Variations in weathering intensity across western Greenland based on radiogenic isotopes

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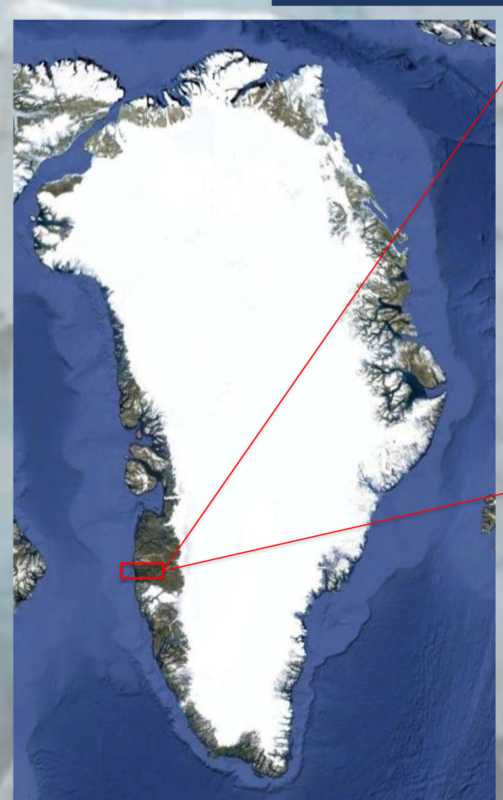
Introduction

- Physical weathering of continental ice sheets enhances chemical weathering, which impacts fluxes of radiogenic isotopes and nutrients to the oceans and atmospheric fluxes of carbon
- The western margin of Greenland, which represents a region of retreat of a modern continental ice sheet, provides a good location to assess spatiotemporal variations of glacial weathering environments. These environments include: 1) proglacial watersheds, where the water is sourced directly from the ice sheet, and 2) deglaciated watersheds, which are hydrologically separated from the ice sheet and only drain precipitation and permafrost melt.
- Chemical weathering of fresh material preferentially releases radiogenic Sr and Pb isotopes due to preferential weathering minerals enriched in radiogenic isotopes and leaching of radiogenic Sr and Pb from radiation-damaged crystals (Blum and Erel 2003). This creates an offset between the isotopic composition of weathered solution and weathered rock (bedload).
- The bedload-water offset decreases as extent of weathering increases, allowing a measure of the extent of weathering
- Scribner et al. (2015) documented an increase in the extent of weathering across western Greenland from the ice sheet toward the coast that coincided with increasing moraine ages and a transition from a negative to positive water balance (see Fig. 1).
- As the Greenland Ice Sheet (GrIS) retreats in response to global warming, the proportion of deglaciated to proglacial watersheds will increase and the water balance will shift inland.
- These changes in response to ice sheet retreat could account for a documented rapid increase in seawater-derived Pb isotopes during Termination 1, following the last glacial max
- Here we show that differences in isotopic composition of minerals are similar to the variation in water compositions, suggesting that solid phases may record the geologic history of ice sheet retreat

