VISCOUS CREEP RELAXATION OF IMPACT CRATERS WITHIN THE MARTIAN POLAR LAYERED DEPOSITS. A. V. Pathare1, D. A. Paige1, E. P. Turtle2, and W. K. Hartmann3, 1UCLA (Geology Room #3806, Earth and Space Sciences, UCLA, Los Angeles, CA 90095, USA: avp@mars.ucla.edu, dap@mars.ucla.edu), 2Univ. of Arizona (Lunar and Planetary Lab, Univ. of Arizona, Tucson, AZ 85721, USA: turtle@lpl.arizona.edu), 3Planetary Science Institute (620 North Sixth Ave., Tucson, AZ 85705, USA: hartmann@psi.edu).

Introduction: The intricate layering characteristic of the Martian Polar Layered Deposits (PLD) is strongly indicative of recent orbitally-modulated climate change. Establishing the surface ages and/or resurfacing rates of the PLD can help constrain the time scales for the climatic shifts presumably resulting in layer formation. However, the surface ages derived from North and South PLD crater counts vary widely depending on the size of the observed craters, in a manner that is not consistent with depth-dependent resurfacing mechanisms. Therefore, we propose that viscous creep relaxation of the dusty water ice that comprises the PLD plays a predominant role in its resurfacing. As demonstrated by our finite-element simulations, relaxation of the PLD is the resurfacing mechanism most consistent with the ubiquitous shallowness of PLD craters.

Surface Ages: Martian PLD surface ages can be estimated using a relative Martian-to-lunar crater production model (we assume an average Mars/lunar impact efficiency = 0.5 [1] and adopt a relative Mars/lunar bolide ratio = 2.6 [2]). Analysis of mid-sized craters (1 km < D < 5 km) within the North and South PLD reveals a multimillion year disparity, as the lack of any observed mid-sized craters upon the NPLD indicates crater retention surface ages < 1 Ma [3], whereas the presence of 31 craters with D > 1 km upon the SPLD [4] indicates surfaces ages of 60 Ma.

A dramatic difference in N/S PLD surface ages is not evident, though, from either small or large PLD craters. For example, both PLD exhibit a relative paucity of small impact craters (D < 500 m), indicating surface ages < 100 kyr for the NPLD [3] and << 1 Myr for the SPLD [4]. Similarly, the margins of both PLD contain large impact craters about 20 km in diameter [5,6]. But in contrast to the recent activity implied by the lack of small PLD craters [4], the continued presence of these large craters is suggestive of the long-term stability of the PLD, since such large impacts should only occur upon each PLD once every 200-300 Myr.

Resurfacing Mechanisms: The most commonly suggested candidate mechanisms for PLD crater resurfacing involve either deposition (of ice and/or dust) or ablation (via sublimation or eolian erosion). However, the observed size distribution of PLD craters is problematic for any such depth-dependent resurfacing mechanism, as the vertical resurfacing rates required to eradicate the (missing) smallest craters should have long ago obliterated the (still observed) largest craters.

Furthermore, virtually all mid-sized SPLD craters (1 km < D < 5 km) have depths of less than 50 m, making them extraordinarily shallow relative to other Martian craters [4]. Such uniform shallowness is clearly inconsistent with depth-dependent vertical resurfacing mechanisms, which should produce craters spanning a range of depths (relative to the base of the initial crater cavity).

Viscous Creep Relaxation: Therefore, instead of deposition or ablation, we propose that PLD crater resurfacing predominantly occurs via viscous creep relaxation of the dusty water ice comprising the PLD itself. We have extensively modeled this process with the finite-element code Tekton [7] using laboratory-measured rheological parameters [8] for water ice undergoing grain size sensitive (GSS) creep, which we find dominates basal dislocation creep at Martian PLD thermal and pressure conditions.

For our PLD mid-sized crater simulations, we adopt the following baseline parameters: crater diameter D = 2 km, initial crater depth d = 0.3*D = 600 m, PLD thickness = 2 km, water ice grain size diameter = 1 mm, volumetric dust/ice fraction = 0.25, annual average surface temperature = 165 K, and subsurface thermal gradient = 10 K/m.

Results: Fig. 1 shows the results of our baseline PLD mid-size crater simulations (note that the upper reddish layer corresponds to the deformable ice-rich PLD, while the lower orange layer represents immobile bedrock). Initially, the relaxation of the crater is quite rapid, as the depth decreases from d = 600 m at t = 0 to d = 430 m at t = 100 kyr to d = 80 m at t = 1 Myr. Extending the simulation to t = 10 Myr, however, does not completely obliterate the crater, due to the persistence of small-scale topographic features.

Fig. 1 clearly demonstrates that viscous creep results in mid-sized PLD craters that relax to extremely shallow depths for most of their lifetimes, which is in excellent agreement with the SPLD depth-diameter observations of [4]. Additional simulations for large PLD craters (D = 20 km, d = 1800 m) show that large craters relax even faster than mid-sized craters (normalized to their initial depth), provided that the underlying PLD deposits are at least a few hundred meters...
thick. Thus, viscous creep can also nicely explain the presence of large craters at the PLD margins, where the underlying PLD is too thin to substantially relax. Further simulations for small PLD craters (D = 200 m, d = 60 m), though, indicate that significant relaxation does not occur for ice grain sizes of 100 microns and greater; hence, viscous creep can not explain the absence of small craters upon the SPLD.

Conclusions: (1) Viscous creep relaxation is the PLD resurfacing mechanism that best explains the shallowness of mid-sized SPLD craters. (2) Viscous creep relaxation is also the only PLD resurfacing mechanism consistent with the presence of large craters at the PLD margins. (3) Another resurfacing mechanism must be responsible for the lack of small PLD craters—as well as the absence of mid-sized NPLD craters (note that sublimation of water ice would probably best explain the multi-million year N/S PLD mid-sized crater retention surface age disparity).

Implications: (1) Despite the young surface ages of the PLD, their “true” age—i.e., the amount of time the geologic unit has existed—is likely on the order of several hundred Myr. (2) Since relaxation preserves layer stratigraphy, the estimated time scales of individual layer formation and destruction become significantly longer. (3) If viscous creep and sublimation are acting in concert to eradicate PLD craters, then glacial flow must also be occurring within the PLD.


Figure 1: Results of PLD baseline mid-sized crater simulations at t = 0 yr, 100 kyr, 1 Myr, and 10 Myr. Upper reddish layer corresponds to deformable ice-rich PLD; lower orange layer represents immobile bedrock. Baseline parameters: crater diameter D = 2 km, initial crater depth d = 600 m, PLD thickness = 2 km, water ice grain size diameter = 1 mm, volumetric dust/ice fraction = 0.25, annual average surface temperature = 165 K, and subsurface thermal gradient = 10 K/km.