TOWARD VERTICAL PROFILING OF ORGANICS IN PLANETARY ICES WITH ECONOMICAL USE OF SPACECRAFT RESOURCES. D.P. Winebrenner[1], R.C. Bay[2], and N.E. Bramall[3], [1]University of Washington, Box 355640, Seattle, WA 98195, dpw@uw.edu , [2]University of California Berkeley, bay@berkeley.edu, [3]Leiden Measurement Technology, n.bramall@leidentechnology.com

Introduction: Understanding the occurrence and evolution of habitable (or inhabited) niches in planetary ices requires information on depositional history and transport of organics (or biomolecules or organisms) [1,2]. Data on vertical distributions of organics are thus critical for astrobiological exploration of Mars and Ocean Worlds, as well as Earth.

Borehole sidewall imaging of polar ice at Greenland Summit, using native fluorescence excited by ultraviolet light, has revealed organic matter 'hotspots' with depth-varying compositions and abundance [3] (somewhat analogous to imaging of organics in terrestrial [4] and Martian rocks [5]). This imaging promises exceptional insight about ice microhabitats but presently requires at least minutes to image areas of a few square centimeters. This in turn significantly limits the cadence of data acquisition at different depths, and requires not only deployment to depth in the ice, but also the ability to hold the instrument stationary in the hole during imaging. Mechanically drilled boreholes can support 'parking' for data acquisition, but are (at least historically) very expensive and low TRL for depths greater than ~100 m. The newest generation of ice melt probes with internal winches [6] may support 'parking', but are presently also logistically complex, far from flight-ready, and limited to depths of ~200 m.

Means to survey organics relatively rapidly, over a wide range of depths and at relatively low logistical (i.e., spacecraft resource) cost, would therefore be valuable for locating features that merit high-cost investigation, and for understanding such features in their large-scale context.

Here we outline an approach to realizing such surveys in terrestrial analogs in the near-term, by combining previously separate work on: (1) non-imaging deep-UV fluorescence profiling in ice, which has demonstrated fine depth resolution and high sensitivity, with discrimination between mineral and organic fluorescence, as well as some discrimination between organic fluorophores [7-9]; and (2) a vehicle for fluorometer deployment, namely an ice melt probe which will be commissioned to 3000 m depth at Greenland Summit in Summer 2023. Melt probes can meet planetary protection standards [10] and avoid drilling fluids, which interfere with fluorometry of materials outside a borehole. Such probes also scale favorably for 100-1000m-scale drilling on Mars and Europa [11] with requirements on spacecraft resources that are relatively low for subsurface access.

Deep-UV Fluorescence Profiling in Ice: In 2000-2010, Bramall, Rohde and co-workers built a series of profiling fluorometers to detect and characterize microbial and mineral fluorescence in boreholes in polar ice sheets [7], archived polar ice cores [8,9], and in the waters of Lake Tahoe [7].

In particular, Bramall built a borehole fluorometer using excitation and backscattering at 224 nm wavelength, together with fluorescent emission observations at 310, 325, 340, 355, and 385 nm, and deployed that instrument in a borehole at South Pole [7, chp. 4]. Figure 1 shows plots of indices of microbial and mineral fluorescence derived from the emission observations, as functions of depth below the ice surface. Microbial and mineral emission are well separated, and microbial emission shows an intriguing peak near the time of the last glacial maximum.

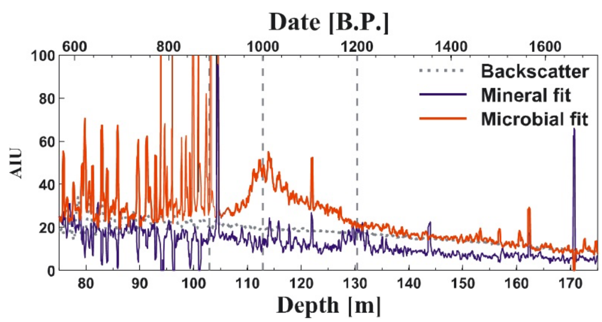

Figure 1. Indices of microbial-protein and mineral fluorescence vs. ice depth in the South Pole SPRESO borehole [7, chp. 4]. The peak in inferred microbial abundance near 112 m depth, clearly separated from mineral fluorescence, may be related climate-related variations in geographic locations of dust sources at South Polar during the so-called Medieval Warm Period.

