THE LIMITS OF ICE ON MARS: ICE EXPOSED BY A LARGE NEW IMPACT CRATER AT 35ºN.
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Introduction: Ground ice is widespread at middle and high latitudes on Mars, but becomes rare or absent near the equator. New impact craters at middle and high latitudes have been used to probe the Martian ice table [1–3]. The stability and distribution of water ice are controlled by the current and recent climate; thus, determining the distribution and latitude limits of ice, particularly over broad areas rather than microclimates on steep slopes, is of great importance for understanding that climate history. Additionally, the lowest-latitude ice is of interest for assessing the possibility for In Situ Resource Utilization (ISRU) [4] and for determining Planetary Protection policy [5].

A 150 m-diameter, 21 m-deep new impact crater (Fig. 1) formed in the Amazonis Planitia region at 35.1ºN, 189.8ºE on December 24, 2021 [6]. This is a region of particular interest because it includes the previous lowest-latitude impact-exposing crater near 39.1ºN and various other indications that ice extends to relatively low latitude [2, 3]. This abstract summarizes work in press [7] describing the implications of this new crater for Martian ground ice.

Observations: Bright blocks up to 3 m in diameter and bright patches of material around the crater are observed in images from the High Resolution Imaging Science Experiment (HiRISE). Some blocks are observed as far as 700 m from the crater. Ratio spectra from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) show a 1.02-μm wavelength feature indicative of water ice.

A field of thousands of secondary craters surrounds the primary crater. Many of the larger craters have flat floors, indicative of excavation to a resistant layer. Given the evidence that shallow ice is present, this resistant layer is likely the ice table. Geometric measurements [cf. 8] indicate that this layer is at ~0.5–1.5 m depth with a mean of 1 m, but many other craters of similar size lack flat floors, indicating that either the depth to ice is variable or the presence of ice is patchy, or both. The flat floors are generally not bright, suggesting that the shallowest ice is pore-filling rather than having a high ice content.

Modeling: We simulated the formation of the crater using iSALE2D [9, 10]. The simulated crater is 128 m in diameter and 33 m deep, somewhat smaller but deeper than the real crater. This may in part be due to an absence of rim collapse in the simulation and the assumption of a vertical impact. In the simulation, excavated material in the continuous ejecta is from no more than 8 m depth, and more distal material (including blocks thrown hundreds of meters) derives from shallower depths. Improved simulations of the crater formation will be presented elsewhere at this meeting [11].

Setting and Regional Geomorphology: The crater occurs in a region mapped as Late Amazonian flood lavas [12] thinly covered by mid-latitude mantle deposits that are thought to be mostly a mixture of ice and dust [13]. This mantle fades out equatorward of 33–34ºN, transitioning to platy-ridged lava. The sizes of impact craters with rocky and non-rocky ejecta near the new impact indicate that the mantle is >7 but <40 m thick. It is just south of radar reflectors thought to indicate decameters-thick massive ice [14]. Surface reflectivity from SHARAD [4] is consistent with ice in the upper 5 m of the subsurface, but neutron spectrometer data [15] do not indicate high ice abundance in the upper 50 cm of the subsurface. Ice stability models [16] indicate that these longitudes are relatively favorable for lower-latitude ice due to relatively high albedo and low thermal inertia. When stable, the stability depth is likely shallow (<1 cm) due to relatively high albedo and low thermal inertia, although the ice is likely unstable at current humidities.

The surface immediately around the crater has a hummocky texture suggestive of ice loss as well as several expanded craters that are interpreted to indicate partial loss of massive ice [17]. Isolated mounds on the mantle deposits appear to result from inversion of expanded craters during progressive ice loss, which can ultimately produce a mound from material trapped within the crater. The largest of these mounds is ~200 m across, suggesting that at least ~30 m of ice (the approximate depth of the crater below the original ground surface) has been removed to fully invert the topography.

Discussion: Overall, these observations are consistent with the presence of massive ice that is unstable at present but has been occasionally stable in geologically recent time, undergoing net loss but occasionally accreting an overlying coating of pore ice. Given the proximity to radar reflectors and likelihood of loss of tens of meters of ice, the location may have been a distal part of the regional deposit still extant to the north. The marginal (in)stability at this location and coincidence with the edge of the mid-latitude mantle suggests that this is near the edge of currently extant, widespread, shallow ice; any lower-latitude ice should have retreated to greater depths or exist on local pole-facing slopes [18, 19]. This information is an essential constraint for considering ISRU plans and setting Planetary Protection policy.

