THE SUBLIMATION AND RELAXATION OF TROUGHS AND SCARPS WITHIN THE MARTIAN NORTH POLAR LAYERED DEPOSITS.
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Summary: The kilometer-scale topography of the North Polar Layered Deposits (NPLD) is dominated by troughs and scarps: Fig. 1 shows both (a) the ubiquity of troughs throughout the NPLD, and (b) the enhanced steepness of scarps at the margins of the NPLD (e.g., along the inner wall of the channel-like reentrant, Chasma Boreale). Although the surface slopes and total depths of NPLD troughs and scarps are widely presumed to result from surface ablational processes, here we propose that an alternative mechanism, viscous relaxation of subsurface water ice, governs the morphological evolution of NPLD troughs and scarps.

Topography: Using the 64 pixel/degree MOLA altimetry grids, we constructed eight radial profiles spaced at 45° longitudinal intervals through the North Polar Dome. Along each profile, we have identified all interior troughs and marginal scarps with depths greater than 200 m located between 80°N and 87°N. Fig. 2 plots maximum 1.6-km baseline surface slopes observed along the equatorward-facing (EWF) walls of troughs and scarps, as well as upon the poleward-facing (PWF) walls of troughs.

As previously noted [1], most NPLD troughs are asymmetric: our measurements (Fig. 2A) indicate that maximum EWF slopes (α_ε) are on average 75% steeper than maximum PWF slopes (α_ρ). Although primary scarps at the periphery of the NPLD are generally at least twice as steep as interior troughs, we find that there is no significant dependence of trough slope (Fig. 2A) or depth (not shown) upon latitude. Interestingly, the slopes and depths of NPLD troughs and scarps are strongly correlated with one another (Fig. 2C).

Sublimation: The most widespread theories of PLD evolution [1,2] presume that the asymmetrical slopes of most NPLD troughs ($\alpha_\varepsilon > \alpha_\rho$) result from preferential H_2O sublimation from EWF trough walls. However, our modeling indicates that there is no long-term sublimation advantage of EWF trough walls, due to the effects of obliquity upon the slope dependence of sublimation rate (Fig. 3). We define a parameter R comparing the sublimation rates from the mean EWF and PWF trough wall slopes of $\alpha_\varepsilon = 5.4°$ and $\alpha_\rho = 3.1°$, respectively; at the present obliquity ($\theta = 25.2°$), the relative sublimation ratio $R = 1.33$.

However, the sublimation enhancement of EWF slopes is limited to lower obliquities, since as obliquity increases and the average solar zenith rises, the benefit of being tilted towards the sun close to local noon is offset by the disadvantage of being tilted away from the sun during the now brighter nighttime hours. Thus at

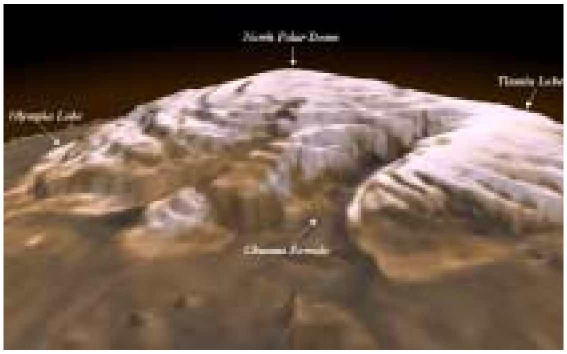

Fig. 1. Overlay of an NPLD Viking image mosaic upon MOLA topography, created by the GSFC Scientific Visualization Studio and the MOLA Science Team. Vertical exaggeration ~ 300x.

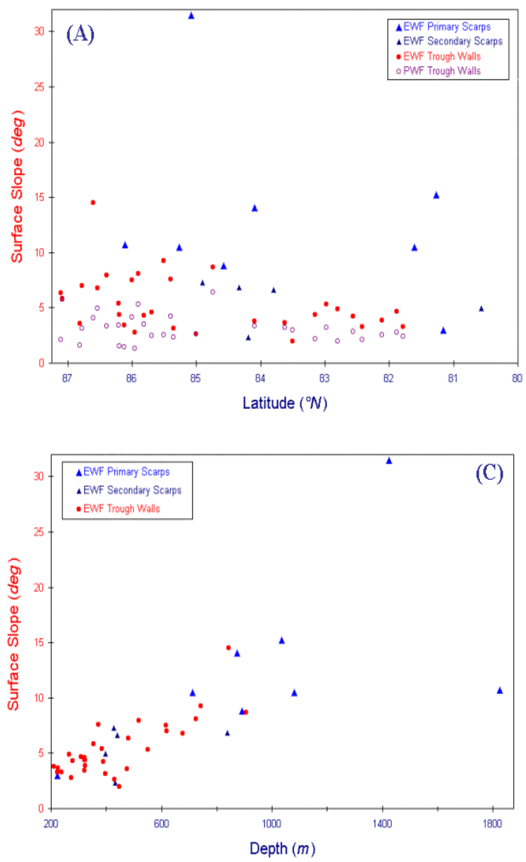

Fig. 2. Dependence of the maximum surface slopes of NPLD trough and scarp walls upon (a) latitude and (c) depth. Surface slopes are calculated over an approximate 1.6-km baseline.

obliquities of θ = 32.1° / 37.5° / 45.0°, the relative sublimation ratio R = 1.06 / 1.00 / 0.98. (Note that sublimation is actually slightly enhanced from PWF trough walls at near-maximum obliquities).

