Subglacial Access Working Group
Access Drilling Priorities in Subglacial Aquatic Environments

1) Summary: Subglacial hydrodynamics are an important yet poorly understood factor in ice sheet dynamics in both Antarctica and Greenland. The volume and distribution of water exert a strong influence on the resistance of the bed to ice flow and therefore, is an important control over ice velocities. Aqueous and sedimentary subglacial environments in Antarctica and Greenland are inhabited by microorganisms and are a potentially large planetary reservoir of microbes and (microbially derived) organic carbon, perhaps of the same magnitude as that in the surface oceans. Modeling suggests these environments could contain large volumes of the greenhouse gas, methane, which could impact atmospheric methane concentrations in response to rapid deglaciation. It has also been hypothesized that the flux of dissolved elements and sediments in subglacial waters can enhance primary productivity in the marine environments that they drain into. Elucidating the spatial and temporal distribution and dynamics of these aqueous environments, including their physical and chemical properties (such as temperature, salinity and pressure) and associated biogeochemical processes (i.e. microbial communities and material fluxes) is key to understanding ice sheet stability and the role of large continental ice sheets in global biogeochemical cycles. The rapid changes anticipated in the size of polar ice sheets may trigger significant reorganization of subglacial hydrologic conditions, which may feed back into acceleration of ice sheet retreat and may force adaptation of subglacial biota to rapidly changing conditions.

2) Compelling research questions:
These research questions are not listed in a prioritized order, and they primarily focus of microbiology, geochemistry and its interaction with subglacial water and geology. These dovetails with many of the questions raised in other white papers and could be addressed in research projects combining different scientific expertise to maximize outcomes from subglacial access drilling.

2.1 What is the volume distribution of subglacial water and what controls its temporal variability in both Antarctica and Greenland? What are flow velocities and discharge capacities? In what mode is the subglacial water – distributed sheet, channel/canal, interstitial within subglacial sediment, lakes, groundwater? How does the relative distribution of these modes change on seasonal and inter-annual timescales? Are physical and chemical properties of these aquatic systems spatially variable, and, if yes, how is this variability controlled by glaciological and geological factors?

2.2 How much subglacial water is transported to the ocean, on what timescales, what is the chemical and microbiological composition of the transported water, and does it significantly affect ocean biogeochemistry (e.g., primary production, drawdown of atmospheric CO_2)? How much of the water generated in the interior is refrozen to the base of the ice versus flowing directly to the ocean? To what degree does subglacial freshwater discharge affect stratification and mixing in the coastal ocean?

2.3 What is the phylogenetic and metabolic diversity of microbial ecosystems below polar ice masses. What are the physical, chemical, and ecological factors that control their diversity?

2.4 What are the spatial and temporal biogeochemistry trends of subglacial aquatic environments? What processes control these differences?

2.5 How do the changing distribution, temperature and composition of water below polar ice masses affect glacier dynamics?

2.6 How variable is subglacial geothermal heat flow across the ice sheets? What control does that have on ice dynamics and microbial ecosystems? Do extremely high heat flow and/or volcanic eruptions locally, have the potential to drive catastrophic ice sheet demise?

2.7 How long have the water and life below the polar ice masses been isolated from the surface?

3) Scientific rationale:
Scientific drilling that provides access to and samples of subglacial water and sediment environments is necessary to address key priorities laid out by the NAS 2015 report on *A Strategic Vision for NSF Investments in Antarctic and Southern Ocean Research.* Specifically, samples retrieved from subglacial environments will allow for the measurement of metabolic activity, flux of important biogenic gases (i.e. CO_2 and CH_4), composition of the microbial communities, and elements mobilized from the subglacial environment that may impact global biogeochemical cycles. Biomarkers (microbial fossils) and phylogenetic histories contribute to multiple records of past ice sheet change to understand rates and processes. Very few samples have been available from below the world's ice sheets for microbiological analyses. New samples would allow genomic and transcriptomic analysis of biological adaptation and response across Antarctic organisms and ecosystems which would address Strategic Priority II on the evolution and adaptation of Antarctic biota.

Only one project (WISSARD) to date, has directly sampled an aquatic environment at the bed of a polar ice mass using a microbiologically-clean hot water drilling technique. Other samples of subglacial water and sediments have been collected from below the Kamb Ice Stream (clean access not employed), from subglacial outflow from below the Taylor Glacier at Blood Falls, accretions ice of Subglacial Lake Vostok, Antarctica, and basal ice and subglacial outflow from Greenland. These samples as well as many others from alpine glaciers have demonstrated that active microbial communities exist in subglacial environments. These organisms are capable of metabolizing in the absence of light and importantly mediate the biogeochemical cycling of elements including C, Fe, S, N, Si, and P.

Direct in situ measurements and retrieval of water and sediments from a range of subglacial environments collected using clean access techniques are required to advance the state of knowledge, including both spatially distributed sampling, and time series measurements of physical, chemical and biological parameters (including redox sensitive dissolved gases such as H_2, CH_4 and H_2S) at the bed over both short (hours to days) and long (months to years) time scales.

