THE PALEOCLIMATE RECORD OF OUTLIER ICE DEPOSITS NEAR THE MARTIAN POLES

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Introduction: A long-standing goal of polar science on Mars has been understanding the paleoclimate record of ice deposits. A special focus is placed on confirming or refuting the hypothesis that planetary climate is strongly driven by changes in orbital and axial parameters, like obliquity variations. Usually, research is focused on the north and south polar layered deposits (NPLD and SPLD), kms-thick sheets of nearly pure H_2O ice. While great progress has been made in understanding the records within these deposits [e.g., 1–5], decades of research has ultimately not yet fully deciphered and age-dated an orbital signal, which may be difficult to identify even if it is present [6, 7].

One way to address this issue is to consider other, smaller ice deposits that are not connected to the PLDs. Outlier ice deposits exist as mounds within impact craters in both polar regions of Mars. Because they are at lower latitudes than the PLDs, they may be more sensitive to climate change [8] and represent younger stratigraphy that has undergone fewer periods of accumulation and ablation. The ice mounds have been mapped and characterized in the north polar region [9], but not the south.

Here, we progress toward understanding the climate records stored within ice mounds on Mars. First, we present results of our identification and characterization of ice mounds in the south polar region that are analogous to the landforms found in the north polar region. Second, we focus on one particular ice mound in the south polar region, found in Burroughs crater, and consider the possibility that it contains a decipherable paleoclimate record. Finally, we discuss ways in which the stratigraphy of these ice mounds could elucidate planetary paleoclimate.

Ice mounds near the south pole: We identified 31 circumpolar crater-filling deposits (CCFDs) in the south polar region of Mars (defined here as poleward of 60°S). Criteria for this classification includes that the landform is approximately circular in plan-view, is located inside an impact crater, has convex topography, covers >10% of the crater floor area, and is spatially separated with the SPLD. We also identified 7 marginal deposits that meet all criteria above but are partially contiguous with the SPLD, and 66 irregular deposits that represent positive topography inside south polar craters but fail at least one of the criteria to be classified as a CCFD. Locations of all of these deposits are mapped in Figure 1a, and an example of each class of deposit is shown in Figure 1b.

We conclude that the 31 CCFDs are mostly composed of H_2O ice for several reasons. (1) They are morphologically similar to previously identified H_2O ice mounds in the north polar region [8]. (2) They are morphologically similar to the 7 marginal deposits, which are presumably H_2O by virtue of their contiguous nature with the mostly H_2O SPLD. (3) They display a trend of decreasing volume with increasing distance from the south pole, perhaps reflecting volatile stability. (4) Our analysis of SHARAD radargrams reveals a dielectric constant of CCFDs consistent with H_2O ice. (5) Some CCFDs display evidence of having viscously flowed, consistent with glacial deformation of ice. Some of the 66 irregular deposits may also be primarily H_2O ice, but we cannot confidently conclude that composition on the basis of current analysis. In total, the 31 CCFDs represent an ice volume between 15000–38000 km^3, depending on assumptions about deposit thickness. This volume represents between 1–3% of the H_2O ice volume of the SPLD.

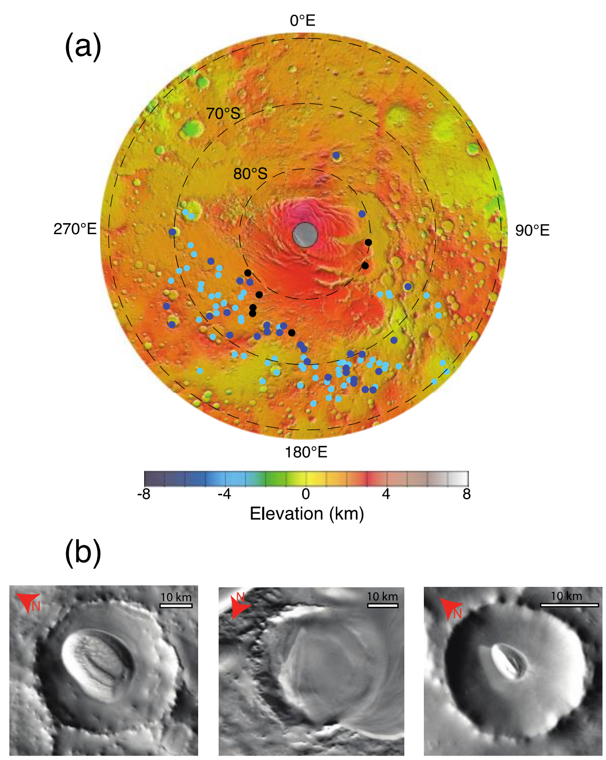

Figure 1. (a) Locations of 31 CCFDs (dark blue points), 7 marginal deposits (black points), and 66 irregular deposits (light blue points) overlain on a south polar projection of MOLA-derived topography. (b) Examples of a CCFD (left, 70.5°S, 159.0°E), marginal deposit (middle, 80.1°S, 96.7°E), and irregular deposit (right, 70.0°S, 181.4°E). Images are from a daytime THEMIS mosaic.

