Next Steps in Mars Polar Science: In Situ Subsurface Exploration of the North Polar Layered Deposits. M. H. Hecht[1], A. Aharonson[2], S. Byrne[3], W. Calvin[4], S. Clifford[5], K. Herkenhoff[6], T. N. Titus[6], [1]Jet Propulsion Laboratory, California Institute of Technology, M/S 306-431, Pasadena, CA 91109 (email: mhecht@jpl.nasa.gov), [2]California Institute of Technology, Pasadena, CA, [3]University of Arizona, Tucson, AZ, [4]Univ. of Nevado, Reno, NV, [5]Lunar and Planetary Institute, Houston, TX, [6]U.S. Geological Survey, Flagstaff, AZ,

Why is polar science a high priority?: With the exception of the Phoenix mission, Mars surface exploration to date has emphasized the grand arc of history that is revealed and preserved at low latitudes. In contrast, study of the polar regions emphasizes ongoing *processes* such as climate modulation that have shaped the history of the planet, and that operate in useful analogy to modern processes (including climate change) on Earth. Polar studies were, accordingly, called out in the Decadal Survey as important New Frontiers class missions.

The North Polar Layered Deposits (PLD) are a particularly interesting polar exploration target. Visible stratigraphy within the PLD suggests a historical imprint, much like the ice record of Earth's climate. Climate modulations reflected in these strata should be seen as a typical response to astronomical forcing that has been present in every epoch. Such cycles may be responsible for sedimentary strata [1], the deposition of low latitude surface ice and mountain glaciers [2], or the triggering of episodic events such as flooding in the Noachian and early Hesperian. Moreover, implicit in the paleoclimate record is the history of conditions for life – indicated, perhaps, by a record of amino acids, methane, or signs of past melting. Extant biological and pre-biotic markers are also most likely to be found in these young deposits.

With respect to human exploration, a polar surface mission is relevant if a polar destination is under consideration for astronauts. Such a destination is of scientific interest for reasons described here. It also has much to recommend it logistically: Minimal thermal cycling (more important than absolute temperature); plentiful ice for producing water, oxygen, and fuel (the robotic mission described here would produce hundreds of liters of water), and as a readily-worked building material for radiation shelter; long periods of uninterrupted line-of-sight communication and sunlight; and negligible dust and soil hazards.

Polar Science goals: The past decade has witnessed significant progress in our understanding of Mars polar processes. The continuity of strata across the PLD has been confirmed with MOC images [3,4] and the MARSIS and SHARAD radar instruments [5]. Earth-based spectroscopy has revealed large spatial and seasonal variations in the atmospheric D/H ratio, underscoring its value as a climate marker in ice [6]. Related observations have suggested the transient release of methane in the atmosphere, a signal that could potentially be archived in the NPLD [7].

While orbital studies may eventually suffice to link the stratigraphy to Milankovich cycles, they are limited in resolution and will not reveal the climate conditions associated with those cycles and strata. *In situ* subsurface access is needed to capture fine scale stratigraphy (e.g. annual cycles of deposition); to measure climate markers such as isotopic fractionation, dust content and entrained salts; to establish a record of global events; to seek evidence of episodes of liquid water and ice flow; and to establish an absolute chronology.

The following broad questions have been suggested to guide future Mars Polar Science [8-12]:

1. What is the mechanism of climate change on Mars? How has it shaped the planet, and how does it relate to climate change on Earth?
2. How do the PLD evolve, and how are they affected by global cycles of water, dust, and CO_2?
3. What is the global history of ice on Mars? Where is it sequestered outside the polar regions, and what processes allow it to persist there?

Here we restrict ourselves to a discussion of question 1, with the goal of determining what seasonal and interannual variability, geologic history, and record of climatic change is expressed in the stratigraphy of Planum Boreum. To this we add a secondary goal of understanding any geochemical and biological record that may be preserved in the NPLD.

Suggested subsurface investigation: Using thermal drill technology, a NPLD subsurface investigation would: (a) Explore a significant number of layers of the stratigraphy; (b) Analyze D/H and $^{18}O/^{16}O$ with cm-scale resolution; (c) Visually measure dust concentration and ice structure with mm-scale resolution; and (d) measure soluble chemical species;.

The intentionally-vague term "significant number of layers" is chosen rather than a chronological reference because we understand the layering structure far better than we understand the timeline, and we have some notion of what constitutes a representive segment of the structure. Layer thicknesses have been observed from orbit to range from 1.6-16 m thick [13]. A 50 m descent, transecting several layers, would be feasible under solar power alone. A 150-m descent, transecting nu merous strata, would only be feasible under radioisotope power or with a chemically-fueled energy source

Radar observations have established that the NPLD consist of nearly pure ice [5], which could be excavated with modest infrastructure and high reliability. A small Mars-compatible thermal drill developed by JPL [14,15] successfully bored through 50 meters of Greenland ice in approximately two days, returning meltwater for analysis and performing down-hole imaging (Fig. 1). Laboratory tests have demonstrated the drill's ability to reliably operate at the low temperature and atmospheric pressure of the NPLD. Studies for Discovery-class missions using the JPL drill indicate that a 50-m descent is possible on a Phoenix-like platform during a solar-powered summer mission.