Bramall then went on to build and deploy, in Lake Vida in the Antarctic Dry Valleys, a more compact fluorometer [7, chp. 5] with a diameter of 5.1 cm, which could be compatible with deployment in an existing ice melt probe, as we describe next.

The University of Washington Ice Diver: Ice melt probes penetrate ice masses using heat (in terrestrial applications derived from electrical power supplied from the ice surface) to melt their way downward under gravity [12], surrounded by meltwater jackets typically 1-3 millimeters thick. Power requirements depend primarily on descent speed, probe radius squared (i.e., cross sectional area), and ice temperature, and range from kilowatts in typical terrestrial applications to hundreds of watts in many designs for planetary probes. The melt hole above a descending probe typically refreezes and makes the probe non-recoverable, thus motivating expendable instrumentation.

The University of Washington Ice Diver melt probe [13] will, in its most recent development, deploy optical dust logging instrumentation [14] to measure the age of Antarctic ice versus depth below the ice sheet surface, as part of the National Science Foundation-sponsored Center for Oldest Ice Exploration (coldex.org). This Ice Diver (cf. Figure 2) will be commissioned in Summer 2023 by acquiring a record of dust content variations versus ice depth to 3000 m below the ice surface at Greenland Summit.

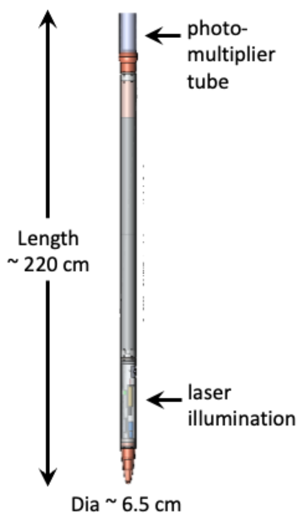

Figure 2. Engineering drawing of the COLDEX Ice Diver highlighting optical dust logging instrumentation components including a laser and sapphire window in the electronics pressure vessel and a photomultiplier tube receiver in a separate pressure vessel. Data are telemetered over wires that convey power to the probe.

Engineering already accomplished to integrate optical dust logging with the Ice Diver – including accommodation of the light source within the probe electronics pressure vessel, sapphire windows for illumination of ice outside the melt hole and for observation of scattered light, and telemetry of dust logger data and control signals over the wires that convey power to the probe – provides a basis for incorporation of a profiling deep-UV fluorometer in the Ice Diver, in place of the optical dust logger. With its ability to penetrate ice sheets without the use of drilling fluids, the Ice Diver melt probe provides the opportunity for clean drilling and profiling of ice sheets.

Status and Next Steps: Deep-UV fluorometers have demonstrated capability for identifying locations in polar ice that warrant detailed study, and for placing those locations in context. Technology even a decade ago yielded fluorometers nearly compact enough to consider delivery to depth in ice masses using existing, relatively logistically light melt probes.

At the same time, melt probe technology is now sufficiently advanced to demonstrate optical dust logging (with some overlap with fluorometry in instrumentation) to depths of kilometers in polar ice sheets. The inside barrel diameter of the University of Washington Ice Diver of ~6 cm somewhat exceeds that of a highly capable field-going fluorometer built in 2007.

Thus there is a clear basis for efforts to raise TRLs of current technology toward flight readiness, possibly using advances in deep-UV light emitting diodes over the past decade [15] to replace expensive, voluminous laser sources and further miniaturize capable fluorometers.

Concurrently, by incorporating fluorescence scanning into the Ice Diver currently under development, we can realize rapid surveying of the vertical distribution of both organics and mineral dust, at high sensitivity and depth resolution, in terrestrial analog ice masses. Such development would provide age, mineral dust and organics, as well as their association, at low logistical cost and therefore in many locations. Those data will strengthen the scientific basis for astrobiological exploration of Mars, Europa, and other solar system icy worlds.

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