SCIENCE GOALS FOR DEEP DRILLING IN ICE-RICH PERMAFROST ON MARS.

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Introduction: In 2008 the Phoenix mission will begin the subsurface exploration of the ice-rich ground in the Martian polar regions. In this paper we consider the scientific rationale for a deep drilling mission (~4m depth) as a followup to the Phoenix lander.

Polar Regions on Mars: As first pointed out by Murray et al. [1], the conditions in the polar regions of Mars change dramatically in response to changes in the parameters of Mars' orbit. Recent analyses [2] show that of particular interest over the past 10 Myr are periodic changes in the obliquity and in the phasing of perihelion. Figure 1 shows the obliquity, eccentricity, and summer solstice insolation at the north pole over the past 10 Myr. It is useful to consider three epochs in this time history; the last 0.5 Myr, from 0.5 to 5 Myr ago, and 5 to 10 Myr ago

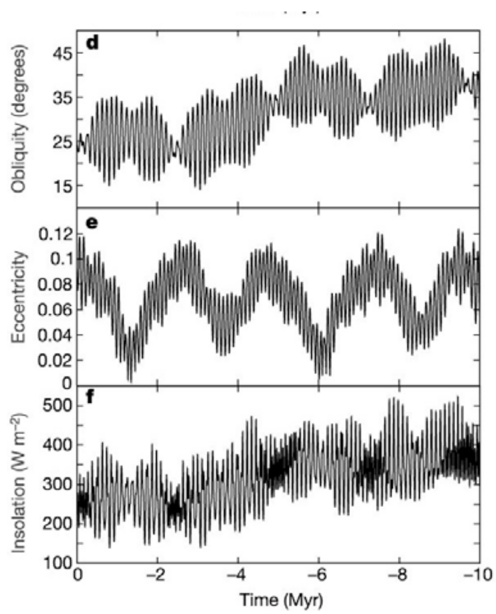

Figure 1. Orbital variations and north polar insolation over the past 10 Myr (from Laskar et al. [2]).

In the first epoch (the last 0.5 Myr), changes in polar conditions are dominated by the relative phase of perihelion and equinox. Today perihelion (Ls=257) almost coincides with southern summer solstice (Ls=270) and therefore the southern summer sun is stronger than the northern summer sun. Precession of the orbit reverses this situation in ~50,000 years. The results are not symmetrical because the north polar regions are at low elevation – higher pressure and, therefore, the formation of liquid water by the melting of ground ice is possible.

From about 0.5 Myr ago to 5 Myr ago the obliquity of Mars varied over the range 15° to 35°, with the average value approximately equal to that of today, 25°. Beyond about 5 Myr ago the obliquity assumed a larger average value (35°) with excursions as high as 45° [2]. During this epoch, the maximum summer sun in the north polar regions was 2.5 times the present value. These values are listed in Table 1.

Models suggest that these high insolations can produce surface melting in the north. Costard et al. [3] computed peak temperatures for different obliquities for varying surface properties and slopes. They found that peak temperatures are >0°C at the highest obliquities, and temperatures above -20°C occur for an obliquity as low as 35° [3].

Table 1. North Polar Insolation over time.

Time Period	Maximum North Polar Summer Insolation
1 Martian year	200 W m^{-2}
< 0.5 Myr	300 W m^{-2}
0.5 to 5 Myr	400 W m^{-2}
5 to 10 Myr	500 W m^{-2}

Cold Life: Life can grow at low temperatures if liquid is present. Jakosky et al. [4] discuss the potential habitability of Mars' polar regions as a function of obliquity. They conclude that temperatures of ice covered by a dust layer can become high enough (-20°C) that liquid brine solutions form and microbial activity is possible. Rivkina et al. [5] have shown that microorganisms can function in ice-soil mixtures at temperatures as low as -20°C.

Science Questions: We have identified a specific set of questions that could form the science framework for a permafrost drill mission to Mars. The main science goal for such a mission would be to advance the search for signs of life on Mars and determine the recent habitability of subsurface ice-rich environments on Mars. Several lines of evidence suggest that the ice-rich terrain in the northern polar regions of Mars is a promising candidate for such a search.

