Sedimentological observations aided by microCT scans of NW Greenland sub-glacial sediment core provide evidence of ice-driven and ice-free surface processes during MIS11

Cat Collins[1,2], Nico Perdrial[1,2], Zoe Courville[3], PH Blard[4], Halley Mastro[1,2], Juliana Souza[1,2], Paul Bierman[1,2]

1.University of Vermont, Burlington, VT USA, 2 Gund Institute for Environment, Burlington, VT USA,
3. Cold Regions Research and Engineering Lab Hanover, NH, USA, 4. Université de Lorraine, Vandœuvre-lès-Nancy, France

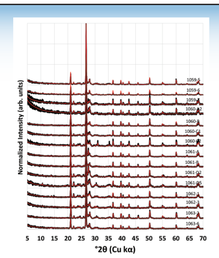
Introduction

Camp Century was the first deep ice core extracted from Greenland in the 1960s. Underneath nearly a mile of ice, an unprecedented 3.5m of subglacial sediment was brought to the surface. Recent analysis of the sediment indicates that NW Greenland experienced extended ice-free conditions during MIS 11 (Christ et al., 2021, 2023).

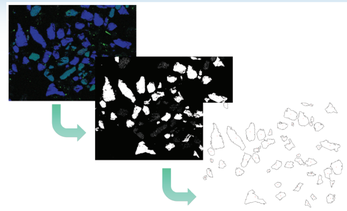
Our objective is to determine the landscape evolution of this ice-free period using multi-scale sedimentology characterization methods.

Methodology

We investigated these sediments on three scales
At the macro scale we used X-ray diffraction (XRD) to understand mineral assemblage throughout. At the meso scale we utilized 3D models constructed from micro computed tomography (uCT) scans to observe sediment structures. Lastly at the micro scale we used scanning electron microscopy (SEM) and electron dispersive spectroscopy (EDS) to investigate individual grain coatings, shape, and size. We used these combined observations to refine our understandings of the paleo-environment in Greenland during MIS11.



Quantitative XRD diffractograms of bulk sediment samples. A representative selection of 15 samples were extracted from the core, ground, and analyzed using the Rietveld method (Rietveld, 1969).



Steps used in SEM/EDS image preprocessing. Chemical map is shown in the left most image. The second image was creating using a color threshold to isolate the quartz grains. Then particle analysis was performed in ImageJ to extract grain size, circularity, and roundness.

Results

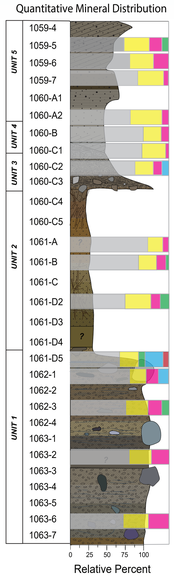
Scales:

Macro: sediment composition

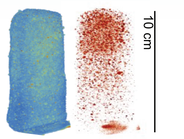
Meso: sedimentary structures

Micro: grain characteristics

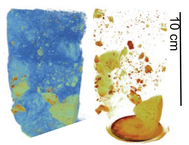
Quantitative Mineral Distribution



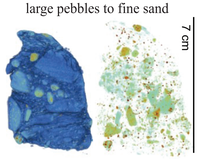
Quantitative mineral distribution modeled by qXRD. Sediments are dominated by quartz, plagioclase, and k-spars with minimal variability throughout. The presence of pyroxenes in unit 3 and at the top of unit 1 and a 14A phase at the top of unit 1 is noteworthy.



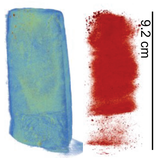
1059-5: "unit 5", bedded sand that coarsens upward



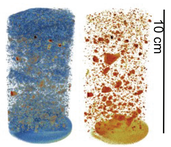
1060-C3: "unit 3", deformed sediment fines upward from large pebbles to fine sand



1062-1: "unit 1", poorly-sorted homogenous diamicton

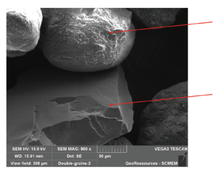


1060-C1: "unit 4", fine grained bedded sand, cross cuts lower unit



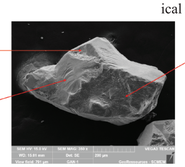
1061-D3: "unit 2", ice containing suspended sediment with some linear alignment

Legend for µCT images
Low Material density High



Rounded grain with weathering, dissolution pits, and fresh fractures
1. Fluvial transport
2. Long storage in soil
3. Glacial crushing?

