Paleoenvironmental reconstructions for pre-Holocene ice-free periods on northwestern Greenland using lipid biomarkers in Camp Century sub-ice sediments

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The terrestrial climate history of Greenland prior to the Holocene is poorly understood. However, reconstructing climate of pre-Holocene ice-free periods can provide valuable insights into how the Greenland Ice Sheet responds to warmth. Sediments recovered in the 1960s beneath the Greenland Ice Sheet at Camp Century in northwestern Greenland reveal five distinct stratigraphic units, each representing different depositional environments from bottom to top: Unit 1 is a till; Unit 2 is dominated by ice with few dispersed fine sediments; and the upper Units 3-5 are likely fluvial sediments. Optically stimulated luminescence ages suggest the uppermost sediment sample was likely deposited during Marine Isotope Stage 11. Lipid biomarkers were analyzed in all samples to infer past climate and environment: leaf wax distributions indicate vegetation communities, leaf wax hydrogen isotopes reflect plant source water isotopic composition, and branched glycerol dialkyl glycerol tetraether (bGDGT) distributions can indicate changes in temperature. All lipid biomarkers were likely produced on the northwestern Greenland landscape ice-free periods, and were either deposited *in situ* (Units 3-5), or were transported by ice and subsequently incorporated into sediments deposited at this site (Units 1 and 2). The abundance and the hydrogen (δ^2H) and carbon ($\delta^{13}C$) isotope values of long chain ($\geq C_{26}$) and mid-chain ($\leq C_{24}$) *n*-alkanoic acids were determined in all the samples. On the assumption that the apparent fractionation (ε) is constant over time, the empirically derived median epsilon values between leaf waxes and lakes and precipitation at high -latitude sites were used to convert the leaf wax to source water hydrogen isotope values.

The compositions of these leaf wax biomarkers are different between Unit 1, Unit 2, and Units 3-5. Unit 1 contains *n*-alkanoic acid distributions similar to modern terrestrial plant communities on Greenland. The $\delta^{13}C$ values of all carbon chain lengths are relatively stable throughout Unit 1. In this unit, the $\delta^{13}C$ values of long chain *n*-alkanoic acids are similar to modern shrubs, while the $\delta^{13}C$ values of mid-chain *n*-alkanoic acids are within the range of both modern shrubs and aquatic plants. Mid-chain waxes shared a similar pattern in term of $\delta^{2}H$ values, as well as the long-chain waxes. Unit 2 had consistent high concentrations of *n*-alkanoic acids, with $\delta^{2}H$ values generally ^{2}H-enriched compared to other units. Units 3-5 contain more abundant mid-chain *n*-alkanoic acids and comparison to modern plant $\delta^{13}C$ values indicates both terrestrial and aquatic plants may have contributed biomarkers to these sediments. This is also supported by the distinct $\delta^{2}H$ patterns between the mid- and long-chain *n*-alkanoic acids.

Source-water $\delta^{2}H$ values inferred from leaf-wax $\delta^{2}H$ values are close to modern precipitation $\delta^{2}H$ values at Thule, Greenland: precipitation $\delta^{2}H$ values inferred from long-chain waxes in Unit 1 are close to modern summer precipitation $\delta^{2}H$ values and pore ice $\delta^{2}H$, whereas precipitation $\delta^{2}H$ values inferred from long-chain waxes in Unit 1 are close to modern mean annual precipitation $\delta^{2}H$ values. Wax-inferred source water $\delta^{2}H$ values for all chain lengths in Units 3-5 fall between mean annual and summer precipitation $\delta^{2}H$ values, with long-chains ^{2}H-enriched relative to mid-chains and relative to pore ice. In Unit 2, wax-inferred source water $\delta^{2}H$ values are ^{2}H-enriched compared to other units, falling closer to modern mean summer precipitation $\delta^{2}H$, and strongly ^{2}H-enriched relative to pore ice, which is ^{2}H-depleted relative to mean annual precipitation $\delta^{2}H$.

The brGDGTs have different distributions between Unit 1, Unit 2, and Units 3-5, suggesting different environmental conditions or bacterial sources, but brGDGT distributions in all units fall within the range of those found in modern high-latitude lakes. Changes in the concentration,

distribution, and indices from Unit 3, through Unit 4, and into Unit 5 indicate different sources or environmental conditions. Given the similarity with modern lake brGDGTs, we applied a lake calibration to infer mean summer air temperature for each unit. The mean brGDGT-inferred summer air temperature for all units is 5.0 to 5.9°C, 2°C warmer than modern summer air temperature at Thule. These values are close to other regional records of early Holocene temperature. These temperature and source water hydrogen isotope results suggest that climate and vegetation on northwestern Greenland that led to pre-Holocene ice-free periods was similar to that of the Early Holocene.