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Extended Abstract

IceMole – A Maneuverable Probe for Clean In-Situ Analysis and Sampling of Subsurface Ice and Subglacial Aquatic Ecosystems

Bernd Dachwald*
FH Aachen University of Applied Sciences, Aachen, Germany

Jill A. Mikucki†
University of Tennessee, Knoxville, TN

Slawek Tulaczyk‡
University of California, Santa Cruz, CA

Ilya Digel§
FH Aachen University of Applied Sciences, Jülich, Germany

Marco Feldmann¶
FH Aachen University of Applied Sciences, Aachen, Germany

Clemens Espe‖
FH Aachen University of Applied Sciences, Aachen, Germany

Engelbert Plescher**
FH Aachen University of Applied Sciences, Aachen, Germany

Changsheng Xu††
FH Aachen University of Applied Sciences, Aachen, Germany

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The "IceMole" is a novel maneuverable subsurface ice probe for clean in-situ analysis and sampling of subsurface ice and subglacial water/brine [1, 2, 3]. It is developed and build at FH Aachen University of Applied Sciences' Astronautical Laboratory. A first prototype was successfully tested on the Swiss Morteratsch glacier in 2010. Clean sampling is achieved with a hollow ice screw (as it is used in mountaineering) at the tip

*Corresponding author. Professor, Faculty of Aerospace Engineering, Hohenstaufenallee 6, 52064 Aachen, Germany, +49-241-6009-52343, dachwald@fh-aachen.de
†Professor, Department of Microbiology
‡Professor, Department of Earth and Planetary Sciences
§Scientist, Institute of Bioengineering
¶Graduate Student, Faculty of Aerospace Engineering
‖Undergraduate Student, Faculty of Aerospace Engineering
**Senior Engineer, Faculty of Aerospace Engineering
††Graduate Student, Faculty of Aerospace Engineering

of the probe. Maneuverability is achieved with a differentially heated melting head. Funded by the German Space Agency (DLR), a consortium led by FH Aachen currently develops a much more advanced IceMole probe, which includes a sophisticated system for obstacle avoidance, target detection, and navigation in the ice. We intend to use this probe for taking clean samples of subglacial brine at the Blood Falls (McMurdo Dry Valleys, East Antarctica) for chemical and microbiological analysis [4, 5].

In our conference contribution, we 1) describe the IceMole design, 2) report the results of the field tests of the first prototype on the Morteratsch glacier, 3) discuss the probe's potential for the clean in-situ analysis and sampling of subsurface ice and subglacial liquids, and 4) outline the way ahead in the development of this technology.

IceMole Design

The concept of melting probes for deep ice research is already known since the 1960s [6]. These probes, however, have three main drawbacks: 1) they penetrate only vertically down and cannot change direction; 2) they cannot penetrate dust/dirt layers; 3) they cannot be recovered from greater depths. To remedy these drawbacks, we have based the IceMole design on the novel concept of combined melting and drilling (or screwing) with a hollow ice screw (Fig. 1). The probe has the shape of a rectangular tube ($15\,\mathrm{cm} \times 15\,\mathrm{cm}$ cross section) with a $\approx$3-kW melting head at the tip. The required electric power is generated by a surface aggregate and transmitted via a cable that is uncoiled from the probe. Communications and data transfer to the surface is also via the power cable. The driving force of the ice screw presses the melting head firmly against the ice, thus leading to a good conductive heat transfer. The IceMole can change direction by differential heating of the melting head, which generates a torque that forces the IceMole into a curve.

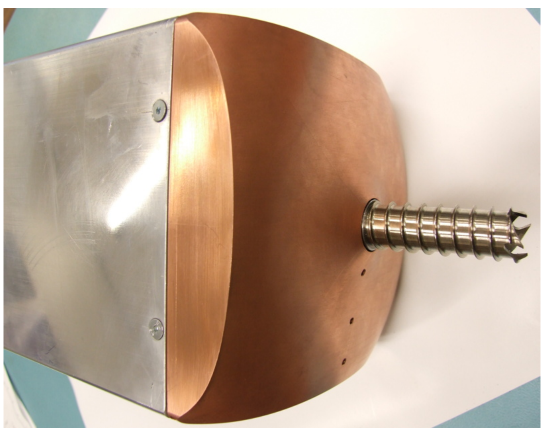

Figure 1: IceMole melting head with ice screw.