Field Area: Western Greenland



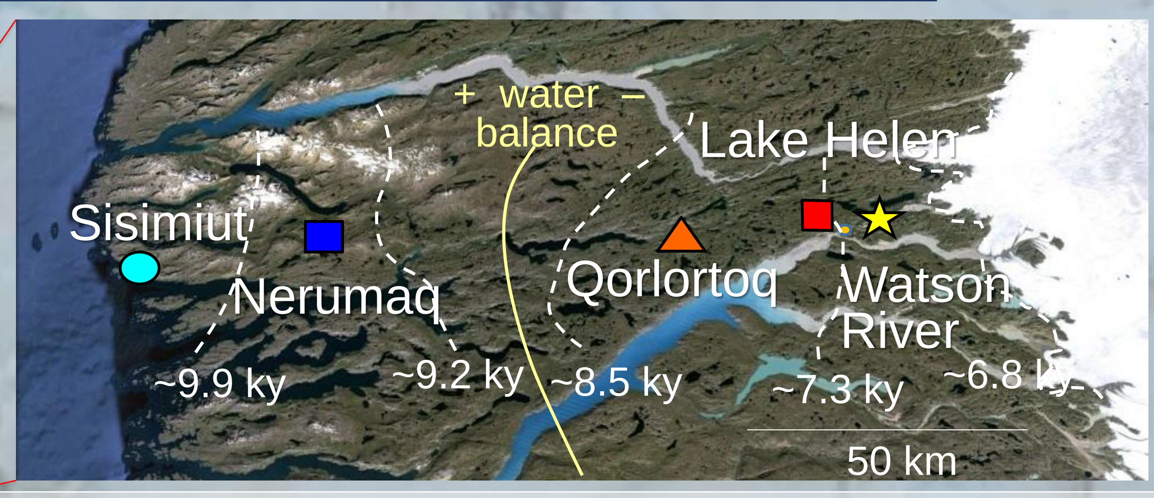


Fig. 1- Location Map of Watersheds:
- *Proglacial watershed:* Watson River (yellow star)
- *Coastal deglaciated watersheds:* Sisimiut (light blue circle), Nerumaq (dark blue square)
- *Inland deglaciated watersheds:* Qorlortoq (orange triangle), and Lake Helen (red square)
- Moraine ages (in white).

Sr Isotope Weathering Trends

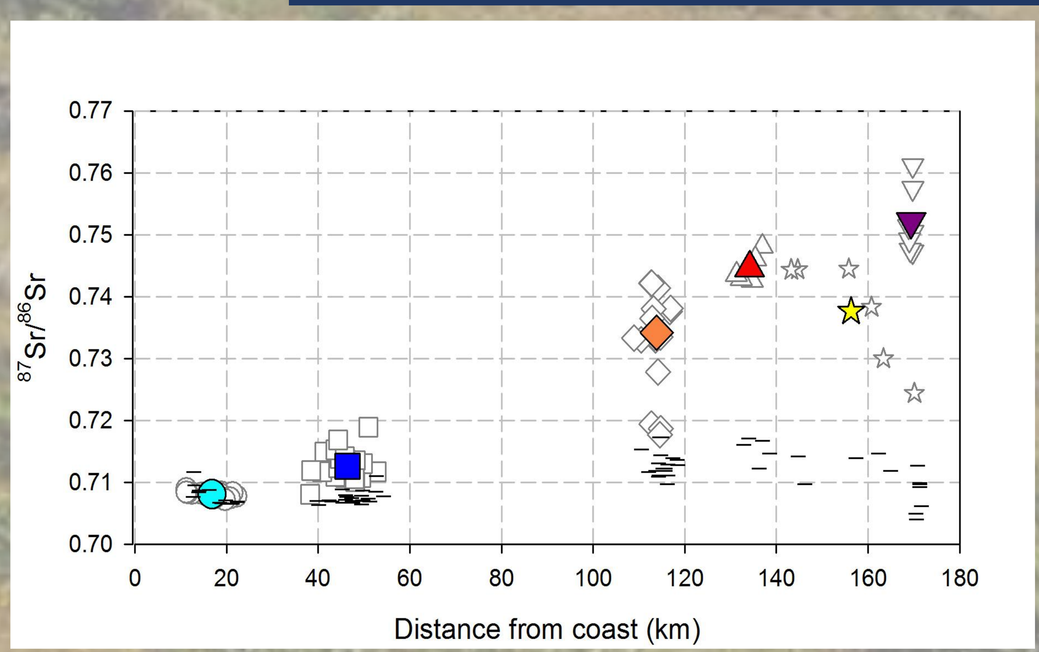
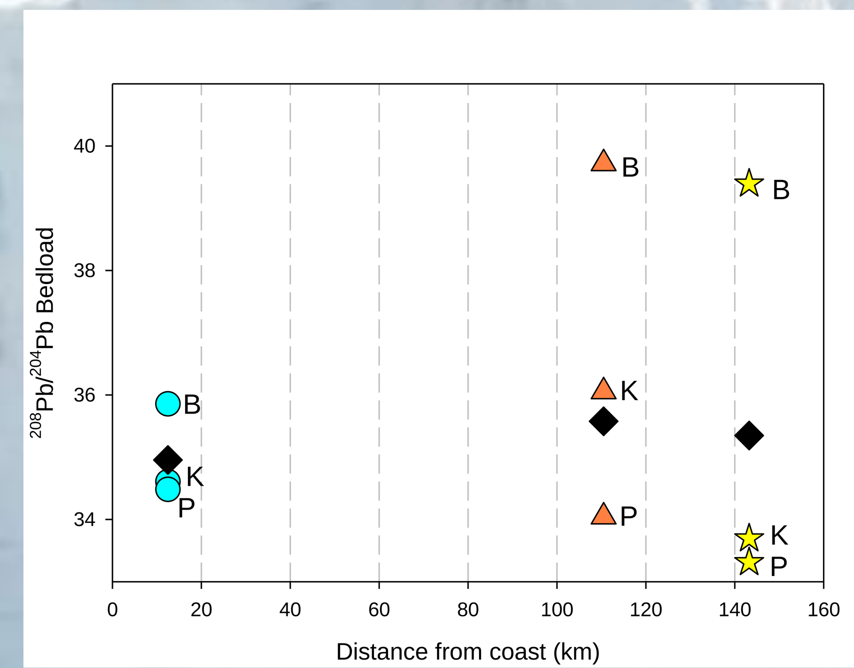


