

Project Title: Interpretations of Polar Environments at the Nanoscale

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Project Background and Justification

X-ray computed tomography (CT) provides non-destructive 3D imaging and analysis of internal structure for any porous media. Our team utilizes CT imaging to probe permafrost and sea ice for microbes in samples collected from Alaska, Canada, and Greenland. Recent advances in this technology now allow for imaging at the nanoscale, where we ultimately seek to visualize microorganisms inhabiting the pore spaces. By characterizing this structure, we will further our understanding of how microbial communities relate to their environment, and how changes such as increased freeze/thaw cycles in a changing climate may impact their health and microbial function. In addition to imaging the permafrost and sea ice, we extract DNA from samples to examine microbe diversity to connect the physical and biological characteristics of cores from different sites and by depth. This work will provide the first images of permafrost and sea ice at the nanoscale.

The knowledge gained in developing the nano-scale imaging techniques to characterize permafrost, snow, and sea ice, and then locate microbes will help answer a variety of applied research questions. These include, but are not limited to:

- How do microorganisms impact material properties of permafrost soils, snow, and sea ice? Do they contribute to the strength by altering the microstructure? Does their orientation have any impact on the material properties?
- What can nano-scale parameters of structure tell us about the overall strength of the material? Can quantities such as pore connectivity or pore sizes be used to determine the ability to install infrastructure on various terrain?
- How might material properties change as a result of climate change? What is the influence of freeze-thaw cycles on the distribution of microbial communities and biologic processes? How significantly do freeze-thaw cycles impact the microstructure and subsequent material strength of various media?
- What microbes are there in permafrost and sea ice, and based on their growth niche, which will be most likely to perish when environmental conditions change?

We are only just beginning to realize the critical importance of sub-micron level detail on the structure and biological function within various environmental media. In a changing climate, nowhere is this more operationally essential than in the Arctic. Microbes are ubiquitous in Arctic ecosystems, but their precise microstructural location and distribution remains unknown. Increased freeze-thaw cycling in permafrost stresses this environment, resulting in changes to the microbial community function. This work attempts to leverage existing resources and advances in imaging capabilities to improve our scientific understanding of these biogeochemical processes.

Field Research and Methodology

The entire scope of this project involves fieldwork across the Arctic, covering Alaska, Canada, and Greenland. For the fieldwork in Cambridge Bay May 11-25 2025, we will select 5-6 permafrost locations outside of town and accessible by truck. As much as possible, we will seek to co-locate field sites with previous permafrost studies for comparison with the literature and traditional ecological existing knowledge. Similarly, we will select 5-6 sea ice coring locations in the Cambridge Bay harbour to be accessed via snow machines. Both sea ice and permafrost cores will be approximately 1 m in length and 7.5 cm in diameter. All cores will be shipped back to Vermont at sub-eutectic temperatures until imaging as described above.

Sharing Results:

While in Nunavut, we plan to share our work with the local community via public presentations and outreach events in the local school if welcomed. For any community where we complete fieldwork, we prioritize sharing our research with the local community and thoroughly enjoy the exchange of ideas at such gatherings. For example, while in Utqiagvik, Alaska in February 2025, we presented at a community dinner gathering as well as with the local high school. We try to get students using our drills to core their own samples of either permafrost and sea ice, and let the students get hands on experience looking at the ground beneath them.

Additionally, we plan to publish the scientific findings of this work in peer-reviewed academic journals and present at both scientific conferences and with the general public. Already we have presented at the American Geophysics Union annual meeting (December 2024), as well as local presentations at Vermont State University. We plan to continue reaching out to schools in our area upon returning to Vermont.