IS VISCOUS FLOW IMPORTANT AT THE MARTIAN POLES? Michael M. Sori[1], Shane Byrne[1], Christopher W. Hamilton[1], and Margaret E. Landis[1]. [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA (sori@lpl.arizona.edu).

Introduction: The North and South Polar Layered Deposits (NPLD/SPLD) on Mars are primarily composed of kilometers-thick domes of dusty water ice. Despite being the subject of much study, large uncertainties exist in estimates of the composition [e.g., 1], deposition rates [e.g., 2], and ages [e.g., 3] of both PLD. However, studies of the population of impact craters have yielded constraints on accumulation rates at both the north [3] and south [4] poles. Geophysical modeling of impact craters [5] and spiraling troughs [6] has suggested the importance of viscous relaxation in modifying these features over long time scales.

Here, we expand upon the basic approach of Pathare et al. [5,6] in modeling viscous flow of topography observed in the NPLD. We use a finite element model (FEM) code called Elmer/Ice [7] to simulate gravity-driven flow of ice. Firstly, we model viscous flow of steep scarps [8] in an effort to constrain the ages of those features. Secondly, we model three-dimensional flow of impact craters in the PLD to quantitatively constrain the relative importance of viscous flow in shaping the topography we observe today.

Steep Scarps: Steep scarps of ice have been observed near the north pole [8], cutting into the edges of the topographic dome of the NPLD. While temporal monitoring by the High Resolution Imaging Science Experiment (HiRISE) camera onboard the Mars Reconnaissance Orbiter (MRO) has produced observations interpreted to be avalanches of carbon dioxide ice and frost with dust, such events are unlikely to play a major role in the evolution of the steep scarps [8]. This inference, combined with the high slopes of the scarps (with sections as thick as ~100 m approaching 90°) and their resulting warm annual-average temperatures (~200K), make these features prime candidates for viscous relaxation.

We model viscous flow of these steep scarps in two dimensions, approximating the shape of the scarps as a quarter sine wave. We solve the Navier-Stokes equations in our FEM code under the assumption that the PLD are made of pure water ice at Martian gravity, and that the relationship between strain rate and stress is approximated by Glenn's flow law. We set a boundary condition of zero flow velocity at the edge of the domain. We consider two scenarios: one in which the material below the base of the scarp is composed of pure water ice, and one in which the material below the base of the scarp is immobile. These two end-members provide constraints on the flow velocity, as in reality the material there is likely sandy ice that does not flow as readily as the ice without impurities.

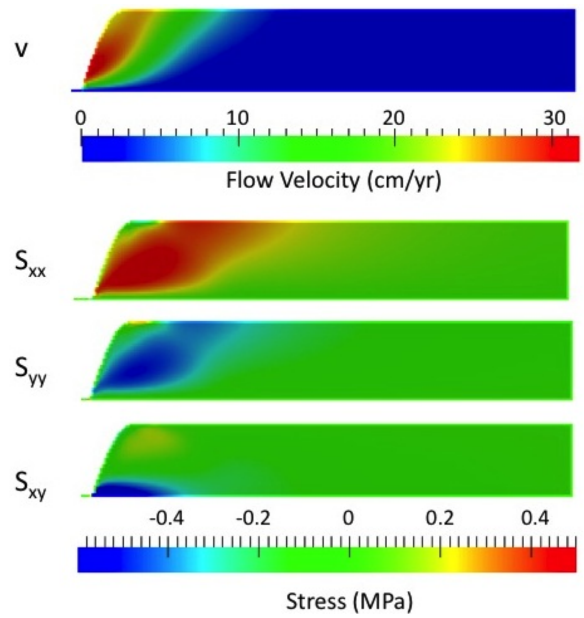

Figure 1. Flow velocities (top) and state of stress (bottom) for an 800 m high and 400 m wide scarp with a uniform ice temperature of 200 K, where the material beneath the bottom of the scarp does not flow. The flow velocities are given in centimeters per (Earth) year and imply viscous flow is an important mechanism in the evolution of these features. Stresses are deviatoric, with positive stresses tensile.

We find that viscous flow is likely a significant factor in modifying these scarps. For example, we find that an 800 m high scarp experiences maximum flow velocities on the order of 10s of cm/yr at 200 K; see Figure 1. In Figure 2, we show the sensitivity of our models to ice temperature. These results are not sensitive to our mesh size or the domain considered.

Craters: Searches of the MRO Context Camera (CTX) and HiRISE imagery have yielded 38 craters on the NPLD with a diameter larger than 44 m [3, 9]. Using a newly estimated production function of small impact craters on Mars [10], authors have estimated a surface age on the order of kyrs for the NPLD [9]. This is significantly younger than the previous estimate of 10-20 kyr [3], based on a different production function [11].

Using these results to guide our choice of model parameters, including crater diameter, crater latitude (i.e., temperature), and estimated age, we model three-dimensional viscous flow of these impact craters. We use Elmer/Ice to simulate flow as in the case of the scarps. An example result is shown in Figure 3.

