The authors requested a **poster**

Surface Exposure Age And Erosion Rates Of Sub-Ice Soils In Western Greenland

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Due to its size and sensitivity to changing climate conditions, the Greenland Ice Sheet has likely had a major role in sea level fluctuations over past glacial/interglacial cycles. During several periods in the Pleistocene, climate conditions were warmer than present and much of Greenland may therefore have been ice-free, most recently during the Eemian period, 130-116 ka before present. Modelled Greenland Eemian temperatures closely resemble those forecasted for c. 2100 in global warming models (Overpeck et al., 2006). Therefore, the Greenland Ice Sheet's Eemian behavior may predict future sea level change. Our data show that rock and sediment presently emerging from ablating Greenland glacial ice was exposed at or near the surface during earlier interglacial periods. Data and modeling show that some fine-grain sediment presently emerging from the Greenland Ice Sheet has tens of thousands of years of prior surface exposure, suggesting that Pleistocene interglacial phases had both spatially and temporarily significant ice sheet retreat.

Meteoric ^{10}Be forms in the upper atmosphere and is deposited in precipitation or as dryfall, where it strongly adheres to the grain coatings of sediment. Because ^{10}Be-bearing aerosols are deposited on the ice sheet during glacial times, any ^{10}Be inventory in the basal ice-bound sediment must have accumulated during interglacial surface exposure.

We sampled ice and ice-bound fine sediment at three locations in Western Greenland: Kangerlussuaq (67.1° N), Ilulissat (69.4° N), and Upernavik (72.5° N) (Figure 1). Meteoric ^{10}Be was measured through the total fusion of this ice-bound silt and sand. $\delta^{18}O$ and $\delta^{2}H$ were measured in the surrounding ice. These stable isotopes can help determine the global and local climate conditions when the ice formed and can trace subglacial processes.

In our sediment samples, ^{10}Be concentrations vary from $3.2 \cdot 10^{6}$ to $2.1 \cdot 10^{8}$ atoms/gram. While all three sites have similar minimum values, the maximum value varies significantly by latitude, the higher latitude sites having progressively greater maximum values. The warmer temperatures and higher rates of precipitation in southern Greenland suggest that the ice sheet there is more responsive to climate change. It is therefore unlikely that our higher latitude sites experienced longer surface exposure during past interglacial periods, so this latitudinal variation may be explained by differences in glacial period erosion rates.

In order to evaluate the duration of surface exposure experienced by the soils from which our sediments were sourced, we compiled a global database of meteoric ^{10}Be soil profiles. ^{10}Be is mobile in the soil profile, and the maximum ^{10}Be concentration is often not in the soil's top layers (Pavich et al., 1986). We conservatively assumed that the highest measured ^{10}Be value at each of our sites represents the maximum ^{10}Be concentration in source soils at that site. We compared peak ^{10}Be concentration to the total ^{10}Be inventory in 48 soil profiles from our global database. We then used this correlation to estimate the total ^{10}Be inventory in the source soils of each of our 3 sites (Figure 2).

To convert a total ^{10}Be inventory to a soil age that corresponds to surface exposure duration, a ^{10}Be deposition rate must be known. ^{10}Be deposition rates in the interior of Greenland are well-constrained by measurements of ^{10}Be in ice cores (Finkel and Nishiizumi, 1997). To estimate the deposition rate in coastal areas, we applied the deposition per unit of precipitation in the mid-Holocene sections of the ice cores to the local annual precipitation at each of our field sites. Because it is not known whether the ice-bound sediment is sourced from coastal or interior regions, these two deposition rates form a bracket of possible ages. Our results show soil ages of 53-95 ka at Upernavik (72.5° N), 33-61 ka at Ilulissat (69.4° N), and 14-15 ka at Kangerlussuaq (67.1° N). These ages represent minimal surface exposure durations as glacial period isotope loss to decay and erosion are not considered.