Since 80% of NPLD sublimation over the last 10 Myr takes places at obliquities above the median θ = 32.1°, our calculations demonstrate that EWF trough wall sublimation, when integrated over an obliquity "cycle", is not much greater than that from PWF trough walls (R = 1.02 since t = 10 Ma). Hence we conclude that, contrary to expectations, the steeper EWF slopes of NPLD trough walls do not result from long-term preferential sublimation driven by insolation variations.

Relaxation: But then what causes the slope asymmetry of opposing trough walls? We propose that viscous relaxation of subsurface water ice—which we have previously shown to be important to South PLD crater morphology [3]—may also govern NPLD trough and scarp evolution. Although [2] suggested that the continued presence of troughs argues against PLD flow, our trough simulations of NPLD troughs with the finite element model Tekton [4] predict trough closure times of approximately several million years.

Furthermore, Fig. 4 shows that if the EWF half of the trough is just 2 K warmer than the PWF half—which is consistent with the slope-dependent temperature variation over the last few Myr predicted by our subsurface thermal modeling—then maximum EWF slopes will become significantly steeper than maximum PWF slopes (Fig. 5), due to the slower rate of uplift of the inner PWF trough walls (which can be attributed to the increased subsurface viscosity below the colder PWF slopes). Additionally, we show that relaxation of NPLD trough and scarps can readily account for the correlation of surface slope and total depth (Fig. 2C), an observation that is particularly difficult to explain via sublimation or eolian erosion.

Conclusions: (1) The slope asymmetry of PLD troughs does not result from preferential sublimation but rather from differential relaxation of opposing trough walls. (2) Present-day NPLD troughs have formed since 5 Ma, and are not sites of long-term deposition. (3) Glacial flow probably governs the large-scale evolution of the North PLD.

References: [1] Thomas P. *et al.* (1992) in Mars, Ed. H. Kieffer *et al.*, Univ. Arizona Press, Tucson, 767-795. [2] Clifford S. *et al.* (2000) *Icarus* **144**, 210-242. [3] Pathare A. V. *et al.* (2002) *LPSC XXXIII*, Abstract #1972. [4] Melosh H. J. and Raefsky A. (1980) *Geophys. J. Royal Astron. Society* **60**, 334-354.

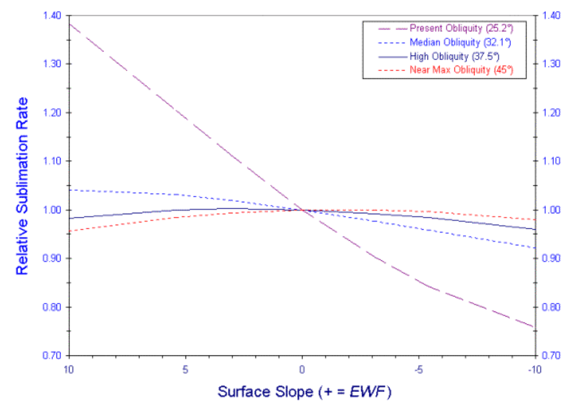

Fig. 3. Dependence of sublimation upon EWF surface slope, expressed relative to the net annual sublimation rate at α_ε = 0°, for four different obliquities and nominal North PLD conditions.

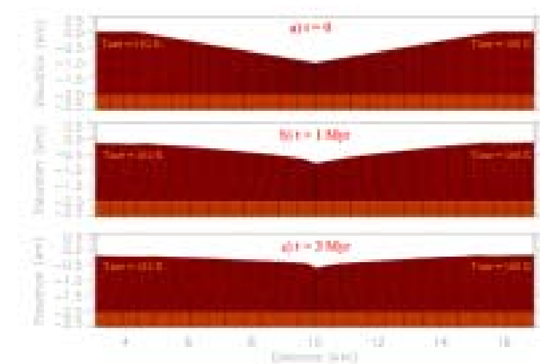

Fig. 4. Relaxation history at time steps of t = 0 / 1 / 3 Myr for baseline simulations of an North PLD trough characterized by T_{sav} = 162 K upon the EWF wall and T_{sav} = 160 K upon the PWF wall. A total PLD thickness of Z = 2 km is assumed.

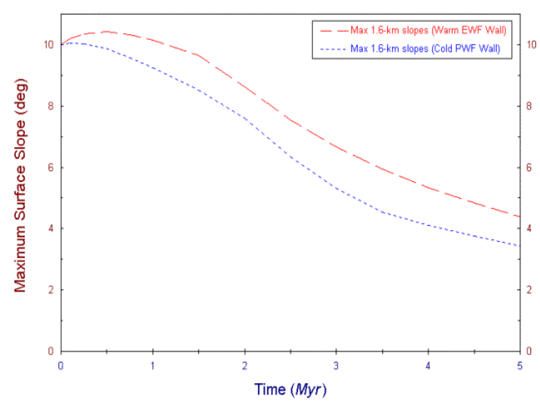

Fig. 5. Temporal dependence of maximum 1.6-km surface slopes for both EWF and PWF trough walls, derived from baseline North PLD trough simulations for differential thermal conditions shown in Fig. 4.