THICK, EXCESS WATER ICE IN ARCADIA PLANITIA, MARS A. M. Bramson[1], S. Byrne[1], N. E. Putzig[2], S. Mattson[1], J. J. Plaut[3], J. W. Holt[4], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ (bramson@lpl.arizona.edu), [2]Southwest Research Institute, Boulder, CO, [3]Jet Propulsion Laboratory, Pasadena, CA, [4]Institute for Geophysics, University of Texas at Austin, Austin, TX

Introduction: Knowledge of the distribution and nature of water ice on Mars is important for understanding past Martian climates, and also has implications for future human exploration. Radar sounding data from the Shallow Radar (SHARAD) instrument on the Mars Reconnaissance Orbiter (MRO) show a widespread radar-transparent layer in Arcadia Planitia, Mars [1]. The delay time of this radar reflection relative to that from the surface varies across the region, being greatest to the south. Geomorphological evidence [2] and ice-exposing impacts [3] suggest that this region contains abundant excess ice (higher water ice abundances than can fit into the pore spaces of the regolith).

We have used terraced impact craters (e.g. Figure 1) in conjunction with this regional radar reflection to constrain the dielectric constant ε_r of the layer, finding it to be consistent with relatively pure ice (ε_r = 3.15). Converting the delay times of the SHARAD interface to depths using a composition of pure water ice gives an average thickness of the layer of ~45 m (Figure 2, overleaf).

Climate models suggest widespread deposition of ice could have occurred in the mid-latitudes during Mars' high obliquity (> 35°) periods under certain conditions [4]. These depositional episodes would be good candidates for the origin of this ice layer in Arcadia Planitia. However, thermal modeling suggests that ice in the mid-latitudes has been unstable in the recent past [5]. If these thick deposits date to high-obliquity periods, their survival through the more recent periods of instability indicates a gap in our understanding of the climatic history of Mars.

Here, we constrain the thickness and extent of this unusual mid-latitude ice deposit and discuss its implications for the climatic history of the planet.

Methods: Terraces in simple craters form due to changes in the strength of the target material at a given depth. We mapped dozens of these terraced craters within Arcadia Planitia (Figure 2) in CTX images and followed up on many with HiRISE imaging. From stereo data collected with the HiRISE camera on MRO we made Digital Terrain Models (DTMs) and calculated depths to terraces.

We assume the change in material responsible for the terraces is the same dielectric interface that causes the subsurface SHARAD reflection. We mapped the surface and subsurface interfaces across Arcadia Planitia in 230 SHARAD tracks. By comparing the depth of the terraces to the time gap between surface and subsurface radar reflections we can determine wave velocity and thus, dielectric constant of the overlying material.

Figure 1 shows a DTM for one such doubly-terraced crater located at 46.581°N, 194.85°E. The large, flat terrace at the floor level is at a depth of 40 m. A second, shallower (14 m depth) and smaller terrace in the crater wall suggests additional complexity in the subsurface, perhaps a change in porosity or dirtiness of the ice.

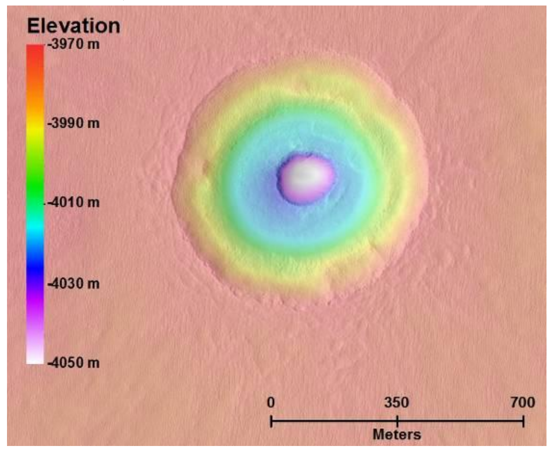

Figure 1: A Digital Terrain Model (DTM) of a doubly-terraced crater located at 46.581°N, 194.85°E made from HiRISE stereo image pair ESP_018522_2270 & ESP_019010_2270.

Two SHARAD tracks pass nearby this crater with one-way delay times of the subsurface reflector ranging from 0.18 μs to 0.27 μs. Fitting the delay times to a plane and solving for the time at the location of the crater gives an expected one-way delay time of 0.23 μs relative to the surrounding surface. If the SHARAD interface corresponds to the small wall terrace at 14 m depth, ε_r would be ~24, an unrealistically high value. Associating this delay time to the floor-level terrace at a depth of 40 m yields ε_r ~3, consistent with pure water ice. The floor-terrace depth of another crater for which we have a DTM and SHARAD reflector also yields a dielectric constant similar to that of water ice (3.7).

The extent of the SHARAD reflector we have mapped is limited by the strength of the surface echo, which hides any other possible reflectors within ~0.17 μs one-way delay of the surface (~20-30 m depth in ice). We imaged a smaller terraced crater that is in one such area where no SHARAD subsurface reflection appears. Its floor terrace is at 16 m depth, within the near-surface range where SHARAD cannot distinguish subsurface returns due to the interference from sidelobes of the surface return. It is conceivable that the layer does not disappear when the reflector disappears but rather the layer becomes too shallow to be detectable by SHARAD. Thus, the extent of the deposit shown in Figure 2 is a lower limit.

