THE ROLE OF SUBLIMATION IN THE MIGRATION OF MARS' SPIRAL POLAR TROUGHS.

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Introduction: Spiral troughs expose the upper layers of the martian north polar layered deposits (NPLD). These troughs have been integral in shaping our understanding of the polar caps as products of orbital-induced climate variations. Understanding the mechanisms by which these troughs formed and evolved will provide important insights into the mass balance of volatiles on Mars and the climate of the planet during the most recent part of the Amazonian.

Ground-penetrating radar from the Shallow Radar (SHARAD) instrument onboard the Mars Reconnasaince Orbiter (MRO) discovered discontinuities in the subsurface stratigraphy (Fig. 1) that have been interpreted as trough migration paths, or bounding surfaces, undertaken since their formation [1]. The trough walls currently exposed at the surface have slopes of ~2-15°, while the subsurface trough migration paths exhibit slopes of 0.33-1.65° and extend from the surface to depths of up to 1000 m [2]. The oldest troughs have migrated up to ~100 km while experiencing ~1 km of ice accumulation over the same time period [2]. These migration paths represent the net effect of NPLD accumulation between troughs and ice-loss at trough walls over time.

The troughs have been migrating northward and upwind, and wind patterns have been found to be perpendicular to the troughs [3–5]. Katabatic winds from Coriolis forces likely play an important role in the shape and position of the troughs, and are expected to enhance sublimation on the upwind side. [3] identified three independent processes that determine the slope of the trough migration pattern: (1) lateral transfer of ice by wind, (2) insolation-induced sublimation, and (3) atmospheric deposition. They identified the contribution of sublimation due to insolation on the upwind and generally-equatorward-facing high sides of the troughs as an outstanding question.

We investigate the loss of ice on the equatorward-facing walls of these polar troughs. To do this we combine a thermal conduction model with calculations of ice sublimation and subsequent lag growth to predict the amount of ice that has been lost over the time that these troughs have been migrating. Comparing sublimation over time to the trough migration path slopes will allow us to place additional constraints on the mass balance that has been experienced by the intervening flat areas of the NPLD. Additionally, if trough migration rates can be independently determined, the slope will give the accumulation rate of the entire NPLD.

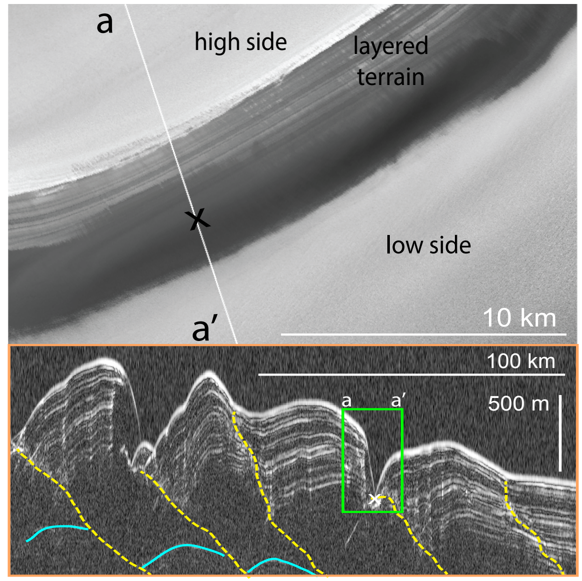

Figure 1. Trough observations from [2]. Top: Portion of CTX image P01_001595_2665_XN_86N319W of the trough in green box below. Bottom: Trough migration paths (yellow) mapped in SHARAD radargram 1247002.

Methods: We model temperatures of the Martian subsurface using a 1D semi-implicit thermal conduction model that simulates surface energy balance and transfer of heat between subsurface layers. The model allows for subsurface layers of different thermophysical properties, which we use to model a sublimation lag deposit atop ice. Within this lag deposit, we allow for the resupply of ice into the pore-spaces at and below its equilibrium depth with the atmosphere. We assume no retreat of the ice when there is pore-filling ice in this lag as it can choke off diffusive exchange of vapor. Additional details about the model can be found in [6]. Additionally, we calculate surface temperatures for an icy flat surface, that we use in simulating reradiation of heat from a surrounding surface towards our sloped trough wall. We multiply the retreat perpendicular to the surface by a factor of 1/sin(slope) to calculate the amount of horizontal change that would occur as a proxy for trough migration.

We run the model for south-facing slopes over the last several million years of Mars' orbital parameters from [7]. Our nominal case uses an obliquity-dependent scheme for atmospheric water vapor content from [8], though we also run the model with no near-surface atmospheric water vapor to place upper limits on sublimation and investigate the dependence of our results on this parameter.

When the ice retreats, it leaves behind any silicate material embedded within it, thus growing the lag deposit. We implement the growth of this regolith layer following the method described in [9]. However, the equatorward-facing trough walls clearly show NPLD layers <1 m thick, suggesting the lag remains thin. As such, we include the ability for the lag deposit to be thinned over time in the model, which is observed to happen due to mechanical erosion by winds [3].