The implied Upernavik and Ilulissat soil ages are too long to have been acquired in a single interglacial period. If soils were incompletely stripped during glacial periods, soils forming during interglacial periods would have a 10Be inventory inherited from previous interglacial periods. This inherited component would likewise be present in the interglacial period dust, whose wide distribution would add ^{10}Be to locations were it had been otherwise stripped by glacial erosion. Inherited ^{10}Be concentrations of approximately $5{\cdot}10^{7}$ atoms per gram are found in North American loess deposits that date from the Pleistocene-Holocene transition (Harden et al., 2002). These concentrations are similar to the average ^{10}Be concentrations in our samples.

Alternatively, the Upernavik sediments may be sourced from erosion-resistant Tertiary regolith. Cratonic regolith can be tens of meters deep. However, in extant 10Be saprolite profiles, concentrations sufficient to produce the highest Upernavik values are only found within the top 5 meters of the soil (Brown et al., 1988). As it is improbable that only 5 meters of regolith was eroded over the entire Quaternary, relict regolith accounts for at most an initial inherited signal that increased in intervening interglacial periods.

The younger soil age in Kangerlussuaq can be interpreted as more complete glacial period erosion of the interglacial period soils there. This interpretation is preferred to abbreviated Southern Greenland interglacial periods, as interglacial ice sheet retreat should be more significant in the Greenland Ice Sheet's climate-sensitive Southern Dome. If soils were consistently eroded over several glacial cycles, there would be little to no inherited ^{10}Be in southern Eemian soils.

Sub-ice sediment is entrained in glacial ice by the process of regelation, in which basal ice melts and refreezes around particles or obstructions in the glacial bed. If regelation occurs in an open-system where some of the melted water escapes into subglacial flow, then $\delta^{18}O$ and $\delta^{2}H$ values will be enriched as the heavier isotopes are preferentially retained (Iverson and Souchez, 1996). Because the regelation enrichment effect is stronger in $\delta^{2}H$ than in $\delta^{18}O$, open-system regelation lowers deuterium excess values in the regelated ice. Deuterium excess is defined as δ2H - 8*δ18O. At locations where open-system regelation has occurred, we expect a consistent trend with increasing $\delta^{18}O$ and decreasing deuterium excess. Open-system regelation is most likely to occur where there is abundant subglacial water. As subglacial streams are one of the most effective agents of subglacial erosion (Alley et al., 1997), sediment entrained by open-system regelation is more likely to be sourced from an area where erosion rates are high. As large volumes of subglacial water are derived from surface melts, lower latitudes are expected to have higher erosion by subglacial streams.

In comparing meteoric ^{10}Be concentration and deuterium excess in our samples, we find that the highest ^{10}Be values are found in samples where deuterium excess is also high and open-system regelation is therefore unlikely. The significantly lower meteoric ^{10}Be concentrations found at lower latitudes and the open-system relegation indicated by the deuterium excess values of these samples suggest that glacial erosion rates are significantly higher at lower latitudes and that glacial melt water may be partially responsible for this difference.