Angular edges
=> Fresh bedrock release from glacial advance

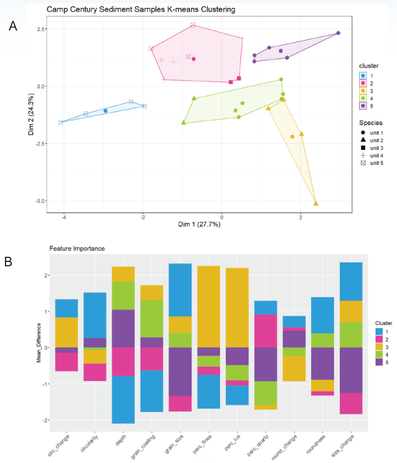


3- Glacial depression, weathered particles adhered to surface

2- younger glacial crushing, concoidal fractures and deep grooves

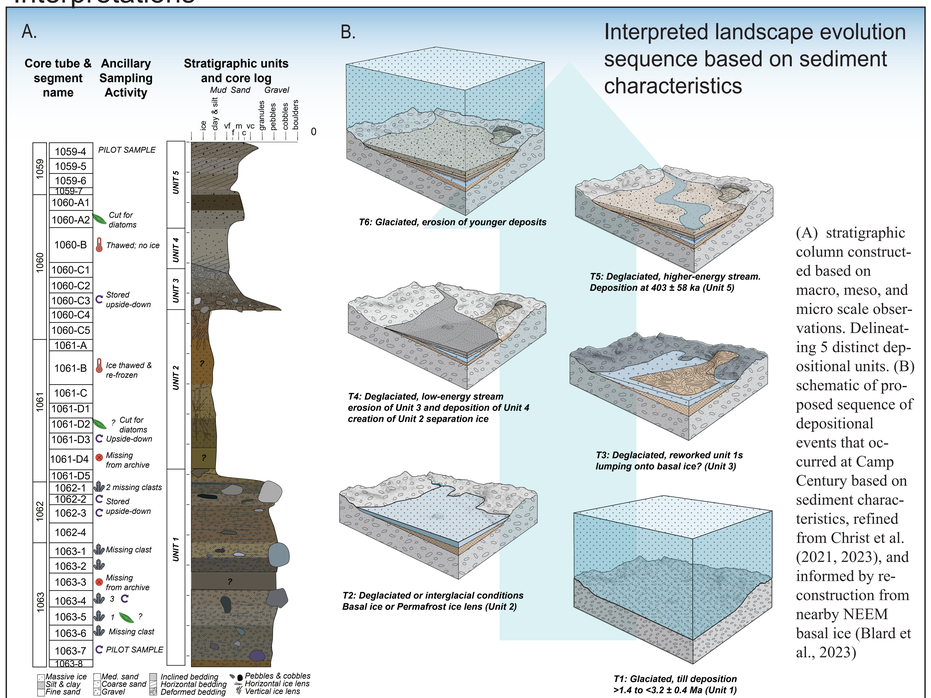
1- Intense weathering of "high relief glacial surface"

Data Exploration



(A) K-means clustering with input parameter values collected from SEM/EDS analysis. 5 clusters were selected to represent the system. With slight variations, the outcome is in good agreement with the units suggested at the macro/meso scale. (B) Z-score of each parameter was calculated by feature within each cluster. This illuminates linkages to depositional surfaces processes.

Interpretations



Interpreted landscape evolution sequence based on sediment characteristics

(A) stratigraphic column constructed based on macro, meso, and micro scale observations. Delineating 5 distinct depositional units. (B) schematic of proposed sequence of depositional events that occurred at Camp Century based on sediment characteristics, refined from Christ et al. (2021, 2023), and informed by reconstruction from nearby NEEM basal ice (Blard et al., 2023)

Conclusions

Macro: Slight variation in relative mineral abundance indicated source material stability affected by variable transport porcesses.
Meso: The preservation of the sediment forms allows us to interpret layer with respect to original depositional conditions.
Micro: Grain surfaces preserve depositional information. Parametric clustering analysis of microscale features refines meso-scale stratigraphic analysis and identifies influential parameters on cluster outcomes which links to underlying environmental processes.
Our analysis suggests that:
1. Multiscale sedimentology analysis is a powerful tool to determine paleo-landscape characteristics under ice.
2. NW Greenland experienced an extended ice-free period with an evolution of the landscape from periglacial to fluvial during interglacial conditions (MIS 11, Christ et al. 2023).
3. With continued warming, the dynamic landscape evolution recorded by Camp Century during MIS 11 serves as a template for predicting future processes resulting from the destabalization of the Greenland Ice Sheet.

Acknowledgments

Dr. Kristen Underwood (UVM), Dr. Andrew Christ

Research supported by NSF-OPP-2114629 to Bierman.
Laboratory support at the University of Vermont from NSF-EAR-1735676 to Bierman and Corbett.

for more info, visit our website campcentury.org:

Literature Cited

Blard, P. H., et al.. (2023). Basal debris of the NEEM ice core, Greenland: a window into sub-ice-sheet geology, basal ice processes and ice-sheet oscillations. J. Glaciol., 268(11).

Christ, A. J., et al. (2021). A multimillion-year-old record of Greenland vegetation and glacial history preserved in sediment beneath 1.4 km of ice at Camp Century. PNAS, 118 (13) e2021442118

Christ, A. J., et al. (2023). Deglaciation of northwestern Greenland during Marine Isotope Stage 11. Science, 381(6655), 330–335.

Rietveld, H. M. (1969). A profile refinement method for nuclear and magnetic structures. J. Appl. Cryst. 2, 65-71.