Thursday, October 16, 2003
Afternoon Session II
GOING DEEP THROUGH ICE ON EARTH AND MARS
3:45 p.m. Victoria Room

Carsey F. D. * Hecht M. H. [INVITED]
Evolving Technologies for In-Situ Studies of Mars Ice **[#8102]**

Dahl-Jensen D. * Johnsen S. Willerslev E. Miller H. Thorsteinsson Th.
Basal Water at the NorthGRIP Drill Site **[#8135]**

Thorsteinsson Th. * Jóhannesson T. Larsen G. Sigurdsson O. Schmidt K. G. Forwick M.
Dust Flux into the Grímsvötn Subglacial Lake, Vatnajökull Ice Cap, Iceland, Estimated from Ice Core Data **[#8134]**

Briggs G. A. * McKay C. George J. Derkowski G. Cooper G. Zacny K. Fincher R.
Pollard W. Clifford S.
An Automated, Low Mass, Low Power Drill for Acquiring Subsurface Samples of Ground Ice for Astrobiology Studies on Earth and on Mars **[#8018]**

GENERAL DISCUSSION

6:30 – 9:00 p.m. CONFERENCE DINNER

EVOLVING TECHNOLOGIES FOR IN-SITU STUDIES OF MARS ICE F. D. Carsey[1] and M. H. Hecht[2], [1]MS 300-323, Jet Propulsion Laboratory California Institute of Technology, 4800 Oak Grove Dr., Pasadena CA 91109, USA, fcarsey@jpl.nasa.gov, [2]MS 264-255, Jet Propulsion Laboratory California Institute of Technology, 4800 Oak Grove Dr., Pasadena CA 91109, USA, mhecht@jpl.nasa.gov.

Introduction: Icy sites on Mars continue to be of high scientific importance. These sites include the polar caps, the southern mid-latitude subsurface permafrost, and the seasonal frost. These sites have interest due to their roles in climate processes, past climates, surface and near-surface water, astrobiology, geomorphology, and other topics. As is the case for many planetary features, remote sensing, while of great value, cannot answer all questions; in-situ examination is essential, and the motivation for in-situ observations generally leads to the subsurface, which, fortunately, is accessible on Mars. It is clear in fact that a Mars polar cap subsurface mission is both scientifically compelling and practical.

Recent data from orbiting platforms has provided a remarkable level of information about the Mars ice caps; we know, for example, the size, shape and annual cycle of the cap topography as well as we know that of Earth, and we have more information on stratification that we have of, for example, the ice of East Antarctica. To understand the roles that the Mars polar caps play, it is necessary to gather information on the ice cap surface, strata, composition and bed.

In this talk the status of in-situ operations and observations will be summarized, and, since we have conveniently at hand another planet with polar caps, permafrost and ice, the role of testing and validation of experimental procedures on Earth will be addressed.

Exploration Science: The usual Mars scientific topics, life, climate, geophysics and water, are all well connected to Mars ice, and in situ examinations are necessary to obtain the composition, stratification, surface processes, or basal conditions. The primary emphasis for these studies are climate history and processes, on Mars as on Earth. More speculative, but not less interesting, is the prospect that the basal environments of the Mars polar caps, in a climate scenario warmer than the present, would be an excellent habitat, supplied with nutrients and protected from Surficial unpleasantness.

Technologies: In short, Mars polar ice subsurface in-situ missions call for transport to Mars, soft-landing on the polar cap, operations on the surface, power, communication, conduct of surface and near-surface science, access to the subsurface, observing and/or sampling of the subsurface ice cap material, sample management of this material for instrumentation, and planetary protection. It is worth emphasizing that in several of these areas polar science can be accomplished more easily that at other sites. We will proceed here assuming availability of transport to Mars.

Soft landing on a polar cap. The polar caps are characterized by springtime CO_2+H_2O frosts of unknown mechanical properties; we need better information on the response of this frost to landing processes.

Surface operations. The polar caps are benign places in summer with steady temperatures and constant or near-constant sunlight; however, overwintering calls for dedicated development for survival of infrastructure, and this can be accomplished, especially with a nuclear power source. In addition, a mission that lands while the frost is present must accommodate to some decimeters of the landing surface burning off, possibly in nonuniform ways, early in the mission.

Power. A summer mission with low power needs, i.e., one that does not involve deep drilling, has access to ample solar power, although degradation of solar cells in the environment must be examined. Nuclear power from a reactor would solve a host of problems related to high power requirements, as for deep drilling, and to multiyear missions, due to the long life and abundant thermal power produced. This thermal output is also an engineering challenge, since it can both melt away its floor and provide heat that will influence local environmental conditions. Finally, the radiation field of a reactor becomes an engineering issue for electronics. Non-reactor nuclear power occupies a middle ground, with modest power, heat and multiyear capability with fewer difficulties, other than acquiring the radioactive salts.

