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Methodology for clean access to the subglacial environment associated with the Whillans Ice Stream

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Introduction

The Whillans Ice Stream Subglacial Access Research Drilling (WISSARD) project is focused on addressing two top-level scientific issues: (1) the potential for the West Antarctic Ice Sheet (WAIS) to make a large contribution to near-future global sea level rise, and (2) the presence of microorganisms and microbial habitats in dark and cold subglacial aquatic environments. The overarching hypothesis being tested is that active hydrological systems beneath WAIS connect subglacial environments and exert major control on ice sheet dynamics, geochemistry, metabolic and phylogenetic diversity, and biogeochemical transformations of major nutrients. WISSARD will explore two subglacial water systems: (1) the active Subglacial Lake Whillans located about 100 km upstream of the grounding line, and (2) the grounding line of Whillans Ice Stream, where ice comes in contact with the upstream edge of the Ross Ice Shelf seawater cavity.

Glaciological studies have highlighted the fact that subglacial water flow and active subglacial lakes may have a significant impact on ice sheet stability [Gray et al., 2005; Fricker et al. 2007; Bell, 2008; Stearns et al., 2008]. Subglacial environments also represent unexplored components of the terrestrial biosphere. In spite of low temperatures, continuous darkness, and isolation from direct atmospheric input, subglacial environments have been shown to support a diversity of microbial life. In fact, prokaryotic organic carbon in subglacial Antarctic ecosystems may be higher than in all surface freshwater lakes and rivers on Earth [Priscu and Christner, 2004; Priscu et al., 2008]. The WISSARD project offers an opportunity to gain direct access to critical subglacial aquatic environments for direct sampling and in situ measurements which will address outstanding scientific issues with potentially broad social implications.

The WISSARD project has developed a set of tools, processes, and procedures to protect the environment and samples to be collected. One critical consideration is the water retention time, or drain/fill cycle, in Subglacial Lake Whillans (SLW), as the retention time strongly influences the duration of any potential impacts caused by the project. WISSARD hot water drilling efforts will include a custom filtration system designed to 1) remove particles (biotic and abiotic), 2) irradiate the borehole water with ultraviolet (UV) radiation, and 3) subsequently pasteurize the water to reduce microbial contamination. WISSARD clean access protocols will also include methods to clean the surfaces of cables/hoses and down-borehole equipment using germicidal UV-based and chemical approaches. These tools, processes, and procedures are based on proven off-the-shelf technology, and have been configured based on experience; results from testing of new equipment and processes; and information from the Lake Vostok and Lake Ellsworth projects.

This paper summarizes information on (i) the hydraulic retention time of SLW, (ii) results from experiments designed to test the efficacy of the filtration system, and (iii) disinfection protocols to be used at drilling sites where biological clean access is a requirement. A more detailed report will be available on the project’s website: http://www.wissard.org

Hydraulic Retention Time of SLW

Analyses of satellite data indicate that SLW has an area of 59 km^2 ± 12 km^2. Data from a high density surface geophysics survey indicates that the lake depth is approximately 8 m, making the total lake volume less than 0.5 km^3. The same data also indicate that the subglacial water volume change during fill-drain cycles of SLW is 0.15 km^3. Consequently, it would take fewer than four fill-drain cycles to exchange the total lake volume. Given that SLW has undergone two complete fill-drain cycles over a 6-year period, we estimate that a water residence time for the lake on the order of 10 years, or less. This decadal scale flushing time for SLW is nearly 100 times faster than that for Subglacial Lake Ellsworth (750 years) and about 1000 times faster than the water residence time for Subglacial Lake Vostok (10,000 years).

Efficacy of the Filtration System

The WISSARD Project is committed to clean access, both for the quality of the samples and to preserve the ecological value of Subglacial Lake Whillans. To ensure that the proposed methods will be successful, WISSARD recently tested components of the clean access system in a laboratory in the United States. WISSARD plans to complete more comprehensive testing in Antarctica during the 2012-2013 season; 1 year prior to SLW entry. The results of the six tests performed on the borehole filtration and UV radiation subsystems in January 2011 are summarized below.

Dye study to determine flow characteristics.

This study was conducted to measure the retention time of water in the filtration unit and to calculate the time required to ensure that the entire water volume from an 800-m borehole passes through the filtration system. These times are used to define the drilling rate needed to achieve the required levels of borehole water cleanliness. The hydraulic retention time measured was about 20 minutes. Therefore it is estimated that it will take approximately 6.2 hours for all of the water in an 0.3-m diameter borehole that is 800 m deep (water volume of 57 m^3) to pass through the system. Completion of a single borehole is expected to take about 24 hours. Therefore the borehole water will go through the filtration system approximately four times while each hole is made. The WISSARD team will have the ability to monitor cleanliness levels of the water going through the drill system. Drilling progress can be stopped before penetrating to the bed to allow the borehole water to circulate through the filtration system until it reaches the recommended level of cleanliness.

Fluorescent micro-bead test to examine the capability to remove abiotic particles between 2-5 μm.

During one pass through the system, the 0.2 and 2 μm filters collectively removed 99.8% of a known concentration of 1-5 μm bead particles from the water.

Silt removal experiment to examine the capacity for the filters to remove sediment.

This test of the performance of the filter system used a starting concentration of silt and clay sized particles of 0.395 g l^{-1}, which is within the range of potential concentrations anticipated in the borehole water (0.0175 g l^{-1} and 1.75 g l^{-1}. Retention time of silt through system without filters in place was approximately 12 min. Addition of the 2 µm filter removed 97.5% of the silt and clay particles after 40 min. Over a 15 hour runtime (75 times the retention time) the 2 µm filter provided a greater than 3 orders of magnitude reduction in particle concentration.

