WE SHOULD SEARCH FOR LIFE IN MARS N. POLAR GROUND ICE.

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Introduction: The 2008 Phoenix Mars lander mission sampled ground ice at 68° N latitude. Mission results, considered along with climate modeling studies, suggest that the site is habitable for life during high obliquity periods. The Icebreaker mission has been proposed to the NASA Discovery program to search for biosignatures produced during habitable periods. This paper explores its rationale and approach.

Rationale for a Habitable Environment: The Phoenix lander dug into the subsurface with a robotic arm equipped with a digging scoop to reveal an ice table at 5 cm depth. The case for habitable conditions encountered is summarized in [1]. Briefly, 1) beneath a cover of dry soil, patches of pure ice was discovered that covered 10% of the approximately 1m^2 excavated by the scoop[2]. The rest of the surface coverage was ice cemented soil. Segregated ice forms when liquid water films are concentrated during freezing. 2) The soil contained pure calcite mineral[3], which forms under aqueous conditions. 3) Microscopic imaging identified a population of soil grains showing evidence of solutional weathering [1]. 4) Energy sources are available to support autotrophic surface and chemoautotrophic metabolism in the ground ice. Semitransparent soil grains that could protect microbes from sterilizing UV radiation are present[1]. Perchlorate found in the soil at ~0.5% [4] is a known chemoautotrophic energy source used by microbes from a variety of environments including permafrost [5].

While current climate conditions are too cold to support metabolism in the polar region, climate modeling studies [6] show that variations in solar insolation associated to obliquity variations cause climate change that would permit periods of growth to occur. For the past 5 Myr, Mars' obliquity has oscillated around a value of 25° but from 5 Myr to 10 Myr ago, the mean obliquity was ~35° and the maximum obliquity was almost 50° [7]. At high obliquities, the maximum insolation is up to 2.5 times the present value, and surface temperatures at 68 N latitude can exceed 273 K up to 100 days per year [8]. At obliquity of 45° the 253K isotherm, the measured limit for terrestrial microbial growth, extends to ~1 m depth for durations allowing microbial growth and population rebound [8].

Terrestrial permafrost communities are an example of possible life in the ice-rich regolith. Studies in permafrost have shown that microorganisms can function in ice-soil mixtures at temperatures as low as -20°C, living in thin films of interfacial water [9]. Ground ice can preserve living cells, biological material, and organic compounds for long periods of time. Microbes have been cultured from Antarctic ground ice that is up to 8M years old [10]. If life is present N. polar ground ice, growing when conditions allow, biomolecular evidence of life should accumulate in the soils.

Surface Age Analysis: Detecting biosignatures produced during episodes of high obliquity depends on accessing ice that has experienced growth periods so it is important to understand the erosional and depositional processes in the landing region. Questions relevant to a sampling mission include: What has been the net level of deposition or erosion over time? What is the thickness of the ice table and how abundant is the ice? The characterization of crater morphology and degradation rates can help assess the presence of volatiles in the regolith, while the characterization of the ejecta can address whether the site has seen net deposition that would bury the ejecta blocks and, by extension, make the most relevant material inaccessible.

We inspected all HiRISE images acquired to date over the area including the Phoenix landing ellipse, covering a total contiguous area of about 4000 km^2 with the aim of cataloguing every identifiable crater within the ellipse on the basis of size, presence of ejecta, and degree of crater degradation [11]. Characterization was facilitated by grouping the craters into size bins of 1) less than 100 m, 2)100-300m, 3) 300-1000m and 4) greater than 1000m. The craters in bins (1) and (2) rarely exhibit ejecta blocks. The transition to craters with ejecta occurs from crater diameters of 200 to 350 meters. The lack of ejecta in the small craters suggests that an incompetent layer of ice-rich material is present to a depth of 20 to 35 m. Small craters disappear rapidly leaving no trace except a circular fracture highlighted by frost in spring. Crater removal rates are substantial: craters less than 100 m lose relief within 10^5 years. Hence, crater infilling in the small craters constitutes a sedimentary process in the region, and potentially a method by which water ice is trapped into the subsurface. In contrast, ejecta blocks detectable down to 40 to 80 cm size are associated with craters in bins 3 and 4 except in the most degraded craters. This and the size frequency distribution for all craters larger than 500 m compared to a model crater frequency distribution [12] is consistent with a surface age of ~1 Gyr with deflation being the dominant process.

Discussion: In contrast to the generally static to slow erosional history of the region as a whole, net deposition occurs within small craters. The infilling process is likely related to annual deposition of dust during winter when atmospheric CO_2 condenses onto the surface at this latitude, and then sublimates in the spring, leaving the water ice and dust it brought with it behind. Winter images show bright deposits in the small fresh craters that do not fully sublimate away through the summer, implying a slow accumulation of this material within the craters. The crater bowls may prevent the wind from removing the icy dust. If a sufficiently large part of the landing ellipse has been resurfaced by impacts and subsequent crater infilling since the latest habitable period, the scientific viability of a mission seeking to target the habitable zone would be compromised. Since the habitable zone extends to no more than 1m depth, we determined the fraction of terrain excavated and infilled to at least that depth in the last 10 Myr. Given a crater depth-to diameter ratio of 1:5, craters as small as 5 m in diameter forming in the last 10 Myr will remove the record of the most recent habitable period. We estimate that 1.2% of the area surveyed has been resurfaced by craters smaller than 100 meters in diameter in 10Ma.

Icebreaker Mission Concept: The Mars Icebreaker mission [13] proposes to land in high latitude ice rich terrain with a payload designed to address the following science goals: (1) search for molecular signatures of life; (2) assess the habitability of the ice bearing soils in the context of orbital cycles. The mission features a 1-m drill to auger subsurface icy material to the surface where it is delivered to payload instruments that search for organic molecules and have the capability to distinguish patterns in amino acids and fatty acids to discriminate biotic from abiotic sources of organics. By drilling to 1m the full depth of the habitable zone can be probed. The Icebreaker payload fits on the same spacecraft/ lander used by Phoenix and can be accomplished within the Discovery mission cost profile. The solar powered mission is constrained to accomplish its objectives in less than 180 sols. This can be accomplished only with careful operational planning and a highly autonomous drilling system. To facilitate its maturity, the life search payload and sampling system has been extensively tested in field experiments performed in the Chilean Atacama desert performed under the NASA PSTAR program[14].

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