Dielectric Mixing: While the dielectric constant of pure water ice is 3.15, it is possible that this layer of ice is dirty, having a dielectric constant between that of pure ice and that of a dense rock like basalt ($\varepsilon_r \sim 8$). To compare our dielectric constant calculations to the dielectric behavior of a 2-component mixture, we have calculated the effective dielectric constant of a mixture (ε_m) with different volumetric fractions (v_i) of rock inclusions ($\varepsilon_i = 8$) in a host material of ice ($\varepsilon_h = 3.15$) using three different mixing models (Figure 3). The general mixing model formula is:

$$\varepsilon_m^{\alpha} = \varepsilon_h^{\alpha} + v_i\,(\varepsilon_i^{\alpha} - \varepsilon_h^{\alpha})$$

where α=1 in the linear model and α=1/2 in the refractive model [6]. The logarithmic model was proposed by Lichtenecker for the α→0 scenario [7, 8]:

$$\log(\varepsilon_m) = v_h \log(\varepsilon_h) + v_i \log(\varepsilon_i)$$

We can compare our terraced crater results for dielectric constants of the layer to these dielectric mixing models to constrain the composition of this layer that exists across Arcadia Planitia. For example, the dielectric constant of 3.7 calculated from one of our terraced craters would mean the ice could contain up to 12-18% rock inclusions. Likewise, we can calculate the volume fraction of air for air inclusions ($\varepsilon_i = 1$) in ice to understand porosities of the ice. The dielectric constant of 3 calculated from the crater above is consistent with ice with a porosity of ~6%.

Conclusions: We present evidence of subsurface layering from SHARAD radar interfaces and terraced craters across Arcadia Planitia. Combining these datasets shows that the upper layer is likely thick, relatively pure water ice that extends down to the floor terraces of craters, 10s of meters deep. Superposed expanded secondary craters in the region suggest that this ice has been here 10s of millions of years [2]. Understanding the conditions that have preserved this thick, extensive layer of ice through many recent lower-obliquity periods will improve our understanding of the Martian climate system.

References: [1] Plaut J.J. et al. (2009) LPSC XL, Abstract #2312. [2] Viola D. et al. (2013) AGU. [3] Dundas C.M. et al. (2013) JGR, In Press. [4] Madeleine J.-B. et al. (2009) Icarus, 203, 390-405. [5] Chamberlain M.A. and Boynton W.V. (2007) JGR, 112, E06009. [6] Ulaby F.T., Moore R.K., and Fung A.K. (1986) *Microwave Remote Sensing, Active and Passive, vol.III: From Theory to Applications*, Artech House, Massachusetts. [7] Wu Y., Zhao X., and Fan Z. (2003) Journal of Electroceramics, 11, 227-239. [8] Campbell B.A. (2011) *Radar Remote Sensing of Planetary Surfaces*, Cambridge University Press, New York.

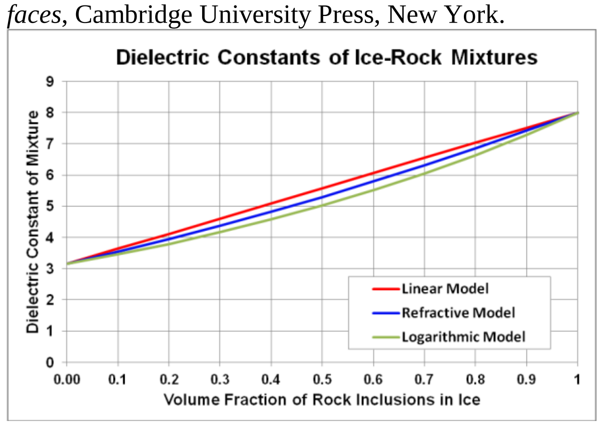

Figure 3: Effective dielectric constant of a mixture of varying volumetric fraction of rock inclusions ($\varepsilon_r = 8$) in ice ($\varepsilon_r = 3.15$) using three mixing models.

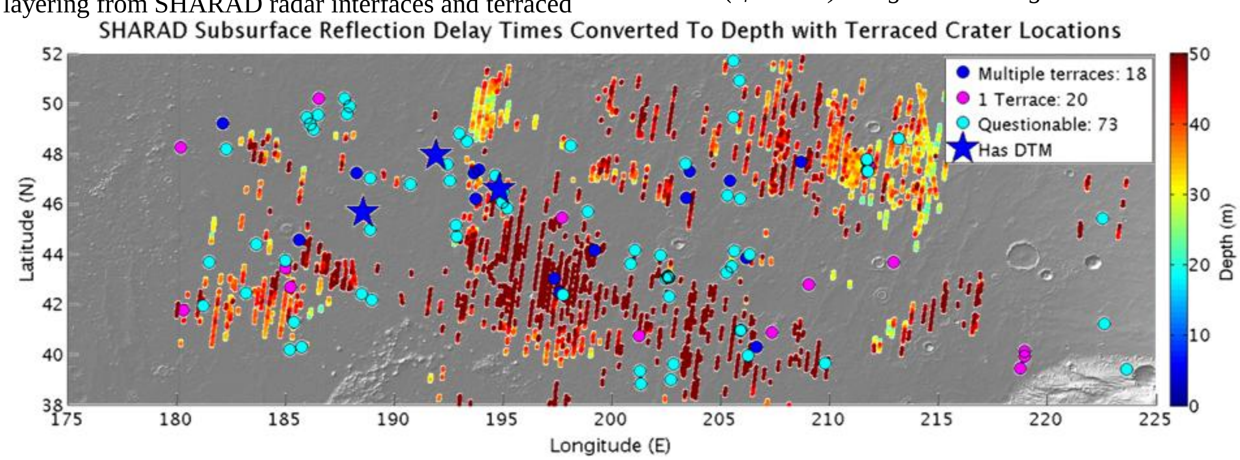

Figure 2: Terraced craters (larger circles) plotted over radar delay times converted to depth in meters (red is deep; blue is shallow) assuming a dielectric constant of pure ice (3.15).