Fig. 2 – $^{87}Sr/^{86}Sr$ of stream waters (colored symbols) and bulk bedload (horizontal black lines) across the transect (Deuerling et al., in prep)

- Bedload Sr isotopes are relatively consistent across the transect
- Streamwater Sr isotopes display a clear decrease with distance from the ice sheet, indicating an increased extent of weathering near the coast.

Bedload Mineral Separates



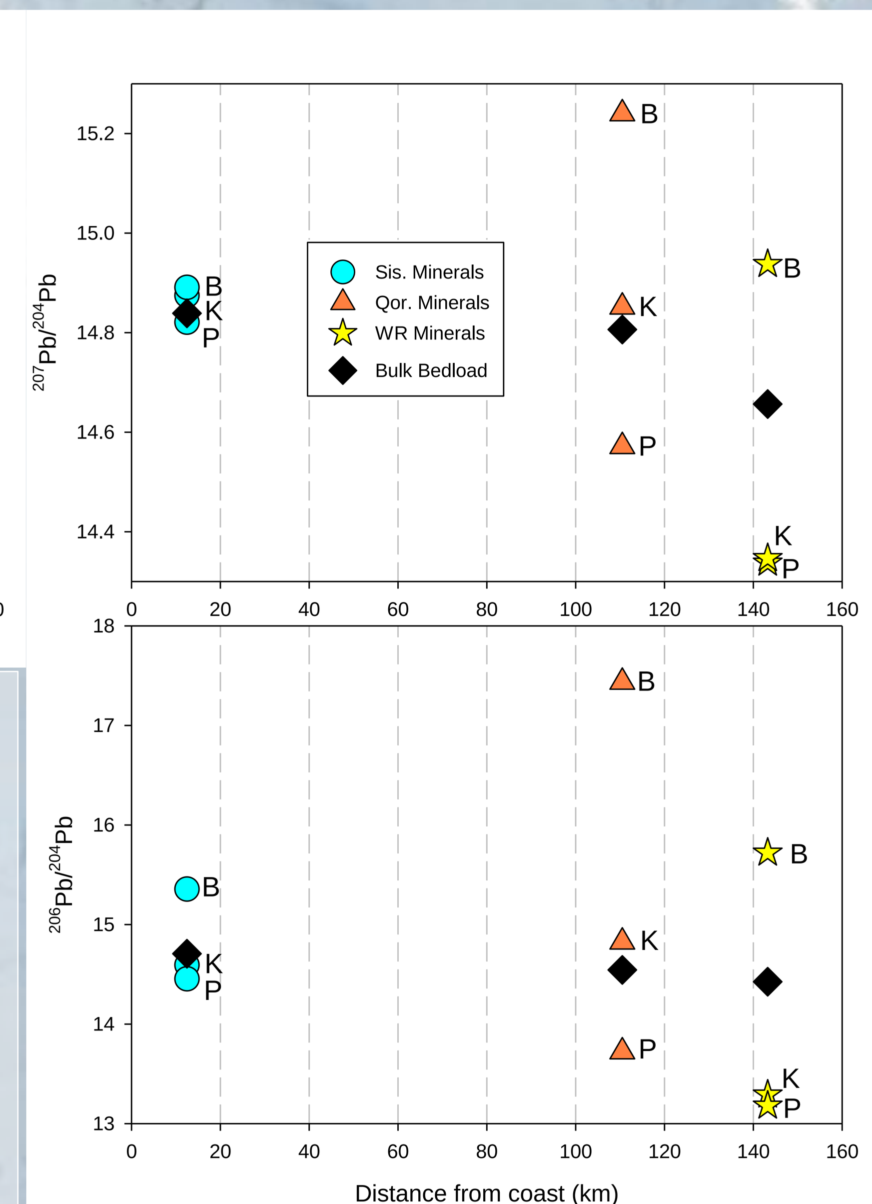


Fig. 3 – Preliminary lead data of common minerals (orthoclase, plagioclase) and biotite found in the watersheds. B - biotite, K - orthoclase, P - plagioclase. Biotite, with elevated Rb content, is important to Sr isotopic values in the watersheds and their associated weathering patterns. All minerals were handpicked from the sand fractions (63 µm to 2mm) of each site. The most radiogenic Pb isotope values were consistently derived from biotite.