4) Drilling parameters:
Clean access is required to preserve the scientific integrity of the samples and for environmental stewardship:

- Access holes with targeted ice core acquisition over short intervals.
- Specific focus on recovery of basal ice cores, with variable debris concentration
- Ice thickness vary from 200m (dry valley outlet and alpine glacier) up to 1200m on ice streams and >3000m for large subglacial lakes.
- Hole diameter will vary by specific project but can range from 10cm to 70cm with smaller diameters for the deeper access holes.

5) Sampling requirements
Direct sampling of the subglacial environment guided by remote sensing data and ground-based geophysical surveys (see Tulaczyk et al., 2014; Annals of Glaciology for details on sample borehole tools and their deployment timeline):

- Collect water samples (ca. 1-10L at a time; at discrete depths where applicable, pumping samples to the surface in some cases for specific analyses).
- Collect subglacial sediment cores (1-3m in general, 10m).
- Deploy sub-ice in-situ water filtration systems.
- Inspect subglacial environments with cameras and/or AUV/ROV vehicles.
- Install a range of sensors beneath and within ice for collection of a spectrum of time-series data.
- Collect short ice cores at target depths and collect basal ice core samples.
- Deploy custom-made PI instrumentation with varying weight (typically <100-1000 lbs but occasionally several thousands of lbs).
- Provide safe working platform around the borehole.

6) Target locations (where):
The abundance and interconnectivity of water beneath polar ice sheets, largely demonstrated through remote sensing techniques, indicates significant and varied aquatic systems including lakes, both active and closed-basin, saturated sediments, aquifers and channelized and linked cavity drainage systems. There is also importance in collecting sediment samples below very old ice near the Gamburtsev Mountains and from deep sedimentary basins in East Antarctica such as Wilkes Basin. These systems can range in terms of chemical and biological properties due to nutrient availability controlled by subglacial geology, salinity, oxygen content and their proximity to enhanced subglacial energy sources such as volcanic or hydrothermal areas.

The group finds high science value in linking hydrological and biogeochemical studies with any project designed to access subglacial environments and although we do not have a prioritized list of specific targets we strongly encourage projects that integrate these components. Potential sampling targets could include distributed and channelized water systems, as well as active lakes beneath Thwaites Glacier and the Siple/Gould Coast region in West Antarctica, including their grounding zones, East Antarctic outlet glaciers (e.g. Taylor Glacier), active and closed-basin lakes, the Leverett/Russell Glacier region in West Greenland, and the Northeast Greenland Ice stream, potential subglacial lakes near Thule, Greenland.

7) Target timeline (when):
Time frame varies by project. A project targeting Subglacial Lake Mercer, West Antarctica, that proposes fieldwork in the 2017-18 field season is under consideration by NSF, but is not currently funded. There are numerous proposals that address the research questions proposed here aimed at exploring diverse aquatic environments.

Synergistic opportunities exist among the other realms discussed including Thwaites, the Ross Ice Shelf and continental interior targets. The New Zealand Antarctic Programme effort on and through the Ross Ice Shelf will happen in the 2017-2018 and 2018-2019 field seasons, as currently planned. Linking projects across realms is a priority but does not need to be synchronized in the same season. Primary locations along the Thwaites Glacier have been identified with multiple drilling field seasons proposed for field seasons starting in 2019. Possible leveraging opportunities exists at Leverett/Russell in West Greenland where U.K.-based groups are actively working on glacier dynamics and meltwater biogeochemistry.

8) Support requirements (how):

- Drilling capabilities vary depending on targets: for larger borehole projects needing a single or few large boreholes, the WISSARD drill and the Roving Hot Water Drill have demonstrated success. These tools currently require significant mobilization support by the ASC, which is appropriate for some targets and project strategies; however, there is a strong need to diversify and provide capabilities that are more flexible and can address a range of project strategies.

- Smaller projects including thinner outlet glaciers and projects that require spatial sampling (2-3 holes or more), more agile capabilities are needed using technologies comparable to the proposed Scalable Hot Water Drill (ScHWD).

- PI-driven instrumentation and clean access requirements for tools such as monitoring capabilities similar to borehole 'CORKS' and the ability to instrument water cavities. To address environmental stewardship concerns, these tools should be constructed out materials that do not pose environmental harm and these tools should be retrievable.

- The diameter of instruments/samplers should be minimized to the maximum extent possible to decrease the need for larger boreholes. These instruments should be designed with clean access approaches in mind.

- Transport depends on project size: larger projects using the full WISSARD drill require traverse capabilities, smaller projects using an agile drill can be serviced with Twin Otter or Basler. Known existing thermal melting drills can be supported by helicopter. Drills and support staff also scale with project.

- Depending on complementary projects that are funded at the same time, traversing capabilities and support need to be invested for future science needs.

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