Bacterial culture test to specifically address the ability of the UV system to kill bacteria with known UV tolerances.

Exposure of *Escherichia coli* to the 185 nm and 254 nm UV light banks at flow rates between 5 and 80 gal min^{-1} (the anticipated average flow rate of the drill and filter system is between 25 to 35 gal min^{-1}) produced at least a 4 orders of magnitude reduction (to the methodological detection limit) in viable cells.

Pond water test to examine the filtration efficiency and disinfecting properties of the UV lamps on natural aquatic microorganisms.

Water from the filtration units that was passed though the UV modules contained at least 20 fold fewer viable cells than the input water. This level was below the detection limits (measured using a formazan dye based method). The cellular ATP concentration, a proxy for microbial biomass, in the tank over the course of experiment 2 (micro-bead test) revealed that cellular ATP decreased by 3 orders of magnitude (detection limit) following 15 minutes of circulation (one pass of water through the system).

Pond water pasteurization test to assess the influence of the heat generated by the hot water drill on microbial viability.

To simulate the anticipated effects of pasteurization in the hot water drill boiler, lake water was heated to 85^{o}C for two minutes, producing a 2 orders or magnitude reduction in the number of viable heterotrophic cells detected. This reduction is in addition to the 4 orders of magnitude reduction provided by the filtration system and 1orders of magnitude to 4 orders of magnitude reduction provided by UV irradiance.

Disinfection Protocols

Disinfection protocols using 3% H_2O_2 and *E. coli* were tested on material (stainless steel tubes and plastic section) representative of equipment that would be used during the project. A solution containing E. coli (1 x 10^7 cells ml^{-1}) was applied to the surfaces and allowed to dry for 5 minutes. Disinfection protocols were applied to control and treated sample surfaces. After cleaning, all samples were below the limit of detection, indicating at least a 3 orders of magnitude reduction in viable *E. coli* cells. These results indicate that spraying instruments with 3% H_2O_2 and allowing this chemical to react with the surface for at least 1 minute before down borehole deployment of instruments is effective at killing the test bacterium.

Results

As tested, the system as a whole reduced all cell/particles 4 orders of magnitude. One passage of a volume of water through the treatment system reduced the total number of microbes by 4 orders of magnitude, and over 99.99% of cells remaining in the water were killed by UV irradiance and pasteurization. For comparison, if seawater was used (10^6 cells/mL) as the input, the water coming out would meet the NRC recommendation (i.e., a 4 orders of magnitude reduction of 10^6 cells/mL is 100 cells/mL; NRC 2007). It is important to note the water from the melted ice and snow that will be used in the borehole is expected to have 10^4 fewer microbial cells than seawater.

While treatment of the water with UV or pasteurization does not physically remove cells, the tests have shown that both of these additional treatments together reduce cell viability another approximately 3 orders of magnitude. Therefore, the combined treatment system is expected to exceed the NRC recommendation for biological cleanliness in subglacial environments (NRC 2007).

Given the rapid flushing of SLW to the sea and the effectiveness of the tests, the WISSARD project has rigorously addressed the stewardship issues described in the NRC report "Exploration of Antarctic Subglacial Aquatic Environments" and the SCAR Code of Conduct.

In addition to using the clean access system (discussed in this paper), further protective procedures will be implemented to access Subglacial Lake Willans. After establishing a clean borehole, and prior to subglacial breakthough, the water level will be reduced to create and maintain under-pressure in the borehole. This ensures that very little mixing will occur between the borehole and subglacial water upon and after entry. In addition, borehole water can be recirculated, without drilling, to ensure that water meets 'clean standards' prior to entry into Subglacial Lake Willians. This combined approach will further help to protect the pristine Antarctic environment during drilling operations and lake entry.

References

Fricker, H. A., T. A. Scambos, R. A. Bindschadler, and L. Padman (2007), An Active Subglacial Water System in West Antarctica Mapped from Space, Science, DOI: 10.1126/science.1136897.

Gray. L., I. Joughin, S. Tulaczyk, V. Spikes, R. Bindschadler, and K. Jezek (2005), Evidence for subglacial water transport in the West Antarctic Ice Sheet through three dimensional satellite radar interferometry. Geophys. Res. Lett., 32, doi:10.1029/2004GL021387.

NRC Report. 2007. Exploration of Antarctic Subglacial Aquatic Environments: Environmental and Scientific Stewardship. The National Academies Press, Washington D.C. 166p. Authors: J.E. Hobbie, A. Baker, G. Clarke, P.T. Doran, D. Karl, B Methe, H Miller, S.B. Mukasa, M. Race.W. Vincent, D. Walton and J. White.

Priscu, J.C., and B. Christner (2004), Earth's Icy Biosphere. 130-145, In: A.T. Bull (Ed.) Microbial Diversity and Prospecting. ASM Press, Washington, D.C.

Priscu, J.C., S. Tulaczyk, M. Studinger, M.C. Kennicutt II, B.C. Christner, and C.M. Foreman (2008), Antarctic Subglacial Water: Origin, Evolution and Ecology. In: W. Vincent and J. Laybourn-Parry (eds.), Polar Lakes and Rivers. Oxford University Press. 119-135.

Stearns, L. A., B. E. Smith, and G. S. Hamilton (2008), Subglacial floods cause increased flow speeds on a major East Antarctic outlet glacier. Nature Geoscience, doi: 10.1038/ngeo356.