We find that viscous flow is unlikely to be an important factor for modifying impact craters at the north pole. Flow velocities for a 200m-diameter crater at a temperature of 170 K (a typical annual average temperature for these flat areas) never exceed a micron/year. Even in the implausible scenario that such an impact crater is as old as the maximum estimated age of the NPLD [12], the crater would not be shallowed by more than a few meters over its lifetime (the total age of the cap is 2–3 orders of magnitude older than the actual age estimates of [9] and [11] for the surface). Again, these results are robust with respect to the mesh size and domain considered. The flow velocities do change significantly with temperature, but even for higher plausible temperatures, flow velocities are too small for viscous relaxation to heavily modify the craters observed today near the north pole. Craters on the SPLD are both larger and older [4], and our modeling does result in larger flow velocities for larger craters as expected. A 2km-diameter impact crater experiences maximum flow velocities of 10^{-4} m/yr at 170 K, which implies significant viscous flow over Myrs, consistent with previous work [5].

Conclusions and Future Work: We conclude that viscous relaxation is probably not an important mechanism for modifying present-day observed craters near the north pole of Mars, but that it is likely significant for the evolution of other topographic features, such as steep scarps. If one assumes an initial state for the scarps of a vertical cliff, our results suggest that the time required to attain the presently observed state is on the order of kyrs. Alternatively, if the scarps are in a steady state, other processes must be operating on a timescale at least as fast to maintain the steep scarp. Our ongoing study will include thermal stresses as in [13] and an additional parameter of ice grain size in the flow law, and thus provide a more accurate estimate of this characteristic timescale. Our method is applicable to viscous relaxation of icy topography in general, and we will investigate gravity-driven flow on other appropriate bodies such as Ceres in the future.

References: [1] Zuber, M. T. et al. (2007), *Science* 300, 299-303. [2] Laskar, J. et al. (2002), *Nature* 361, 608-612. [3] Banks, M. E. et al. (2010), *JGR* 115, E08006. [4] Koutnik, M. (2002), *JGR* 107, E115100. [5] Pathare, A. V. et al. (2005), *Icarus* 174, 396-418. [6] Pathare, A. V. and Paige, D. A. (2005), *Icarus* 174, 419-443. [7] Gagliardini, O. (2013), *Geosci. Model. Dev.* 6, 1299-1318. [8] Russell, P. et al. (2008), *GRL* 35, L23204. [9] Landis, M. E. et al. (2015), *LPSC* 46, this issue. [10] Daubar, I. J. (2013), *Icarus* 225, 506-516. [11] Hartmann, W. K. (2005), *Icaus 174*, 294-320. [12] Jakosky, B. M. et al. (1995), *JGR* 100, 1579-1594. [13] Byrne, S. et al. (2013), *LPSC* 44, 1659.

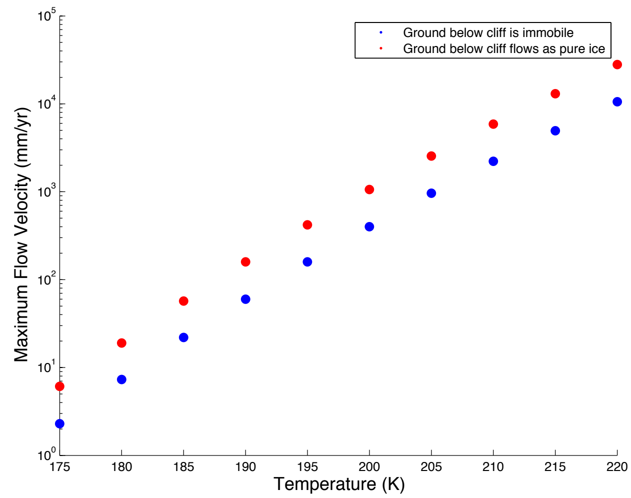

Figure 2. Maximum flow velocities for 800 m high and 400 m wide scarps over a range of ice temperatures. Two model classes are considered: one where the material below the scarp is immobile (as in Figure 2), and one where the material below the scarp is pure water ice that can experience flow. Flow velocity is very sensitive to temperature, but all cases suggest the importance of viscous flow of these features over the lifetime of the NPLD.

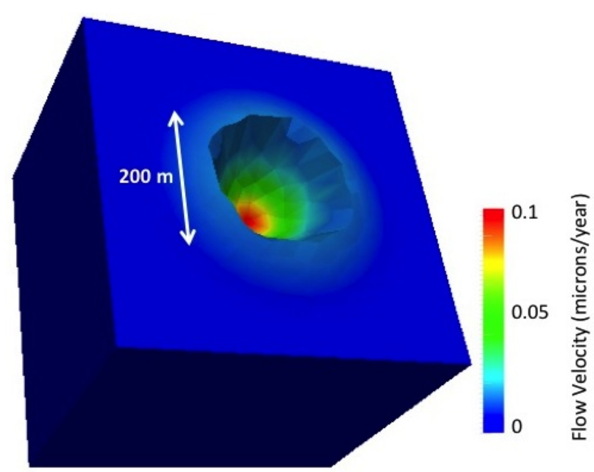

Figure 3. Flow velocities for an idealized 200m-diameter impact crater on the north polar cap of Mars at a temperature of 170 K. Velocities are sufficiently small to imply a lack of importance of viscous flow in modifying presently observed craters near the pole.