGEMENTS

Funding for this work provided by National Science Foundation Grant ARC-1203773 and Graduate Research Fellowship Program Grant DGE-0802270. We thank A. Portier and M. Davlantes for field assistance; J. Curtis and G. Kamenov for analysis assistance; and CPS/KISS for help with field logistics.