Measurements: Observable properties of ice strata related to climate conditions that prevailed during their formation would be measured as follows:

- **Microscopic observation** of the stratigraphy to determine whether the layering is due to variations in dust density, particle size, spatial distribution, aggregation, or ice grain structure; to detect fine-scale properties and characteristics such as lag deposits; and to determine if firn is present at the surface. The technology to perform such measurements is comparable to that of the MER Microscopic Imager, with the addition of laser illumination.
- **Isotopic analysis** of meltwater is the primary indicator of past climate conditions. Atmospheric D/H is known to vary over a much larger range on Mars than on Earth [6], a phenomenon that has been modeled in the context of sampling from different reservoirs (PLD, ground ice, etc.) [16]. Variation of the $^{18}O/^{16}O$ ratio is also expected. Instrumentation for this measurement has been developed under PIDDP.
- **Chemical analysis:** Soluble components of particulates and salts embedded in the ice might include sulfates, halides, perchlorates, and carbonates. Inorganic aqueous analysis would be performed with mature techniques such as those used for Phoenix. Methods for detection of methane and other dissolved gases are under development.

The present-day meteorological record would also be monitored, preferably for a martian year. A PLD platform is also attractive for geophysical measurements of seismic activity and heat flux.

Technology status: Most of the technologies required for the scientific exploration described here have been demonstrated at a TRL level between 4 and 6. For the scientific instruments, the novel challenge is the need to sample a stream of water. The drill itself is at an acceptable level of development for a flight proposal, but would benefit greatly from additional field deployment. Power system selection is the single discriminator of drilling depth. Since drilling depth translates to a total *energy* requirement (~100 kW-hr to descend to 150 m), we have explored chemical engines and fuels cells as possibly the best means to complete excavation objectives in the shortest period of time.

Acknowledgment: Some of the work described here was performed at the Jet Propulsion Laboratory, California Institute of Technology, funded by NASA.

References: [1] Lewis, K.W. et al. (2008) *Science 322*, 1532. [2] Head, J. et al. (2003) *Nature 426*, 797. [3] Milkovich, S. and J. Head (2005) *JGR 110*, E01005. [4] Fishbaugh K. and Hvidberg C. (2006) *JGR.* **111**, E06012. [5] Phillips, R.J. et al. (2008) *Science 320*, 1182. [6] Novak, R. E., Mumma, M. J., Villanueva, G. L. (2011) *Plan. & Space Sci., 59*, 163. [7] Mumma, M.J. et al. (2009) *Science 323*, 1041. [8] Clifford S. et al. (2000) *Icarus 144*, 210. [9] Clifford S. et al. (2005) *Icarus 174*, 291-293. [10] Titus, T. N., Colaprete A. and Prettyman T. H. (2008) *Planet & Space Sci. 56*, 147. [11] Byrne S. (2009) *Ann. Rev. of Earth and Plan. Sci. 37*, 535. [12] Fishbaugh K. et al. (2008) *Icarus 196*, 305 [13] Fishbaugh, K.E. et al. (2010) *GRL*, *37*, L07201. [14] Hecht, M.H. et al. (2007) Proc. 4th Int. Conf. on Mars Polar Sci. & Exploration, Abstract # 8096. [15] Bentley, C. R. et al. (2009), in Y. Bar-Cohen and K. Zacny (Eds.), *Drilling in Extreme Environments*, 221. [16] Fisher, D.A. (2007) *Icarus 187*, 430.

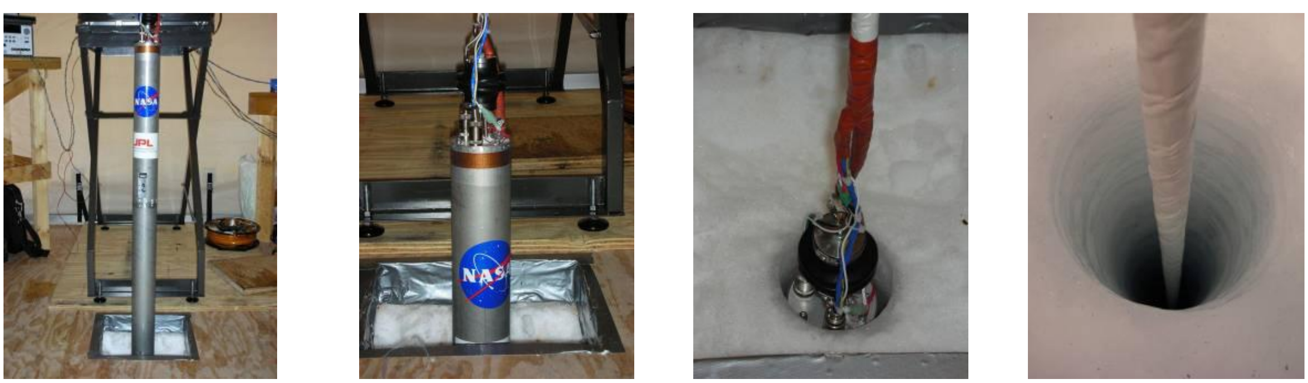

Figure 1: A 7 cm diameter thermal drill descends into the Greenland ice cap returning meltwater for analysis through an aerogel-insulated tether. In the final frame, the drill is 47 m below the surface (images from JPL).