A STUDY OF MARTIAN MID-LATITUDE ICE USING OBSERVATIONS AND MODELING OF TERRACED CRATERS.

A.M. Bramson[1], S. Byrne[1], S. Sutton[1], N.E. Putzig[2], E. Martellato[3], G. Cremonese[3], J.J. Plaut[4], J.W. Holt[5], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ (Bramson@lpl.arizona.edu), [2]Southwest Research Institute, Boulder, CO, [3]INAF-Astronomical Observatory of Padova, Padova, Italy, [4]Jet Propulsion Laboratory, Pasadena, CA, [5]Institute for Geophysics, University of Texas at Austin, Austin, TX.

Introduction: To understand past Martian climates, it is important to know the distribution and nature of water ice on Mars. The conventional picture of Martian mid-latitude ice has been that it is young and pore-filling ground ice, which responds quickly to varying orbital and climatic conditions via atmospheric exchange [1,2]. However, numerous lines of geomorphological evidence, including ice-exposing impacts [3] and thermokarstic expansion of secondary craters [4], suggest ice in the northern mid-latitudes of Mars is in the form of relatively pure, excess ice (higher water ice abundances than available in the pore spaces of the regolith).

The source and timing of excess ice at the mid-latitudes is not well understood. However, Viola et al.'s study in Arcadia Planitia [4] suggests that the excess ice is tens of millions of years old. This is older than predicted by ice stability models, which show that ice should periodically sublimate away with obliquity cycles that vary on much shorter timescales. Understanding ice emplacement mechanisms and timing is important if we wish to understand Martian climatic history, but to do so we first need to put constraints on the distribution and composition of ice on Mars today.

Craters provide a way to probe subsurface structure, and terracing within the walls of simple craters is often indicative of layering within the target material. We can use the morphology of these craters along with radar sounding from the Shallow Radar (SHARAD) instrument to constrain the dielectric properties of a widespread, radar-transparent layer. We also numerically model the formation of the terraced craters to better constrain possible layering and impact environments. This work suggests that the decameters-thick layer across Arcadia Planitia is dominated by relatively pure water ice.

Methods: Terraces in simple craters develop within the crater walls at sudden changes in the strength of the target material with depth, giving the craters a concentric morphology (Fig. 1). We mapped the locations of dozens of these craters within Arcadia Planitia in 311 CTX images, with 32 followed up with HiRISE stereo pairs and 11 Digital Terrain Models (DTMs) created (Figure 2 black and white markers, overleaf). Using the DTMs, we calculated the depths to terraces.

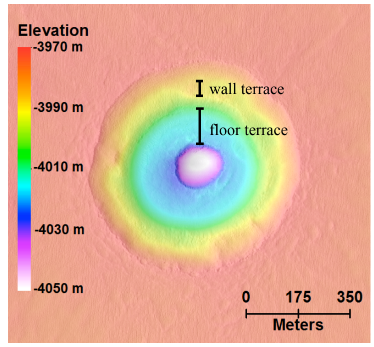

Figure 1: A terraced crater at 46.581°N, 194.85°E with colors representing elevations. The DTM was made using HiRISE stereo pairs ESP_018522_2270 ESP_019010_2270

We also mapped surface and subsurface interfaces in 277 SHARAD tracks within the region (Fig. 2 colors). Assuming the change in subsurface material responsible for the terraces is the same dielectric interface that causes the SHARAD reflections, we can compare terrace depths to delay time differences between surface and subsurface radar reflectors to determine the wave velocity and thus, the dielectric constant of the layer.

The results from mapping these features show the layer is heterogeneous, being deeper (in delay time) towards the south and interspersed with patches lacking subsurface reflectors. However, there are some terraced craters within these patches suggesting that the layer might still exist but just be too thin to be detectable by SHARAD (subsurface reflectors within ~20 meters of the surface may be masked by the surface return or by its sidelobes).

Dielectric Mixtures: The dielectric constant (relative dielectric permittivity), ε_r, is a measure of how effectively an electromagnetic wave can move in a material. This varies with composition, thus our calculations can put constraints on the porosity and rock content of the Arcadia Planitia ice layer. We compare our dielectric constant calculations near the terraced craters to the dielectric behavior for 3-component mixtures of varying volumetric fractions of ice (ε_r=3.15), rock (ε_r=8) and air (ε_r=1) using the following power-law relation: $\varepsilon_{mix}^{1/\gamma} = v_{rock}\varepsilon_{rock}^{1/\gamma} + v_{ice}\varepsilon_{ice}^{1/\gamma} + v_{air}\varepsilon_{air}^{1/\gamma}$ with γ = 2.7, the exponent Stillman et al. 2010 [5] found to best fit sand-ice mixtures (Figure 3).

Many of the craters exhibit more than one terrace, with a shallower, subtler terrace within the crater wall and a wider and deeper "floor" terrace which we interpret to be the bottom of the ice layer. The wall terrace is likely indicative of additional structure within the ice layer or the boundary of an overlying regolith layer.

Four out of the 11 terraced craters for which we have DTMs exhibit more than one terrace (important to ensure we are looking at the floor terrace, and thus the entirety of the ice layer) *and* have subsurface radar reflectors within 15 km (important because of the heterogeneity of the layer). Three of these craters give dielectric constants consistent with a mixture consisting of predominantly pure water ice (3.57, 3.49, 3.35) while one crater's dielectric constant is considerably higher (6.37), matching that of a dielectric mixture of at least 60% basalt when mixed with ice or as high as 80% basalt if mixed with only air (Fig. 3).

