CRATER MOPRHOLOGY IN THE PHOENIX LANDING REGION: INSIGHTS INTO NET EROSION, ICE TABLE DEPTH, AND TIMING OF GEOLOGICAL PROCESSES.

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Introduction: Icebreaker is a Discovery class mission being developed for future flight opportunities [1]. Under this mission concept, the Icebreaker payload is carried on a stationary lander, and lands in the same landing ellipse as Phoenix. Samples are acquired from the subsurface using a drilling system that penetrates into materials which may include loose or cemented soil, icy soil, pure ice, rocks, or mixtures of these. To avoid the complexity of mating additional strings, the drill is single-string, limiting it to a total length of 1 m.

The scientific rationale behind the landing site selection for the Icebreaker mission lies in the presence of an easily accessible, shallow ice table. Ice is an interesting target in the search for evidence of modern life on Mars for two reasons: 1) it can provide liquid water when conditions of temperature and pressure are suitable, thus allowing for biological activity; 2) ice-rich ground may prevent destruction of organics by atmospheric oxidants. The ideal location on Mars to search for biomarkers could be the ice-bearing permafrost in the northern plains [1; 2]. Here, the presence of ice near the surface (4.6 cm deep at the Phoenix site) provides a source of H_2O. The atmospheric surface pressure above the triple point stabilizes the liquid phase even of pure water. Thus, all that would be required to provide liquid water activity capable of supporting life is sufficient energy to melt the subsurface ice. This may occur periodically during high obliquity periods (HOPs), when solar insolation near polar latitudes is higher than at present. Such HOPs, which have a recurrence time of c.a. 125 kyr , have reached obliquities of up to 35º over the past 3 million years, and up to 45º at earlier epochs [3]. Such high obliquities can result in peak surface temperatures above 0ºC in the high northern latitudes at obliquities >40º, and temperatures above –20ºC for an obliquity as low as 35º [4]. [5] showed that when obliquity is 45º melting can occur 50 days per year in the high northern latitudes. Hence, ice-bearing permafrost in the northern plains of Mars could be a site of recent habitability compatible with the survivability of radiation-tolerant microorganisms.

Of particular importance to landing site selection is the development of a framework with which to understand the geological history of the region. Particular questions of interest are:

1. What is the erosional/deposition history of the region. In particular, what has been the net level of erosion or deposition since the last period(s) of high obliquity? Icebreaker's sampling system can reach depths of up to one meter only. Hence, it is important that net deposition not exceeded 1 meter since the last period of high obliquity. We can infer the level of net deposition by measuring the sizes of ejecta boulders around craters of different ages.
2. What is the thickness of the ice table, and what is the abundance of ice? Understanding the thickness of the ice table, and in particular the abundance of ice may provide clues with respect to the history of ice formation in the region.
3. What is the timing of geological processes? Three potential periglacial processes are recognized at the Phoenix landing site:

i. formation of small (3-5 meter) and large-scale (20-30 meter) patterned ground,

ii. formation of boulder piles described in [6] , and

iii. loss of crater relief by infilling and gelifluction.

Procedure: We inspected HiRISE and CTX images over a 4000 km^2 area containing the Phoenix landing ellipse to identify and classify craters on the basis of size, dgree of degradation, and presence of ejecta.

Degree of degradation. The degree of degradation was defined by the presence of a bowl, a rim, ejecta blocks, radial and co-centric fractures, and modification of the interior by the formation of patterns or rock piles.

Ejecta blocks. Ejecta blocks are identified by an increase in spatial density of boulders with proximity to the crater. Boulders may be arranged in an arc around the crater's edge or in straight lines radially away from the crater. Boulders that are found around craters are not considered ejecta if their spatial density relative to that of boulders in the surrounding plains does not increase with proximity to the crater. Ejecta boulders were measured on the basis of pixel size and shadow lengths.

Timing. Geologic timing was established on the basis of associations between morphological features of interest and degree of degradation of the crater they modify. Given a knowledge of the crater formation rate, we can constrain the timing of certain geologic processes. We identified the freshest craters of each size range and assessed for the presence of geologic features such as ejecta boulders, relief, and formation of boulder piles.

Results and Discussion: We identified over 2000 craters in the 4000 km^2 region of interest and binned them into groups on the basis of crater size and degree of degradation.

Degree of degradation. We found that it is fairly straightforward to identify a pattern of modification for each range size. Modification of craters ranging in size from about 100 m to a couple of km typically involves the loss of relief of the crater bowl and rim, coupled with the formation of a network of co-centric and radial fractures within the former bowl. Because bowls disappear more readily than rims, we attribute the loss of relief to the solifluction of ice-rich soil. On the other hand, craters smaller than 100 m typically exhibit loss of their bowl by in-filling with smooth, higher-albedo material inferred to be a combination of frost and dust.