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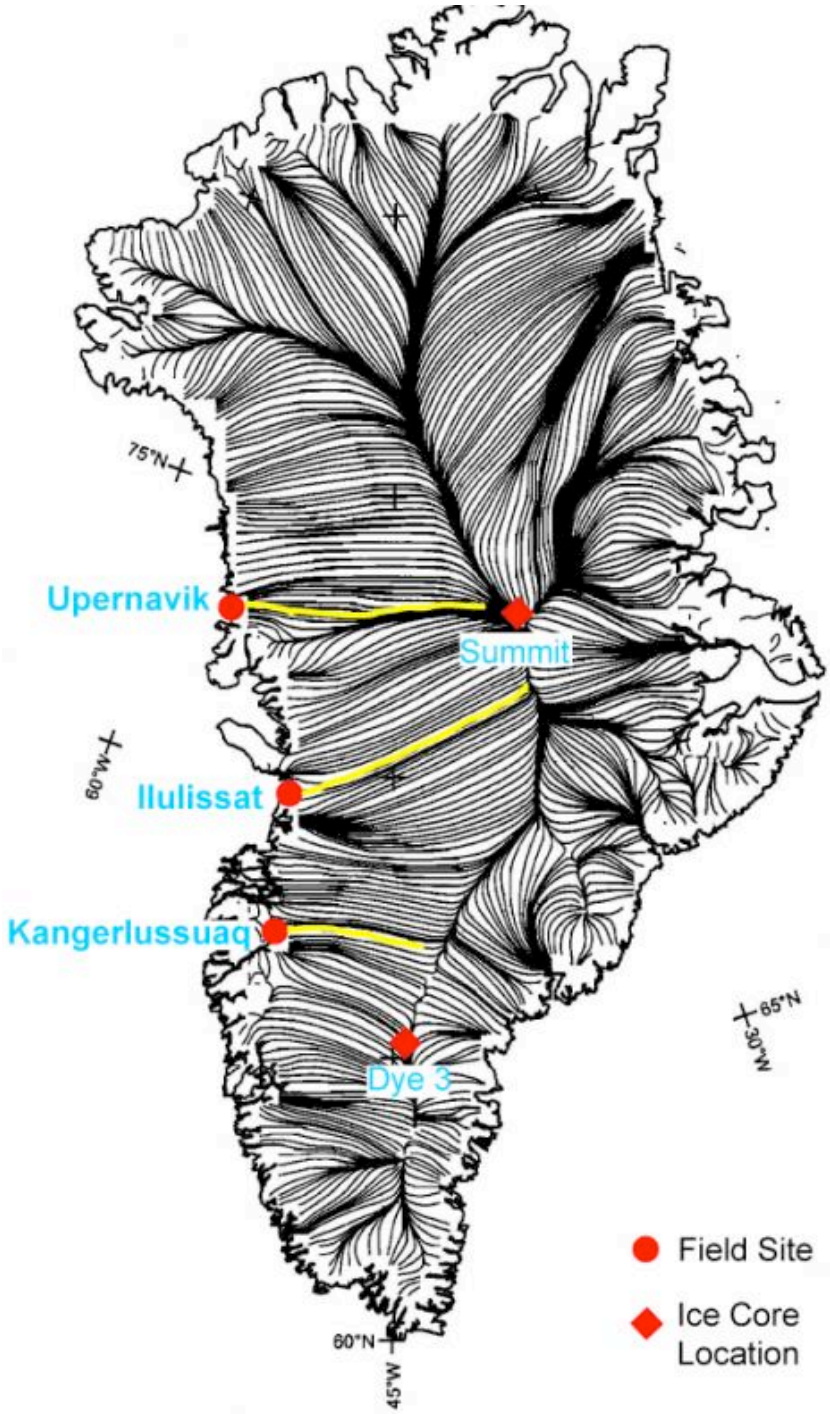

Fig 1.

Modeled glacial flowlines of Greenland (modified from Zwally and Giovinetto, 2001) showing the locations of our three field sites and the flowlines along which sediment may be sourced to these sites. The locations of Dye 3 and Summit Station are also shown.

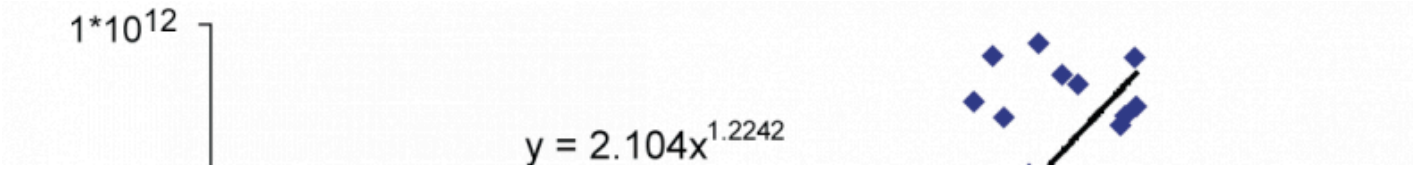

Fig 2.

Correlation between peak ^{10}Be and total ^{10}Be inventory in 48 soils from diverse global locations. Maximum measured concentrations at each of our three field sites are taken as approximations for peak ^{10}Be values in source soils and used to estimate total ^{10}Be inventory in source soils.