The specific hypotheses that could be addressed are:

H1: The upper layers of the subsurface ground ice are deposited from atmospheric vapor exchange.

H2: There has been liquid water generated in the surface soils in the north polar regions within the past 10 Myr due to orbital changes in insolation.

H3: Ground ice protects organic material on Mars from destruction by oxidants and, as a result, organics from biological or meteorite sources will be detectable in polar ice-rich ground at significant concentrations. If habitable conditions were present, then any organics may be of recent (<10 Myr) biological origin.

The direct detection of ground ice that had melted or formed from liquid water, even if millions of years old, would be of interest to geochemical studies of Mars. If this re-frozen ground ice was also shown to contain organics it would become a compelling target for future astrobiology missions.

Even absent any endogenous or biological production, organics should still be present on Mars simply due to the infall of meteoritic material which brings a flux of organic material estimated to be 2×10^{-8} g cm^{-2} yr^{-1}. Table 2 shows the predicted organic content for this carbon flux for a range of dust accumulation rates.

Table 2. Expected Range of Organics in Permafrost for a Carbon Inflow of 2×10^{-8} g C/yr.

Accumulation Rate	Organic content	Note
10^{-9} m/yr	10%	Global average [6]
10^{-7} m/yr	100 ppm	Accumulation for 1 m depth in 10 Myr
5×10^{-4} m/yr	0.2 ppm	layered deposits [2]

As a lower limit, we can consider the mean redistribution rate of material on the surface of Mars, estimated to be ~10^{-9} m/yr [6]. For this accumulation rate, the organic infall would comprise 10% of the surface materials if there were no loss processes. On the other extreme, Laskar et al. [2] estimate that the rate of accumulation in the north polar layered deposits is ~ 5×10^{-4} m/yr. This is a very high accumulation rate and probably only applies to the regions very near the poles. At this accumulation rate, the organic concentration for no losses would be 0.2 ppm. If the pore spaces of the soil are filled with ice, then diffusion of the atmospheric oxidant would be prevented and organics may be preserved in ice.

Note that ppm levels of organics are low for any soil. Even the most barren soils on Earth average more than 10 ppm organics [7]. Glacial and polar plateau ice that formed ultimately from snowfall has far lower levels of organics, but this is not a good analog for ice-cemented soils. Our expected concentration is in the ppm range or higher. If the concentration of organics in the ice-cemented ground is ppb levels, then it is not to the hypothesis that organics are preferentially preserved in ice rich ground.

Sample Requirements: To address the science hypotheses listed above both physical and chemical measurements are necessary. Thus, both large intact pieces, perferrably of cm size, for physical analysis and ground material, preferably of size mm or less, suitable for input into chemical analysis instruments are required. Thus both cores and cuttings are required from the drill system. In addition, many of the analyses require minimal loss of ice during sample handling.

The fabric of the ice and its relationship to the soil can reflect its mechanism of formation. Ice that deposits from vapor is expected to be different in morphology from ice that forms from a liquid. Thus microscopic examination of the morphology of the ice soil matrix, the ice-to-dust ratio in the ice-cemented ground and the mechanical strength of the ice-cemented ground are all physical properties that can reveal if the ground ice is vapor deposited (H1) or has melted and refrozen (H2). Measurements on small sized material to indicate the salinity and dissolved ions of the ice-cemented ground will also bear on these hypotheses. Testing for the presence of organics (H3) will also require samples fine enough to be ingested into analytical instruments.

Depth Requirements: The Phoenix mission will reach the subsurface ice and sample several cm into this ice. The Odyssey measurements of subsurface ice refer to the uppermost 1 m. For a followup mission core and cuttings samples from the permafrost to a depth of many meters would be desired thereby taking a significant step forward in exploring the subsurface of Mars. Several meters depth promise to provide samples with the record of the events of the last few million years. Shallower samples may merely reflect current atmosphere-surface equilibrium. Some level of laterial mobility may be desirable to avoid rocks and sample the possible diversity of the permafrost.

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