Ejecta blocks. Overall, we found that ejecta boulders are visible down to the resolution limit of HiRISE (~30 cm/pixel) for most craters larger than 200-300 m in diameter. Absence of ejecta boulders is typically associated to the most modified craters (*i.e.*, craters with no apparent relief and craters whose interiors are covered with boulder piles), and craters smaller than about 200-300 meters (Fig. 1). Where present, minimum boulder sizes were measured to be 30 cm in plan size and 25 cm (using shadow lengths). This minimum size size measurement was limited by the pixel scale. Hence, we determined that the region not has experienced a net deposition of 1 meter or more since the ejecta was emplaced.

Ice table thickness. The absence of ejecta blocks in most craters smaller than 200-300 meters is particularly intriguing as it suggests impacts onto a layer of ice-cemented, friable, or unconsolidated soil approximately 40-60 m thick (assuming an excavation depth 1/5 of the crater diameter [7]). This layer overlies a basement of more competent material that generates ejecta blocks in most craters larger than 300 m. The inferred stratigraphy in his region is consistent with observations from SHARAD [8], which identifies a radar return at depths of 15-66 meters in the Phoenix landing ellipse. The presence of significant amounts of water ice, inferred from modeling and observations by GRS and the Phoenix lander [9], could explain the lack of ejecta boulders as due to sublimation of cementing ice post-impact.

Boulder Piles. Boulder piles are found in terrains outside the extended ejecta blanket of the 10 km and 600 My Heimdall Crater and overprint the ejecta blankets and interiors of craters with intermediate to heavy modification. In some cases, boulder piles are seen to overprint the ejecta and interiors of craters within the Heimdal outer ejecta blanket. In these cases, the ejecta blanket appears in positive relief relative to the surrounding Heimdal ejecta in the form of a pedestal, suggesting that these craters may have pre-existed the emplacement of the Heimdal ejecta blanket. We infer that the processes that led to boulder pile formation occurred before the formation of Heimdal 600 Mya. This result is consistent with [6].

Timing. The present crater formation rate at Mars for small craters is modeled by [10,11] and constrained by [7,12]. Given the area of our study region, a crater 200 m or greater forms roughly every million years. Only a few craters in the 200+ diameter range exhibit a bowl, implying that the timescales for the loss of relief for 200+ m craters is of a few million years for the smaller craters in the size range. Such short timescales come as a surprise and may indicate a relatively high (>30%) abundance of ground ice. However, we note that additional work needs to be perfomed to verify this.

References: [1] McKay et al. (2013) Astrobiology, 13(4) 334-353. [2] Stoker et al. (2010) *JGR* 115, E00E20. [3] Levrard et al. (2004) *Nature* **431**, 1072-1075. [4] Costard et al. (2002) 293, 110-113. [5] Richardson and Mischna (2005) *JGR* E3. [6] Heet et al. (2009) *JGR*, 114, E00E04. [7] Daubar et al. (2013) *Icarus* 225, 506-516. [8] Putzig et al. (2014) *JGR* 119, 1936-1949. [9] Mellon et al. (2009) *JGR*, 119, 1936-1949. [10] Neukum, G., In: *Chronol* and *Evol. of Mars*, pp. 87–104. [11] Hartmann (2005) *Icarus* 174: 294-320. [12] Malin et al. (2006) *Science* 314, 1573.

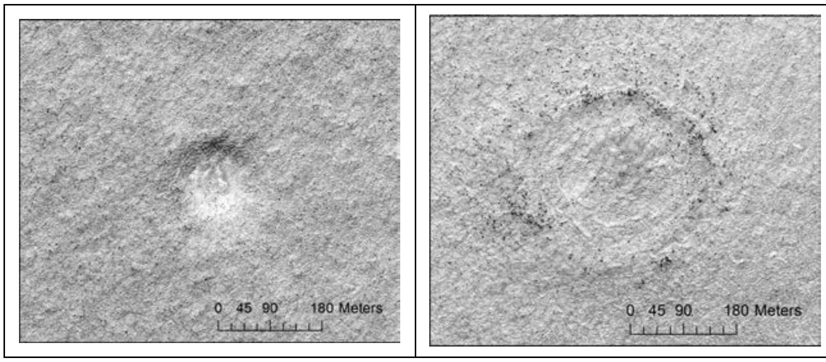

Figure 1. Two craters located about 2.6 km apart and differing in size by 100 meters. **Left:** 200 meter crater with a bowl shape and smooth, higher albedo mantling deposit in its interior. Boulders around the crater do not exhibit an increase in concentration with proximity to crater. Sun is from the top. **Bottom:** Modified 300 meter crater exhibits a flat, co-centrically fractured floor and ejecta boulders.