Communication. Communication from the poles is not challenging. Linkage to orbiters is enhanced by frequent overpasses, and direct communication to Earth is quite simple in the Martian summer.

Surface and near-surface science. Ice cap surface properties and fluxes are likely to be required for any polar cap mission, and the conduct of the measuring programs can be demanding. Key complications are the small variations and fluxes that must be measured accurately, the influence of the spacecraft as an obstacle to windflow and sunlight, operations at the triple point of water, the non-steady surface conditions, and the unknown properties of the surface material.

Access to the subsurface. Drilling even a meter into ice-rich material in the temperature range near –100°C cannot be taken lightly; this material is hard.

Use of thermal methods can be energy intensive and will generate vapor. Thermal methods have received extensive attention and have interesting aspects in their favor at depth, but for shallow penetration with limited power a mechanical approach is favored. Working at depth calls for thermal methods, and both closed-hole (or cryobot) and open-hole strategies have been examined. Power levels become crucial for moderate (10's of meters) and deep (100's of meters) access. It is astonishing to consider that it is within our capability to access essentially any depth of the Mars polar caps.

Scientific observations, sampling and sample management at depth. Once the subsurface has been accessed, sampling must be addressed. Cold ice-rich material is hard and brittle; once a sample is removed and exposed it begins to sublimate if warmed, and if it contains a mix of granular material and salts it may crumble or become mushy or wet; if introduced into instruments, it may adhere to surfaces. Clearly, any observations that can be accomplished non-invasively, e.g., APXS, light scattering, fluorescence, Raman, NMR, etc, are desirable, and some are capable of acquiring data from material within the ice, material not effected by the presence of the drill. On the whole an excellent array of non-invasive scientific instrumentation suitable to subsurface science is in development and requires only adaptation to the specific environment. Sample acquisition and management approaches, of clear value to any in-situ mission, are also in development but have more problems to confront.

Planetary protection. Soon planetary protection requirements for a Mars polar cap mission will be formulated as category IVc, a new (not yet fully documented) category for "special regions" which includes the polar caps. While the specifics of the standards are still in study by the National Research Council, it is clear that rigorous standards of cleanliness will be in force, and these requirements should be integrated into planning early in mission thinking, if possible.

Earth Opportunities for Advancing Mars Polar Exploration Technologies: The high latitudes of Earth contain ice sheets, glaciers, periglacial terrain, permafrost, seasonal snow, rock glaciers and related icy sites in which strong Mars analogs can be developed, as is well known. In the context of climate change, it is of interest to address sites that have changed through cooling, and these are not obvious since Earth seems to be warming now. Some sites worthy of mention:

West Antarctica. The ice streams of West Antarctica (and possibly other locations) are now seen as exhibiting periodic behavior, so called "binge and purge" cycling, in which the bed cools immediately after rapid movement and warms during stagnation.

South Pole "lake". Near South Pole a subglacial flat spot has been observed on airborne radar and identified as a subglacial lake or frozen paleolake or perhaps just a curiously flat spot. Should it be the site where liquid water was present during a previous interglacial, it would today be a fascinating case study in frozen biota, possibly not unlike sites on Mars.

Subglacial volcanoes. At least one active subglacial volcano discovery has been claimed in West Antarctica, and other active volcanoes, with permanent ice and snow covers, can be found in Antarctica and Alaska. Such sites may be highly valuable for comparison with sites in the north polar region of Mars.

Greenland and Antarctica. Substantial regions of both Greenland and Antarctica are at the pressure melting point, and a zone of obvious interest is the transition region between wet and frozen bed areas; these zones can make clear the matter of how this subglacial water alters bed chemistry and biology.

Permafrost. Terrestrial permafrost has long been compared to Mars, and recent Odyssey results certainly encourage this thinking. In the western Arctic, permafrost has been warming, drying, and collapsing, while in Scandinavia there are reports of cooling permafrost. Comparisons of these changes could be useful for Mars thinking. DNA from permafrost has been shown to be well preserved over a few millennia; specific chemical changes to biochemicals over longer time intervals and environments would be interesting for Mars mission planning.

Basal and bed science. For a number of reasons terrestrial glaciology today is strongly interested in bed processes. This is good news for Mars polar science as these projects directly support future Mars polar science in the development of instruments and insights.