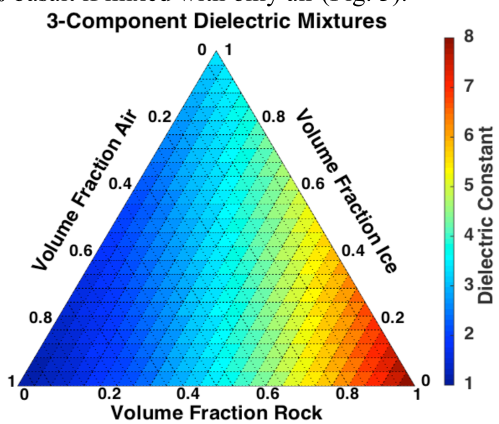

Figure 3: ε_r for mixtures of ice, rock and air.

iSALE Modeling: We modeled crater formation in a layered target with the iSALE shock physics code [6,7,8]. We tested a variety of properties for the layers (thicknesses, porosities, strengths) as well as projectile sizes and speeds, and compared the resulting model profiles to that from one of our terraced crater DTMs (Fig. 4). Preliminary results suggest a 3-layer structure consisting of 10-meters of regolith overlying decameters of ice atop a basaltic crust best matches the DTM profile. These results are consistent with the dielectric constant calculations from the SHARAD and HiRISE measurements.

Conclusions: We present a multi-faceted study of evidence for subsurface layering of ice in Arcadia Planitia, Mars. This study combines datasets from mapping terraced craters and SHARAD radar interfaces, as well as numerical models of terraced crater formation. We find evidence for a decameters-thick layer of relatively pure water ice. The presence of a more subtle, shallower terrace within the wall is consistent with the modeling which suggest a layer of regolith atop this ice layer. The ice layer extends to the "floor" terrace level at ~40 meters depth in most cases. However, the results also show there is much heterogeneity across the region regarding depth and perhaps composition as well. Understanding the conditions that formed this thick, extensive but heterogeneous layer of ice will improve our understanding of the Martian climate system and may also serve as a resource for future human exploration to Mars.

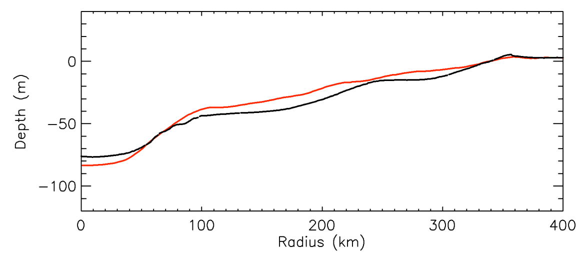

Figure 4: Comparison between a profile from our terraced crater DTM in Fig. 1 (black) and the model run derived with 10m regolith overlying 30m of ice (red).

References: [1] Bryson et al. (2008) *Icarus, 196,* 446-458. [2] Hudson et al. (2007) *JGR*, 112, E05016. [3] Dundas et al. (2014) *JGR Planets, 119,* 109-127. [4] Viola et al. (2015) *Icarus, 248,* 190-204. [5] Stillman et al. (2010) *J. Phys. Chem. B*, 114, 6065-6073. [6] Amsden et al. (1980) *Los Alamos Nat. Lab.,* Report LA-8095. [7] Collins et al. (2004) *MAPS 39*, 217-231. [8] Wünnemann et al. (2006) *Icarus 180*, 514-527.

Acknowledgements: SHARAD radar tracks were processed using the Colorado SHARAD Processing System (CO-SHARPS). We gratefully acknowledge the developers of iSALE-2D, including G. Collins, K. Wünnemann, D. Elbeshausen, B.A. Ivanov and J. Melosh (www.iSALE-code.de). This material is based upon work supported by the NSF Graduate Research Fellowship under Grant No. DGE-1143953.

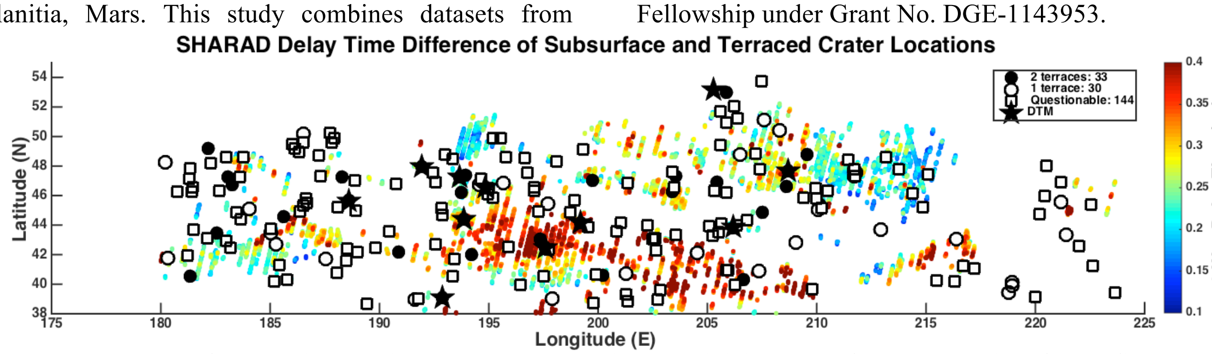

Figure 2: Map of terraced crater locations (B&W markers) and delay time of SHARAD subsurface reflectors.