Bedload Size Fractions

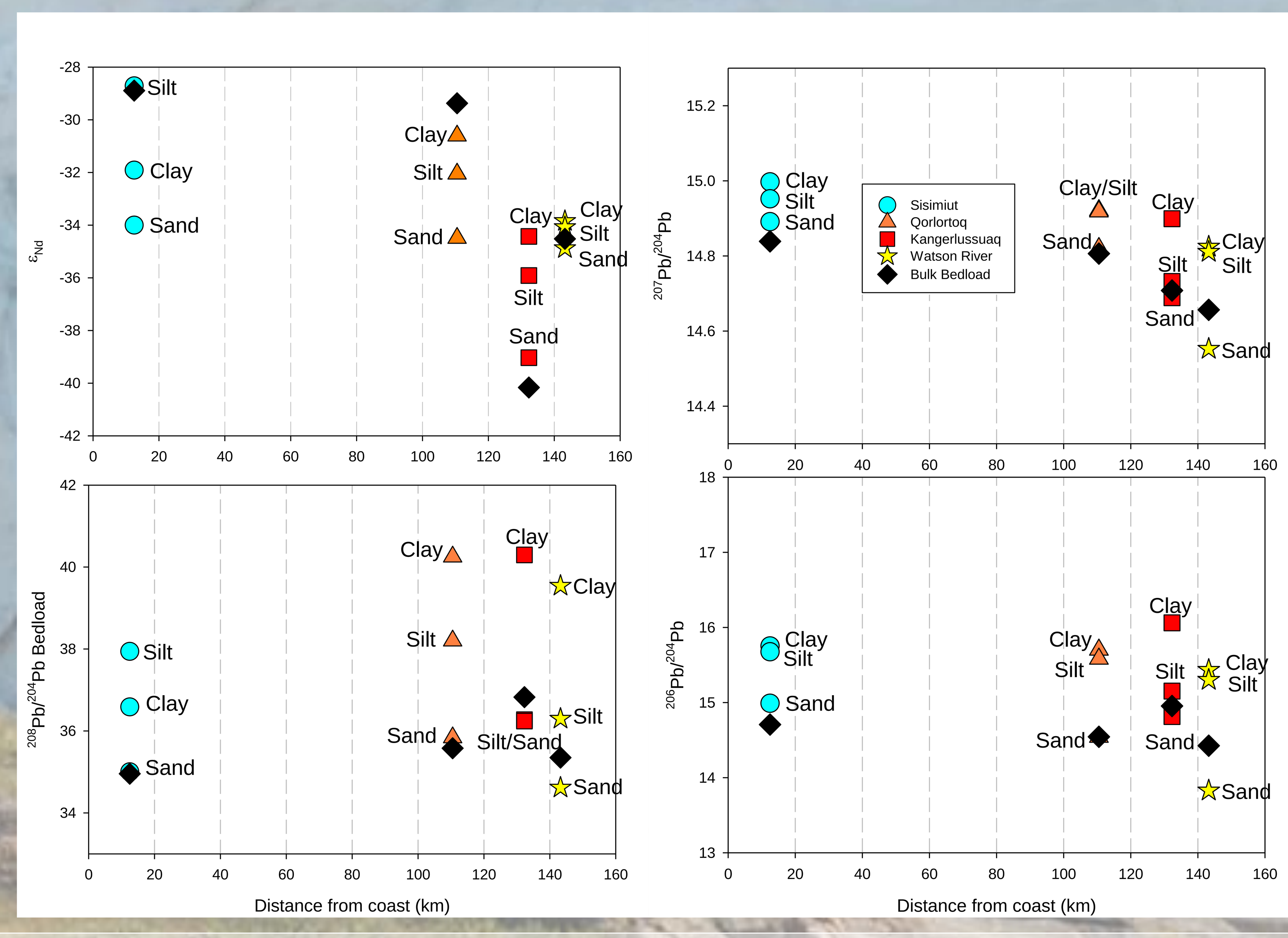


Fig. 4 – Lead and neodymium isotopic analyses of separated sand, silt, and clay fractions of bedload from one coastal deglaciated, two inland deglaciated, and the Watson River proglacial watersheds. Different grain size fractions generally produce unique isotopic ratios. The <2 mm fraction of bedload samples was separated into sand (63 µm to 2mm), silt (2-63 µm), and clay (<2 µm) through sieving and centrifugation. The sand fraction dominated all bedload samples by weight, ranging from 80 wt% in Kangerlussuaq to >99 wt% in Sisimiut.

Results

- $^{208}Pb/^{204}Pb$ extracted from moraine soils follows a similar weathering trend to Sr isotopes (not shown), but this signal is complicated by anthropogenic contamination in waters
- In general, the most radiogenic ratios of Pb and Nd are found in clay (Pb) and clay/silt (Nd) and the least radiogenic ratios are in the sand fraction
- The coarse fraction (sand) dominates the size fractions by weight percent and isotopic composition of the bulk samples
- Bulk isotopic values outside of the range of values for all of the size fractions suggest inherent heterogeneity in the bulk sample material.
- Silt and clay fractions dominate the bulk bedload Nd signal
- The feldspars dictate the bulk bedload Pb signal due to their common nature
- The most radiogenic biotite Pb isotopes occur in Qorlortoq, an inland deglaciated environment, suggesting incompletely developed weathering in this environment that may relate to discharge from channelized drainage systems at the GrIS base.

Conclusions

- Bulk bedload data is relatively constant across the glacial foreland
- The biotite Pb isotopic values are variable across the glacial foreland. The trend in biotite isotopes generally matches weathering trends documented by Sr isotopes. This suggests mineral separates from the geologic record may be useful for tracking the history of weathering extent in a glacial foreland