Conclusion: Mars polar cap science has received much attention at this, as well as other, scientific meetings, and its high value is well understood among the participants here. An examination of exploration technologies shows us that many of the tools we need to conduct comprehensive scientific studies of the Mars polar caps are available or are in active development. Moreover current work in Earth science is addressing analogous questions in analogous sites; there are effective means to develop, test, validate and assess relevant tools and approaches. In short the scientific questions are mature and the means to address them are maturing quickly. The time is essentially here for significant missions to the polar caps of Mars, and the possibilities are very exciting to contemplate. It is up to us to make these missions happen.

BASAL WATER AT THE NORTHGRIP DRILL SITE.

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On July 17 2003, the North GRIP deep ice core drilling program on the Greenland Ice Sheet (75.1 0N, 42.3 0W; 2930 m.a.s.l.), came to a successful end when the drill hit bedrock at 3085 m depth. In the last run the drill was lowered down in the basal water and on surface approximately 10 kg of reddish, bubbly frozen basal water was attached to the drill. A frozen 30 cm long jet of basal water hang from the drill head (www.glaciology.gfy.ku.dk)

The main purpose of the NGRIP project has been to obtain ice dating from the last interglacial period, the Eemian (ca. 115-135 ka BP). A full record of Eemian climate has hitherto not been obtained from a Greenland ice core and the occurrence of rapid climate change during the Eemian, originally inferred from studies of the GRIP ice core, has not been confirmed by other records. Results from airborne radar measurements showed that internal layers, isochrones could be traced from the deep coring sites at Summit in Central Greenland (GRIP and GISP2) to the North GRIP site. However, as the drilling progressed and measurements of ice temperature were made in the borehole, it became clear that the geothermal heat flux was unusually high at NGRIP and that the ice at the bottom was at the melting point.

At present, the bottom ice from the NGRIP core is tentatively estimated to be 127,000 years old. The melt rate at the base is estimated to be 7 mm per year. A study of the internal layers in North Greenland reveal a area of 300 km x 200 km with ice on the melting point. The amount of water produced by the basal melting is enormous and the drainage system must be good as no big lakes are observed under the Greenland Ice Sheet.

The basal water frozen to the NGRIP drill is mainly glacial basal melt water that contains air from the glacial ice. The reddish color however indicates evidence of a content of sediments in the water. Is it possible to find traces of ancient DNA and microbilogical life in the melt water found under the ice which has been closed from the surface for the last 2-5 million years? We hope to return next year and drill cores of the frozen basal water now standing 47 m up in the borehole.

DUST FLUX INTO THE GRÍMSVÖTN SUBGLACIAL LAKE, VATNAJÖKULL ICE CAP, ICELAND, ESTIMATED FROM ICE CORE DATA.

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Introduction. The center of hot-spot volcanic activity in Iceland is located beneath the NW-part of the Vatnajökull ice cap. Continuous melting of the ice cap from below sustains the Grímsvötn subglacial lake; the source of large jökulhlaups which regularly flood regions south of the ice cap [1]. The lake is covered by an ice shelf with an area of 25 km^2 and thickness varying between 100 and 300 m. The bottom of the subglacial lake is covered with sediments of volcanic origin [2], and dust released into the lake by melting of the ice shelf from below is continually being deposited at the lake bed. The Grímsvötn lake has recently attracted the interest of researchers investigating the possible existence of microbial life in Antarctic subglacial lakes and ice covered oceans in the solar system [3].

Ice core study. A 115 m ice core was drilled on the ice shelf in June 2002, concurrently with a thermal drilling that penetrated the ice shelf for geochemical and biological sampling of the subglacial lake [4]. A new core barrel and chips collecting system designed for use in core drilling below the water table in temperate ice was tested with success, and ice core processing involving density measurements, visual-stratigraphic observations, dust measurements and thin section analysis of crystal size was carried out on site.

Density measurements show that the transformation of snow to glacier ice (ρ = 830 kg/m^3) is completed by 16 m depth in the ice shelf, in less than 10 years. The water table in the ice shelf coincides with this transition. Stratigraphic observations reveal the presence of numerous bubble-free melt layers in the core, up to 60 cm in thickness. A 20 cm thick tephra layer from the December 1998 eruption in Grímsvötn was found at 4 m depth, beneath the 2001-2002 winter snow layer, indicating that the entire accumulation of the years 1999-2001 melted during summer. It is thus clear that hiatuses can exist in the annual-layer sequence present within the ice shelf.