This location also serves as an invaluable calibration point for models of past ice deposition [e.g., 20] and long-term ice evolution [e.g., 21]. Climate oscillations must cause regular ice loss cumulatively reaching tens of meters in geologically recent time, but with intervals of stability sufficient to produce a significant pore ice cover that currently begins near 1 m depth. Furthermore, it is likely that this location is near the southern margin of a past decameters-thick regional ice accumulation. These new quantitative constraints should provide motivation and calibration for the next generation of such models.

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References: [1] Byrne S. et al. (2009) Science, 325, 1674-1676. [2] Dundas C. M. et al. (2014) JGR, 119, 109-127. [3] Dundas C. M. et al. (2021) JGR, 126, e2020JE006617. [4] Morgan G. A. et al. (2021) Nature Astron., 5, 230-236. [5] Rummel J. D. et al. (2014) Astrobio., 14, 887-968. [6] Posiolova L. V. et al. (2022) Science, 378, 412-417. [7] Dundas C. M. et al. (2023) GRL, in press. [8] Bart, G. D. (2014) Icarus, 235, 130-135. [9] Collins G. S. et al. (2004) Met. Planet. Sci., 39, 217-231. [10] Wünnemann K. et al. (2006) Icarus, 180, 514-527. [11] Collins G. S. et al. (2023), this meeting. [12] Tanaka K. L. et al. (2014) USGS SIM Map #3292. [13] Kreslavsky M. A. and Head J. W. (2002) GRL 29, 2002GL015392. [14] Bramson A. M. et al. (2015) GRL, 42, 6566-6574. [15] Pathare A. V. et al. (2018) Icarus, 301, 97-116. [16] Mellon M. T. et al. (2004) Icarus, 169, 324-340. [17] Dundas C. M. et al. (2015) Icarus, 262, 154-169. [18] Aharonson O and Schorghofer N. (2006) JGR, 111, 2005JE002636. [19] Mellon M. T. and Sizemore H. G. (2022) Icarus, 371, #114667. [20] Madeleine J.-B. et al. (2009) Icarus, 203, 390-405. [21] Schorghofer N. (2007) Nature, 449, 192-195.

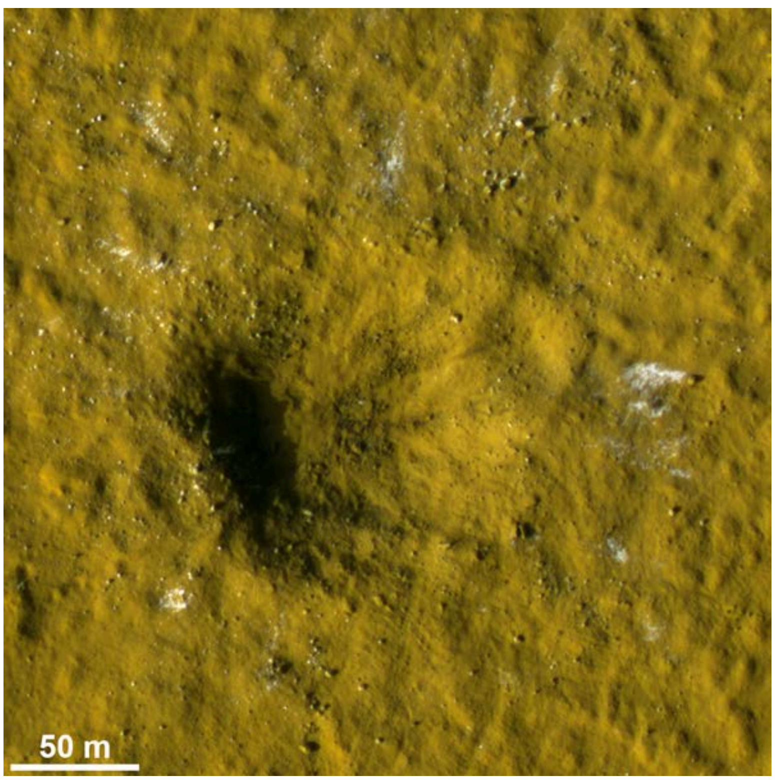

Figure 1: Large ice-exposing impact crater in HiRISE image ESP_073077_2155. Note patches of ice with no visible relief as well as blocks up to 3 m diameter at upper right. North is up and illumination from the left.