THE SUBSURFACE ICE PROBE (SIPR): A LOW-POWER THERMAL PROBE FOR THE MARTIAN POLAR LAYERED DEPOSITS.

G. Cardell, M. H. Hecht, F. D. Carsey, H. Engelhardt, *Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA, (greg.cardell@jpl.nasa.gov)*, D. Fisher, *Geological Survey of Canada, Natural Resources Canada, Ottawa, Canada*, C. Terrell, *Drake University, Des Moines, IA, 50311, USA*, J. Thompson, *Los Alamos National Laboratory, Los Alamos, NM, 87545, USA*.

Introduction: The distinctive layering visible in images from Mars Global Surveyor of the Martian polar caps, and particularly in the north polar cap, indicates that the stratigraphy of these "polar layered deposits" may hold a record of Martian climate history covering millions of years. On Earth, ice sheets are cored to retrieve a pristine record of the physical and chemical properties of the ice at depth, and then studied in exacting detail in the laboratory. On the Martian north polar cap, coring is probably not a practical method for implementation in an autonomous lander. As an alternative, thermal probes that drill by melting into the ice are feasible for autonomous operation, and are capable of reasonable approximations to the scientific investigations performed on terrestrial cores, while removing meltwater to the surface for analysis. The Subsurface Ice Probe (SIPR) is such a probe under development at JPL. To explore the dominant climate cycles, it is postulated that tens of meters of depth should be profiled, as this corresponds to the vertical separation of the major layers visible in the MOC images [1]. Optical and spectroscopic analysis of the layers, presumably demarcated by embedded dust and possibly by changes in the ice properties, would contribute to the construction of a chronology. Meltwater analysis may be used to determine the soluble chemistry of the embedded dust, and to monitor gradients of atmospheric gases, particularly hydrogen and oxygen, and isotopic variations that reflect atmospheric conditions at the time the layer was deposited. Thermal measurements can be used to determine the geothermal gradient and the bulk mechanical properties of the ice.

Ice Drilling Technology: When drilling deep holes in ice, it is necessary to "backfill" the hole with some material or fluid to keep it open. Otherwise, the temperature and plastic properties of the ice at depth are such that it will flow under the pressure of the overlying ice and distort or close the hole on time scales comparable to the time required to drill the hole. In the most common terrestrial drilling method, ice coring, a mechanical bit is typically used, with an organic solvent providing both lubrication and backfill. Intact cores are removed to a laboratory for detailed analysis. If no core is required, hot-water drilling can be used to deploy a sensor deep in the ice. Using only recirculating hot water, such a drill can penetrate a kilometer or more in a matter of hours [2] and the recirculating hot water keeps the water from freezing and acts as backfill. Thermal ice drilling, in which a hot object melts through the ice, was first demonstrated by Philberth and co-workers in the 1960s [3]. A Philberth-type probe allows meltwater to refreeze behind it, and so must carry the full length of its own unspooled tether, reeling it out as it descends. The Cryobot, developed at JPL, added a hot water jet to the Philberth probe, thereby providing it with some of the advantages of a hot water drill [4]. It is a self-contained, deep subsurface probe that performs all scientific analyses internally, and exchanges power and data through its tether.

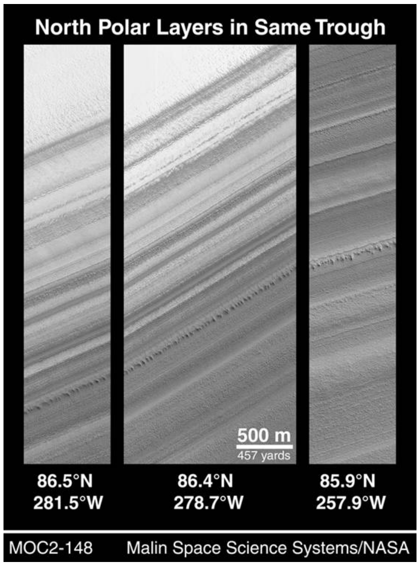

Figure 1: A MOC image of Martian north polar layered deposits. Similar strata should be visible in the sides of a drill hole into the polar cap

