MODELING OF TERRACED CRATERS ON MARS.

E. Martellato[1], G. Cremonese[1], A. Lucchetti[2,1], A.M. Bramson[3], S. Byrne[3], [1]INAF-Astronomical Observatory of Padova, Padova, Italy (elena.martellato@oapd.inaf.it), [2]CISAS, University of Padova, Italy, [3] Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ.

Introduction: Impact craters are circular depressions which occur in many varieties on the surfaces of the planets and small bodies. Their final morphology is mainly due to the resulting collapse of the transient cavity [1].

Simple craters develop if the transient crater is more or less stable in the gravity field. A mix of fractured rocks and melts slip along the crater walls and give origin to a breccia lens on the floor and a bowl-shaped cavity with a depth/diameter ratio of roughly 1/5. Any departure from this canonical shape derives from peculiar compositions and properties of the target material. For instance, terraced craters, with their concentric appearance, are suggested to develop as a consequence of layers within the target having different strengths, with a weak layer overlying stronger material (Fig. 1). In this work, we will present the numerical investigations of the formation of two such terraced craters located in Arcadia Planitia, Mars.

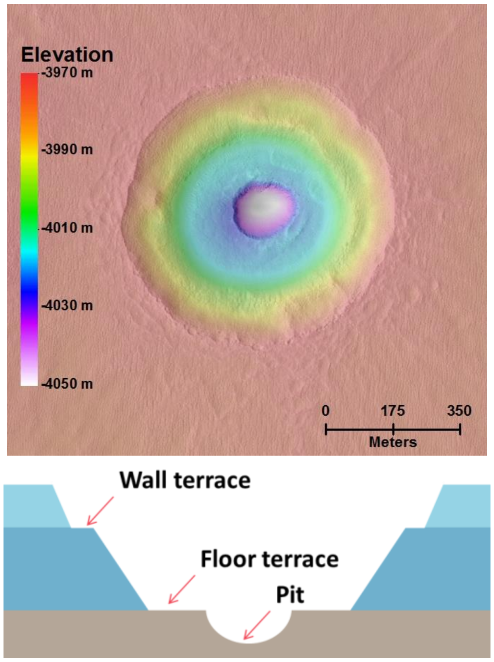

Figure 1. Top: Digital Terrain Model of Crater 1 made from HiRISE stereo pairs ESP_018522_2270 & ESP_019010_2270. Bottom: Cartoon of the profile of the crater, showing the shallower "wall terrace" and the deeper, more prominent "floor terrace", which is predicted to be at the base of the ice-crust interface.

Expected Subsurface Structure: The layered structure in the subsurface of Arcadia Planitia has been established by both the existence of dozens of terraced craters as well as a widespread subsurface interface detected by the Shallow Radar (SHARAD) instrument on board the Mars Reconnaissance Orbiter. From 3D Digital Terrain Models (DTMs) created using High Resolution Imaging Science Experiment (HiRISE) stereo pairs of the craters, we took profiles across the terraced craters to compare to our numerical models.

By combining the depths to the crater terraces with SHARAD subsurface reflector delay times, [2] calculated the expected dielectric constant for the material between the surface and subsurface radar interface (expected to be the same interface as that which causes the floor terrace in the crater morphology) to be 2.5 ± 0.28. Comparing dielectric constants to 3-component dielectric mixing models, [2] concludes the material in the upper decameters of the surface is dominated by ice (that which exceeds the thickness of the regolith) with up to 75% volumetric fraction. Their results can only compute a bulk value for the whole layer which may bias the results towards lower ice contents and is also limited in detecting the finer structure that likely exists in the subsurface.

Here, we present the numerically modeling of these terraced craters, which may allow us to place additional constraints on the finer subsurface structure that leads to the double-terraced structure. The parameters used in iSale to investigate these craters will be used in the future to simulate similar craters where there are no radar data.

Crater Description: Among several impact craters on Arcadia Planitia, two specific cases have been considered for analysis.

Crater 1. The first crater is located at 46.58°N, 194.85°E. It is 710 m in diameter, and has a floor terrace (thought to be the ice-rock interface) at ~40 m depth with an additional, smaller wall-terrace (likely from additional structure within the ice) at ~17 m depth.