Preliminary Results: We run the model at a latitude of 85° N using a surface thermal inertia of 196 $J\ m^{-2}\ K^{-1}\ s^{-0.5}$ and albedo of 0.23. We assume the lag deposit has a porosity of 40% and a diffusion coefficient of $3x10^{-4}$ $m^2\ s^{-1}$, and that the NPLD ice has a dust content of 3%, consistent with that estimated for the bulk composition of the NPLD [10].

Matching both the observations described above and the results of previous studies [5; 11], we find that the lag needs to remain thin (~1cm) in order to get significant ice loss. Thick lag deposits thermally insulate the ice and sublimation is furthermore inversely proportional to the thickness of the lag deposit, both aspects contributing to the minimal loss under thick-lag conditions. If we allow the lag to grow, it quickly grows to 0.5 m and prevents any further trough retreat. The NPLD may have experienced periods like this.

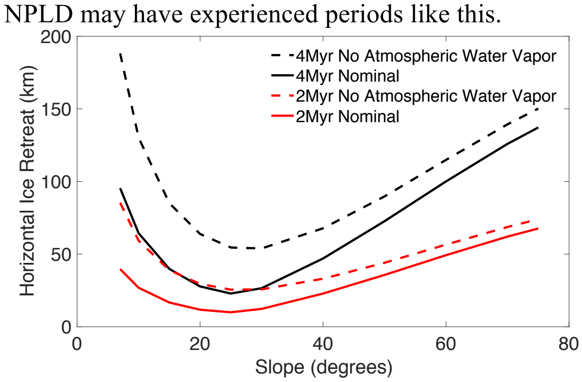

Figure 2. The amount of horizontal ice retreat (proxy for trough migration) through 1 cm of lag for south-facing trough walls over 2 (red) and 4 Myr (black) for various slopes and two different atmospheric water vapor conditions: that of [8] (solid) and no atmospheric water vapor (dashed).

For the case of a constant lag deposit 1 cm thick, we run our model for a range of slopes (Fig. 2) and find that the total horizontal trough retreat is at a minimum for slopes of about 30 degrees. Higher slopes experience more insolation while lower slopes experience more horizontal retreat due to the 1/sin(slope) factor. This suggests that the observed slopes of the fastest moving trough walls are most likely to be shallow, as observed, or composed of many small, nearly-vertical steps that average to the observed slopes.

The time that has passed since the onset of trough formation and migration is unknown. As such, we also run the model for different lengths of time within the last 4 Myr (Fig. 3), which has been proposed as the approximate age of the NPLD [12]. Our preliminary results suggest the troughs could sublimate enough ice over ~4 Myr to migrate ~100 km but that younger ages (especially 100s of kyr) would generate too little sublimation to get adequate migration to match observations. The trough migration paths do not extend all the way to the base of the NPLD so they cannot be as old as the NPLD itself. Instead, the earliest troughs formed about 1/2 way through development of the NPLD and may be 2 Ma old. Some troughs are stratigraphically much younger.

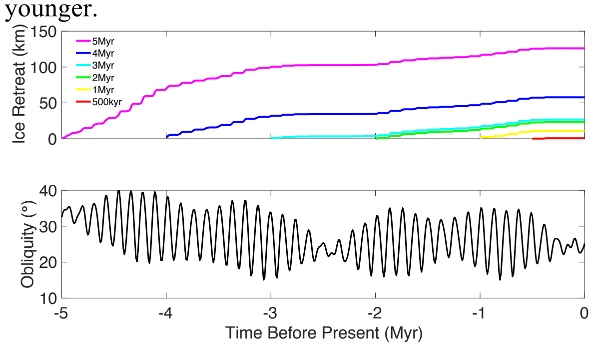

Figure 3. Horizontal ice retreat vs. time for a 7° south-facing slope with 1 cm of lag at 85° N for six different timespans.

Our model currently does not handle situations where ice is at the surface e.g. if eolian lag-stripping exposes the NPLD directly. We will add sublimation due to forced and free convection to our model in order to simulate the overall sublimation expected for these trough walls over time.

We will compare our horizontal ice retreats to observations of the trough migration paths from SHARAD. Doing so will allow us to simulate the expected mass balance that cause these troughs to migrate, and place constraints on the accumulation and orbital-induced climatic variations that have occurred throughout the lifetime of the NPLD.

References: [1] Smith and Holt (2010) *Nature, 465(7297),* 450–453. [2] Smith and Holt (2015) JGR Planets 120, 362–387. [3] Smith et al. (2013) *JGR Planets 118*, 1835–1857. [4] Smith and Spiga (in press) Icarus. [5] Howard (2000) *Icarus 34(3)*, 581–599. [6] Bramson et al. (2017) *JGR Planets 122*. [7] Laskar et al. (2004) Icarus 170(2), 343–364. [8] Schorghofer and Forget (2012) *Icarus 220(2)*, 1112–1120. [9] Schorghofer (2010) *Icarus 208*, 598–607. [10] Grima et al. (2009) *GRL 36*, L03203. [11] Warner and Farmer (2008) *Icarus 196(2)*, 368–384. [12] Levrard et al. (2007) *JGR 112*, E06012.