"SOFTENING" OF MARTIAN IMPACT CRATERS BY CREEP OF ICE-RICH PERMAFROST

E.P. Turtle1,2 and A.V. Pathare1,3, 1PSI (turtle@psi.edu), 2LPL, 3Caltech

**Introduction:** Since the initial Mariner 9 mapping of Mars, researchers have noted the curious “softened” characteristics of high-latitude terrain, which are widely theorized to result from the viscous creep of a near-surface layer of ice-rich permafrost within the Martian megaregolith [e.g., 1-5]. Squyres and Carr [4] classified creep-related landforms, including: (1) debris aprons, produced by mass wasting along escarpments, examples of which include lobate debris aprons, lineated valley fill, and concentric crater fill; and (2) terrain softening, resulting from *in situ* viscous deformation, which is most clearly expressed by craters with degraded rims and flattened topographic profiles. Squyres [5] also conducted finite-element simulations that qualitatively established the ability of viscous creep deformation to reproduce the morphologies of craters in martian softened terrain.

Jankowski and Squyres [6] performed a more quantitative analysis of Martian crater relaxation, concluding that the morphology of mid-latitude craters is consistent with relaxation in a deforming layer no more than 1 km deep. In order to explain the extent of terrain softening observed by [5] with a two-layer model, Jankowski and Squyres [6] required subsurface ice equivalent to a global layer of water 17 m thick, a figure which rises to 55 m if likely locations of terrain softening are included and 125 m if everywhere poleward of 30° latitude is included.

We are using finite-element models of viscous creep relaxation to simulate terrain softening, incorporating more recent laboratory measurements of ice/rock mixtures [7-11]. By comparing the resulting landforms to structural and topographic characteristics documented in MGS MOC and MOLA data we can constrain the conditions necessary to allow such deformation on Mars [e.g., 12,13]. The original intent of this project was to determine how much different past conditions would have to have been, *e.g.*, warmer, higher ice content, etc., in order to allow the observed deformation. However, to our surprise we found that significant deformation of ground ice can occur quite rapidly under current martian conditions.

**Rheology of Ice-Rich Permafrost:** Jankowski and Squyres [6] were forced to make some assumptions regarding the rheology of martian ground ice that may no longer be viable. They devised a soil structure parameter $S$ that relates the viscosity of pure ice to that of ice-rich permafrost. In order to allow 3-km diameter craters to relax gradually over time scales of 4 Gyr, they needed to assume a value for $S$ of approximately $10^{-6}$. I.e., by constraining the relaxation times to be slow enough to be consistent with the continued existence of $D \sim 3$ km craters in Noachian terrain they needed the viscosity of the ground ice to be one million times greater than that of pure ice.

However, more recent laboratory measurements of dust - water ice mixtures conducted by both Durham *et al.* [7] and Mangold *et al.* [11] have yielded maximum relative viscosities of no more than 100 times that of pure ice. The reason for this is that when the volumetric dust fraction gets too high (typically above 75%), the dust grains come in contact with each other and the mixture crosses the brittle-ductile transition and can no longer undergo viscous creep [7,11]. Hence, it is unlikely that the relative viscosity of Martian permafrost is much greater than 1000 times that of pure ice. Consequently, $D = 3$ km craters in a 1-km-thick deforming layer should relax on time scales of Myr (at most), not Gyr. This conclusion is consistent with the finite
element modeling of Pathare et al. [13], who showed that 2-km-diameter craters in the South Polar Layered Deposits undergo relaxation on time scales less than 10 Myr.

**Simulations Under Present Martian Conditions:** We have performed finite-element simulations to investigate the deformation of martian impact craters by creep of an ice-rich surface layer. The models incorporate laboratory measurements of the rheological parameters for dust/water-ice mixtures undergoing dislocation and grain size sensitive creep [7-9]; both are relevant under current conditions: $T_{surf} = 200 \text{ K}$ [14]; $dT/dz = 15 \text{ K/km}$ [15,16].

Simulations with only 30% ice (by volume) demonstrate that even under present Martian conditions, viscous creep can occur quite rapidly, $10^3$-$10^4$ years. This result implies that there cannot currently be a high volume fraction or deep (~1 km) extent of martian ground ice. Another possibility is that the mobility of ground ice is restricted by a surface layer that resists deformation; if, for example, the high volume fractions of ice inferred to be present within a ~1 m surface layer [17] do not continue to significant depths, or a higher viscosity material, e.g., clathrate [18], were present near the surface, the deformation timescales could be significantly longer.

**References:**