Crater 2. The second crater is located at 47.94°N, 191.93°E. It is 580 m in diameter. It's first terrace is at 29 m depth, whereas the deeper, more prominent terrace is at 42 m below the surface.

Methods: Numerical modelling is performed through the iSALE shock physics code. Initially developed by [3], the code has been enhanced through modifications which include an elasto-plastic constitutive model, fragmentation models, various equations of state (EoS), multiple materials, a novel porosity compaction model, the ε-α-model [4, 5, 6, 7]. In addition, the code is well tested against laboratory experiments at low and high strain-rates [7] and other hydrocodes [8].

The model setup is based on a layered target made up of a regolithic layer (described by the basalt ANEOS and the Drucker-Prager model), on top an ice layer (described by the Tillotson equation of state of ice), in turn on top of an underlying basaltic crust (described by the Collins model). The projectile used in the model has a basaltic composition and an impact velocity of 7 km/s. The results of the models are then compared with the HiRISE DTM profile in order to derive the properties which best explain the terraced crater morphology.

Results and Discussion: Using the iSALE shock physics code, we ran numerous 2-layer and 3-layer models to find the model that best fits the actual crater profile. In particular, we tested a variety of properties of the layers (thicknesses, porosities, strengths) as well as projectile size and speed. The results of this investigation suggest that a 3-layer target is needed to account for both the floor terrace at the crust-ice interface and the subtler wall terrace, which likely stands at the base of a regolith layer. Porosities of the modeled ice and regolith are consistent with those expected from [2] dielectric constant calculations, with the best results obtained when the ice has a porosity lower than 30%. Material cohesion has a fundamental role in obtaining a good fit for both the terraces, the rim and the pit.

As for instance, Fig. 2 shows the final snapshot of crater 1. This represents our best fit model (cf. Fig. 3), which was obtained with a 20 m radius projectile, and with cohesion values of 0.003, 0.02 and 0.5 MPa, respectively for the regolith, ice, and crust.

References: [1] Melosh H.J. (1989) Impact cratering: A geologic process. *New York: Oxford University Press*, 245 p. [2] Bramson A.M. et al. (2015) Widespread Excess Ice in Arcadia Planitia, Mars, *Manuscript submitted for publication in GRL*. [3] Amsden A.A. et al. (1980) *Los Alamos National Laboratories*, Report LA–8095. [4] Collins G.S. et al. (2004) *Meteoritics & Planet. Sci.*, *39*, 217-231, 2004. [5] Ivanov B.A. et al. (1997) *Int. J. Impact Eng.*, *20*, 411-430. [6] Melosh H.J. et al. (1992) *JGR*, *97*, 14,735-14,759. [7] Wünnemann K. et al. (2006) *Icarus*, *180*, 514-527. [8] Pierazzo E. et al. (2008) *Meteoritics & Planet. Sci.*, *43*, 1917–1938.

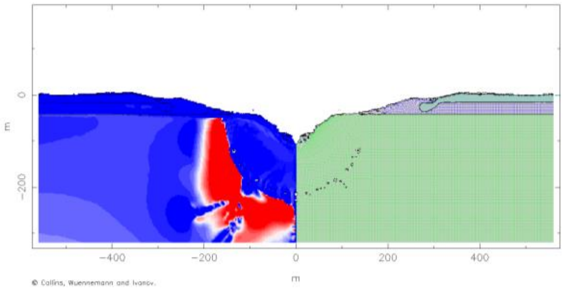

Figure 2. Final snapshot of crater 1. Left side shows pressure contours (red = 10 MPa, blue = 1 MPa); right side shows the materials describing the target.

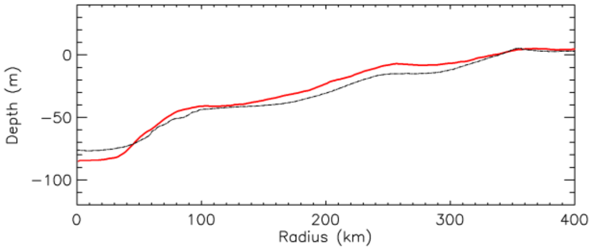

Figure 3. Comparison between the modeled crater 1 profile (red line) with the HiRISE DTM of the structure (black line).

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