The SIPR concept: On Earth, open-hole drilling in ice is confined to descents of ≤ 300 m due to ice flow. However, our models of the Martian North Polar Cap indicate that the reduced gravity and the low temperatures of the ice at depth would allow an open hole to extend through the entire depth of the ice cap (≈ 3 km.) Because of this, on Mars the SIPR open-hole thermal ice drilling technique is practical for exploring the Martian polar layered deposits even at depth. A disadvantage of Philberth-type thermal probes is that they are in excellent thermal contact with the surrounding ice at all times. The SIPR design is an open-hole thermal probe, and seeks to exploit open-hole ice drilling to significantly reduce the thermal losses by continuously removing the melt water from the drill hole, so that only the heating element is in good thermal contact with the ice. In addition, the unspooled tether and most of the instrumentation for investigating the properties of the meltwater can remain on the surface. The probe then only need carry the meltwater pumping system, and a much smaller instrument package, significantly reducing the size of the probe and the amount of energy needed for drilling. The down-hole science instrumentation will include temperature sensors and a side-looking camera for optical examination of the strata: Pumping out the drill hole enables a view of the ice unobstructed by potentially silt-laden meltwater.

SIPR progress: Two different thermal probes have been constructed. In the version one (V1) probe, the main body, including the heating elements, the pump, and the support structure, is submerged. In the version two (V2) probe, only the heating element is submerged. The V1 probe was both tested in the laboratory, and deployed on the Athabasca glacier in October, 2003, where it drilled to a depth of 20 meters in approximately 24 hours (Figure 2.). The V2 probe was operated in the laboratory to obtain performance data on the V2 probe.

Figure 2: The SIPR version 1 probe beginning its descent into the Athabasca Glacier, October, 2003.

In addition, a simple computer model has been developed at JPL for estimating ice-probe performance for various types of thermal probes, based on [5]. The results of this calculation have been found to agree with experimental results from the type V1 and V2 probes. A comparison of the thermal model showing the improvement in thermal efficiency by using open-hole drilling on Mars is presented in Table 1.

Probe	Temp (C)	Rate (cm/hr)	Power (W)
Philberth	-110	10	845
SIPR V1	-110	10	359
SIPR V2	-110	10	86
Philberth	-110	50	1718
SIPR V1	-110	50	627
SIPR V2	-110	50	265

Table 1: Comparison of modeled power vs. descent rate under Martian conditions for the Cryobot (CB) and the two SIPR probe types discussed in the text: A typical mission would require 10–100 cm/hr descents into -110 C ice.

Sampling Techniques: Simple pumping through a smooth tube of constant cross-section presents difficulties because of sample fluid mixing in the tube, and the resulting blurring of the vertical scales. This continuous mixing property of the laminar pipe flow makes it difficult to accurately characterize the vertical resolution. This can be expressed as uncertainty in the percentage of the discharged meltwater retrieved from a specific depth. The problem arises because a long, narrow vertical tube will develop viscous laminar flow, characterized in the simplest case (a circular cross-section) by the Poiseuille parabolic velocity profile. Since the Poiseuille flow solution is exact and ideal, it can be used to estimate the achievable vertical resolution for this sampling scheme. Estimates of the sampling time and vertical resolution achievable with this simple scheme show that within the practical constraints on total power, sampling tube size, and probe size, even moderate vertical sampling resolution is difficult to achieve.

Because of the difficulties presented by Poiseuille flow, we have considered a number of possible sampling techniques to meet the actual requirements of a potential SIPR mission. Vertical sampling resolution is of interest only for some experiments: For others, notably astrobiological investigations, a large quantity of meltwater is desired without regard to stratigraphy. We have developed a sampling technique that uses two tubes, with a small-bore “sampling tube” for (relatively) high vertical resolution, and a large-bore “bulk tube” for removing the bulk of the meltwater for low vertical resolution sampling or disposal. The meltwater is first pumped up the sampling tube and a small, fairly pristine, vertically-constrained sample is be obtained after a suitable pumping interval. The sampling tube is then emptied back down the hole and its contents pumped into the bulk tube, and the process repeated.

The vertical origin of the meltwater is then constrained in both directions, and the vertical resolution is defined by the volume of the sampling tube itself. The achievable vertical resolution can be expressed in terms of the ratio of the sampling tube bore to the probe diameter r as $\Delta h = r^2 L_T$ where L_T is the full length of the sampling tube (see Table 2.)

Probe Parameters	Δh (cm)
2.25” probe 1/16” tube	7.72
3” probe 1/32” tube	1.09
4” probe 1/32” tube	0.61

Table 2: The achievable vertical resolution for the two-tube pumping scheme computed for a 100 m sampling tube

With this sampling method, the descent rate is controlled by the amount of time required to fill and drain the sample tube. We have developed an analytical model for the process of draining the fluid for estimating the amount of time required by this sampling scheme. The required descent rates of 10–100 cm/hour can be easily achieved. Furthermore, sample mixing is no longer controlled by parabolic pipe flow, and vertical resolutions of order 1–2 centimeters are achievable.

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