Burroughs crater: Of the 31 CCFDs identified, 12 have some degree of exposed layering. Layering is of interest because it represents an icy stratigraphy that acts as a paleoclimate record. Differences in layer brightness [e.g., 1] or layer protrusion [10] could reflect differences in layer composition, which may itself be controlled by climate. Thus, layer profiles may be used to quantitatively test the hypothesis that Martian climate is strongly driven by orbital and axial parameters. We examined images of the 12 southern CCFDs with exposed layers using a variety of remote sensing instruments (THEMIS, CTX, MOC, HiRISE) aboard Mars-orbiting spacecraft.

We found that the CCFD in Burroughs crater (Figure 2) represents the most promising case for extracting meaningful profiles of brightness or layer protrusion and comparing the profiles to orbital cycles. Burroughs is a 110-km-diameter crater at 72.3°S, 116.6°E containing a 74-km-diameter ice deposit. The deposit is 236 km away from the SPLD and between 0.6 and 2.4 km thick, depending upon assumptions of the elevation of the crater floor. Layering is visible in images around most of the CCFD margin, in contrast to many other CCFDs that only have localized exposures. The ice deposit also represents a particularly good case study because layer exposures appear to contain multiple periodicities. These frequencies could be similar to the "beds and bundles" in equatorial sedimentary deposits that have been linked to orbital forcing [11], although deposition of volatiles probably results in a more complex pattern than deposition of sediment [5].

We use HiRISE images of the bedding exposure in Burroughs crater for paleoclimate studies. An example of a profile and the HiRISE image it was extracted from are shown in Figure 2. This profile represents brightness (which convolves effects of slope and albedo) as a function of depth (estimated from MOLA data), showing variability that may represent climate at the time of ice deposition. A Fourier transform of this particular profile reveals excess power (relative to a red noise spectrum) at some wavelengths between 1 and 10 m, which could be related to orbital forcing. However, we argue that layer protrusion [5, 10] is the more appropriate metric to consider for this record.

Further analysis of icy stratigraphy in Burroughs crater, including separating the effects of slope and albedo in the record, will be made possible by high-resolution topography. At present, we have three HiRISE stereo pairs of the Burroughs bedding suitable for production into digital elevation models (DEMs). As we create these DEMs, we will use techniques including Fourier analysis, wavelet analysis, and dynamic time warping to look for statistically significant signals in the layers, correlations between Burroughs crater and the SPLD, and evidence of orbital climate forcing.

Conclusions: Mound-shaped deposits located within impact craters in the polar regions of Mars are mostly composed of water ice, with an aggregate volume of a few percent of the NPLD or SPLD. These icy outliers represent a potentially valuable record to decipher paleoclimate. Ongoing work will continue to perform signal analysis on topographic datasets of layer exposures in the ice mounds, and will determine if the stratigraphy contains a record temporally equivalent to the PLDs [12], a younger record forced by the same factors that build the PLDs, or a record uniquely accessible in these features forced by different effects.

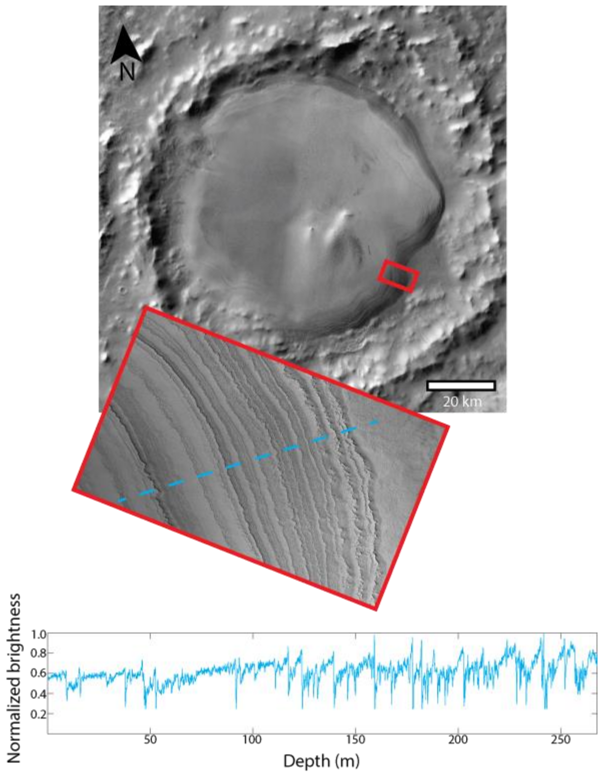

Figure 2. Burroughs crater from daytime THEMIS mosaic, with inset HiRISE image ESP_057650_1070 showing layer exposures. The cyan dashed line represents the normalized brightness profile on the bottom.

References: [1] Cutts and Lewis (1982), *Icarus* 50. [2] Laskar et al. (2002), *Nature* 419. [3] Hvidberg et al. (2012), *Icarus* 221. [4] Smith et al. (2016), *Science* 352. [5] Becerra et al. (2017), *GRL* 43. [6] Perron and Huybers (2009), *Geology* 37. [7] Sori et al. (2014), *Icarus* 235. [8] Bapst et al. (2018), *Icarus* 308. [9] Conway et al. (2012), *Icarus* 220. [10] Becerra et al. (2016), *JGR Planets* 121. [11] Lewis et al. (2008), *Science* 322. [12] Brothers and Holt (2016) *GRL* 43.