Figure 2: Deployment of the IceMole on the Morteratsch glacier.

Field Test Results of the First IceMole Prototype

In September 2010, we have successfully conducted three penetration tests on the Morteratsch glacier in Switzerland (Fig. 2) [2]:

1. melting 45° upwards for $\approx 1.5\,\mathrm{m}$, against gravity (Fig. 3);
2. melting horizontally for $\approx 5\,\mathrm{m}$ (Fig. 4);
3. melting 45° downwards for $\approx 3\,\mathrm{m}$, thereby penetrating three obstructing non-ice layers (made from material found on the glacier) and driving a curve with a radius of $\approx 10\,\mathrm{m}$ (Figs. 5 and 6).

The penetration velocity was $\approx 0.3\,\mathrm{m/hr}$ (but will be increased to $\approx 1\,\mathrm{m/hr}$ for the next prototype).

Figure 3: Channel 1, 45° upwards, ≈ 1.5 m.

Figure 4: Channel 2, horizontal, ≈ 5 m.

Potential for Clean In-Situ Analysis and Sampling

So far, the test results show that the IceMole concept is a viable approach for the clean delivery of scientific instruments into deep ice (and recovering them afterwards), as well as for clean sampling. Contrary to conventional ice-core drilling methods, the IceMole does not utilize any drilling fluid and may by sterilized according to planetary protection standards before its subglacial deployment (additionally, an optional module for in-situ chemical decontamination of the probe during its melting through the ice will be developed). In any case, because the material is sampled by the hollow ice screw at the tip of the probe, it does not come into contact with the exterior of the IceMole. Because the ice screw is thermally isolated from the melting head, the ice is ingested into the probe's interior, where it may be analyzed in-situ. For the alternative clean sampling of subglacial liquids instead of ice, the current design foresees that the liquids are pumped through the hollow ice screw into sterile bags, from where they can be recovered after the probe has returned to the surface. The direct pumping of water to the surface is another option that is additionally envisioned.

Future Development

An advanced IceMole prototype, named ”IceMole 2“, is currently developed at FH Aachen University of Applied Sciences. IceMole 2 should demonstrate the recoverability of the probe and the (probably expensive) payload by melting a standing ”U“ with a curvature radius of ≈ 10 m and a max. depth of ≈ 13 m. In contrast to the first IceMole prototype, as used on the Morteratsch glacier, IceMole 2 will have a better maneuverability and less weight. The melting velocity will be increased to 1 m/hr. The field test for IceMole 2 is scheduled for September 2012 on the Hofsjökull glacier (Iceland).

The current design of the IceMole is adapted to the subsurface investigation of terrestrial glaciers and ice shields, but in the long run, the probe should also be adapted to extraterrestrial ice research (e.g. on Mars' polar caps, Jupiter's moon Europa, or Saturn's moon Enceladus). In February 2012, a consortium led by FH Aachen University of Applied Sciences received a funding of ≈ 3.5-M€ from DLR to develop a much more advanced IceMole probe within the next 3 years, which includes a sophisticated system for obstacle avoidance, target detection, and navigation in the ice. The main technical objective of this project, which is termed ”Enceladus Explorer“ (EnEx), is to test navigation in deep ice in preparation of the IceMole and its navigation technology for extraterrestrial applications, e.g., on Saturn's moon Enceladus. The EnEx-probe will also feature a clean mechanism for the sampling of subglacial brine from a crevasse. We intend to use this probe for taking clean samples of subglacial brine at the Blood Falls (McMurdo Dry Valleys, East Antarctica) in the 2014/15 season. The forward contamination of the subglacial sample shall not exceed the concentration of microbes in the surrounding glacial ice (≈ 2000 cells/ml [4]). Before the deployment of the probe at the Blood Falls, two intermediate field tests are foreseen on the Matanuska glacier (Alaska) and the Canada glacier (McMurdo Dry Valleys, East Antarctica), where the cleanliness of the sampling method will be validated.

Figure 5: Channel 3, 45° downwards, ≈ 3 m, penetration of ≈ 4 cm of "dirt"(found on the glacier).

Figure 6: Channel 3, 45° downwards, ≈ 3 m, curve with a radius of ≈ 10 m (channel was opened afterwards).

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