The dust concentration of melted 20 cm samples was measured continuously on the core with a *Monilog L* turbidity meter, manufactured by Metrisa Inc. The instrument calculates dust concentrations in ppmv from the intensity of infrared light scattered off dust particles at a 90° angle. Results show that the background dust concentration is in the range 0.3-2.5 ppmv, but peak concentrations of 3-33 ppmv occur at depth intervals varying between 0.5 and 5 m in the core. In most cases, the dust producing the peaks seems to be concentrated in < 1 cm thick layers, which often are visible to the naked eye. Studies on a 100 m core drilled at 1800 m elevation on the Hofsjökull ice cap in Central Iceland [5] have shown that dust peaks in that core are due to windblown dust which originates in nearby deserts and is deposited on the ice cap in late summer. The situation in Grímsvötn is more complicated, since dust from a local source (Mt. Grímsfjall, 2.5 km from the drilling site) can probably be deposited on the ice shelf at all times of the year. Thus, the interpretation of the 40+ dust peaks found in the Grímsvötn core is not straightforward in terms of annual layering, but tephra layers of known ages and a 50 year time-series of winter accumulation from the ice shelf help constrain age vs. depth estimates. The tephra layer from the 1934 eruption is known to lie at ~120 m depth, indicating that the average thickness of annual layers in the uppermost 120 m is 1.8 m. Due to the complicated dynamics of the ice shelf [6], it is not clear how the thickness of the annual layers varies with depth in the lower part, but it seems reasonable to assume that 100-200 annual layers are present within the 280 m thick ice shelf at the drilling site.

The average dust concentration in the ice core is 3.9 ppmv, excluding very high concentrations in layers adjacent to the 1998 tephra layer at 4 m depth. We thus take 4 ppmv (~ 10 ppm by weight) as the average dust concentration in the entire ice shelf, and it seems realistic to assume a similar dust content in the ice within the entire Grímsvötn catchment area. This value is comparable to the dust concentration in Greenland ice dating from the Last Glacial Maximum [7].

From mass-balance considerations, it has been estimated that $4*10^{11}$ kg of ice melt annually by geothermal heat within the Grímsvötn drainage basin, which has an area of 160 km^2 [8]. This corresponds to an ice layer of thickness 2.8 m, melted annually from the base of the glacier. Given the average dust concentration of 10 ppm by weight, the amount of dust released from the melting ice within the entire Grímsvötn drainage basin is $4*10^{11}$ kg$*10^{-5}$= $4*10^{6}$ kg dust/year. The lake area is ~25 km^2; i.e. ~15% of the area of the entire drainage basin, and thus $0.15*4*10^{6}$ kg dust/year = $6*10^{5}$ kg dust are released into the lake from the shelf per year on average, according to these estimates. The corresponding areal flux is $6*10^5$ kg/$25*10^6$ m^2/year = 0.024 kg/m^2/year.

SEM images of particles from dust peaks in the Hofsjökull ice core show particles mainly in the size range 1-50 μm, made of basaltic volcanic glass together with basaltic crystalline materials and porous tephra grains. No such images are presently available of the Grímsvötn dust particles, but because of the proximity to the subglacially erupted Mt. Grímsfjall and recent eruption products, the proportion of basaltic glass and tephra particles is likely to be high in the Grímsvötn core.

The thin section studies show that average crystal size increases gradually with depth, from ~3 mm just below the firn-ice boundary to ~3 cm in the lowest part of the core. This trend is interrupted in layers containing high amounts of dust, showing that grain-boundary pinning by dust particles, which is commonly observed in polar ice [9], occurs in temperate ice as well. The data on crystal size changes in the core are currently being analysed in the light of new ideas suggesting that habitats for psychrophilic bacteria are present in interconnected liquid veins along three-grain boundaries in ice [10].

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AN AUTOMATED, LOW MASS, LOW POWER DRILL FOR ACQUIRING SUBSURFACE SAMPLES OF GROUND ICE FOR ASTROBIOLOGY STUDIES ON EARTH AND ON MARS.

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As a project that is part of NASA's Astrobiology Technology & Instrument Development Program (ASTID), we are developing a low mass (~20kg) drill that will be operated without drilling fluids and at very low power levels (~60 watts electrical) to access and retrieve samples from permafrost regions of Earth and Mars. The drill, designed and built as a joint effort by NASA JSC and Baker-Hughes International, takes the form of a down-hole unit attached to a cable so that it can, in principle, be scaled easily to reach significant depths.

A parallel laboratory effort is being carried out at UC Berkeley to characterize the physics of dry drilling under martian conditions of pressure, temperature and atmospheric composition. Data from the UCB and JSC laboratory experiments are being used as input to a drill simulation program which is under development to provide autonomous control of the drill.

The first Arctic field test of the unit is planned for May 2004. A field expedition to Eureka on Ellesmere Island in Spring 2003 provided an introduction for several team members to the practical aspects of drilling under Arctic conditions. The field effort was organized by Wayne Pollard of McGill University and Christopher McKay of NASA ARC. A conventional science drill provided by New Zealand colleagues was used to recover ground ice cores for analysis of their microbial content and also to develop techniques using tracers to track the depth of penetration of contamination from the core surface into the interior of the samples.