- Biotite Pb isotopes are less radiogenic in the Watson River proglacial system than at Qorlortoq. This is surprising because both systems have relatively recently exposed material and a negative water balance. The isotopic difference in the biotite from these two areas suggests less chemical weathering in the Qorlortoq watershed than in sediment discharged from the active glacier in the upper Watson River watershed.
- A possible explanation for the difference in weathering extent between the inland deglaciated and proglacial watersheds may be that actively discharged material in the proglacial system was stored and weathered subglacially in the glacier's unique, seasonally variable hydrologic system prior to discharge.
- The coastal deglaciated environments exhibit more extensive chemical weathering in the mineral separates, as expected
- The size fractions do not appear to track any of the chosen minerals and thus may not serve as a suitable record of weathering changes, possibly due to the heterogeneous mixture of grain sizes left behind in the glacial moraines and till
- The isotopic composition of specific mineral separates, such as biotite, has potential to study weathering in sediments in the geologic past or in locations where water samples are not available

References

Blum and Erel, 1995, *Nature*, 373, 415-418.
Hindshaw et al., 2014, GCA, 145, 50-71.
Blum and Erel, 2003, *Tr. on Geochem.*, 5, 365-392.
Garçon et al., 2014, *Chem. Geol.*, 364, 42-55.
Bhatia et al., 2011, *Jour. of Glac.*, 57, 929-941
Harlavan and Erel, 2002, *GCA*, 66, 837-848.
Scribner et al., 2015, *GCA*, 170, 157-172.
Kurzweil et al., 2010, *EPSL*, 299, 458-465.
Crocket et al., 2012, *Quat. Sci. Rev.*, 38, 89-99.
Harlavan, Erel, Blum, 1998, *GCA*, 62, 33-46

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