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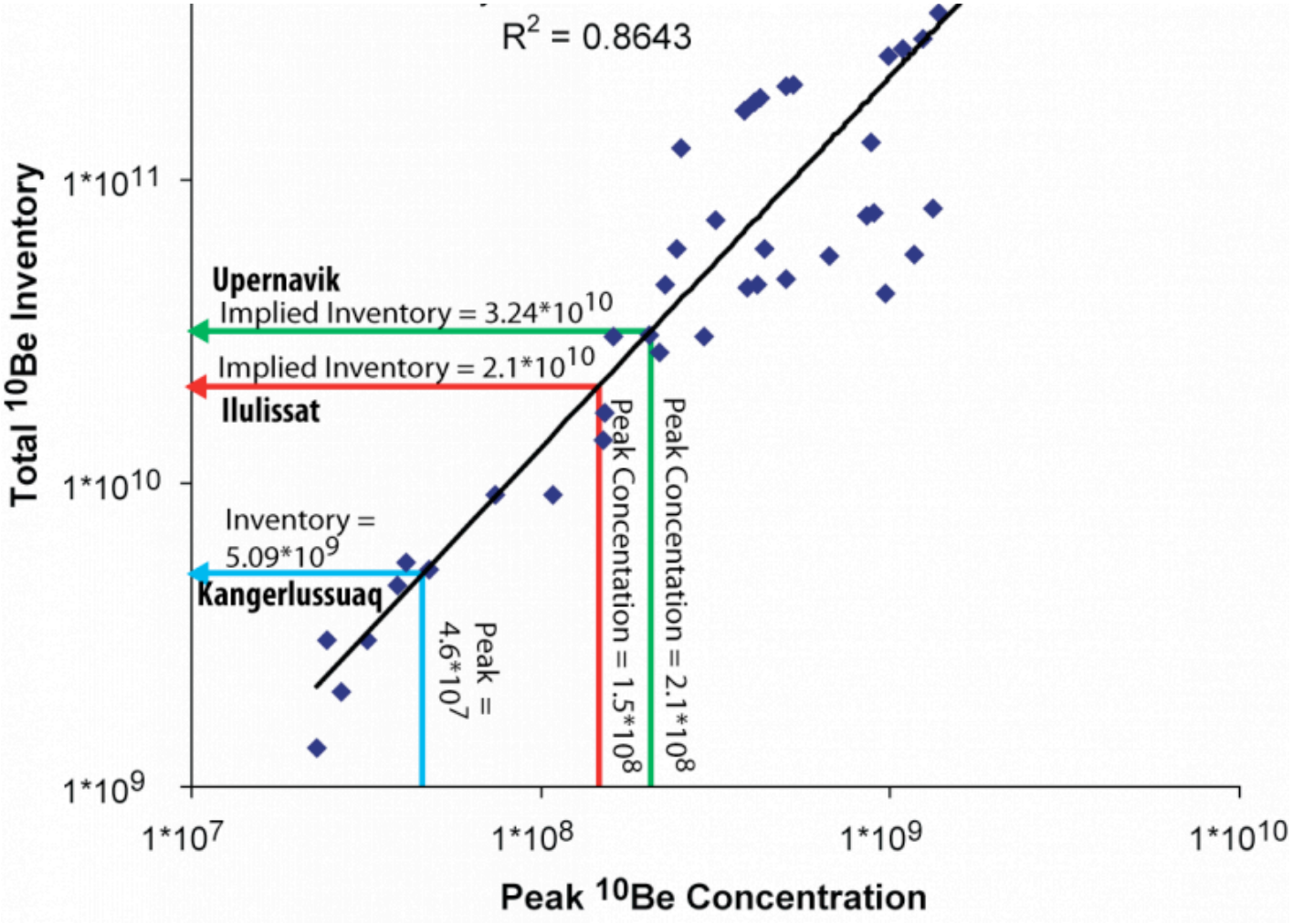

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