THE MASS BALANCE OF MARS’ SPIRAL TROUGHS. A. M. Bramson¹, S. Byrne¹, J. Bapst¹, and I. B. Smith²,
Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 95721 (bramson@lpl.arizona.edu), ²Planetary
Science Institute, Lakewood, CO 80401.

Introduction: Spiral troughs that expose the upper layers of the martian north polar layered deposits (NPLD) have been integral in shaping our understanding of the polar caps as products of orbital-induced climate variations (Fig. 1). 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 Reconnaissance Orbiter (MRO) discovered discontinuities in the subsurface stratigraphy (Fig. 1) that have been interpreted as trough migration paths (TMPs), or bounding surfaces, undertaken since their formation [1]. 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 record the net mass balance at the trough, and the slopes of the migration paths provide a record of the ice accumulation that has occurred on the inter-trough NPLD surface and the ice loss from trough walls.

We investigate mass balance scenarios at the troughs to find those that match the observed trough migration paths. Comparing sublimation over time to the trough migration path slopes will allow us to estimate the accumulation rate that has been experienced by the intervening flat areas of the NPLD. Conversely, if we assume or derive an accumulation rate by a different means, we can test hypotheses of the timescale of trough migration.

Methods: We combine a 1D thermal conduction model with calculations of ice sublimation and subsequent lag growth to predict the amount of ice that has been lost from the trough walls. Details of the model can be found in [3]. Trough migration generally occurs poleward by the equatorward-facing side of the trough. These equatorward-facing trough walls clearly show NPLD layers <1 m thick, suggesting the lag remains thin. As such we implemented a lag removal scheme and our model can remove dust over time (which has been observed at present day to occur due to winds and eolian processes [4]). We also calculate ice sublimation due to free and forced convection (nominal case: 2.5 m/s wind), following the equations in [5], for cases of a bare icy surface (no lag).

The trough walls currently at the surface have slopes of ~2-15° [2], and for our study we assume a constant slope of 7° at 85°N. We run the model for south-facing slopes over timescales within the orbital parameters of [6]. For our preliminary results, we look for nominal cases that generate ~60 km of horizontal retreat while the NPLD surface undergoes ~700 m of vertical accumulation, based on the results of [2]. In these cases, we combine our sublimation calculations with the obliquity-dependent parameterization of accumulation rates from [7] to generate synthetic trough migration paths to compare to the observed TMPs.

Results: Both ablation from the trough wall and accumulation onto the surroundings lead to changes in the x,y position of the trough. For a trough slope of 7°, ~90% of the horizontal migration of the TMPs comes from sublimation with the other 10% due to the up-slope movement caused by accumulation. All vertical migration is due to ice accumulation, and net accumulation of the surrounding surface is required to preserve the TMPs in the subsurface stratigraphy seen by SHARAD.

In 2 Myr, a bare-ice trough wall would generate over 500 km of horizontal retreat due to ice sublimation. Over this same time period, 1700 m of ice would accumulate, though [7] cautions that their obliquity-dependent scheme is not appropriate for some orbital solutions.

Figure 1. (top) Perspective view of the northern polar cap on Mars and its spiral troughs, depressions that spiral clockwise about the cap. (bottom) Portion of the polar cap as seen by depth-corrected SHARAD radargram 1247002. Trough migration paths, as mapped by [2], are in yellow.
particularly when polar insolation exceeds some critical value at high obliquities. [8] suggests an annual accumulation rate of 0.55 mm/year, which would lead to 1.1 km of accumulation in this same time period. This means that if the troughs formed 2 Myr ago, they would need to be covered with a lag to reduce the trough migration to the values that are observed (<100 km). Accumulation rates of the NPLD would also have to be lower than suggested by [7] or [8].

A 5 mm lag on the trough wall would still lead to over 200 km of horizontal retreat, while a 1 cm lag would restrict horizontal ice retreat to only 25 km (Fig. 2). Lag thickness is not expected to be constant, but using a nominal lag thickness provides a first order approximation: if the troughs have been migrating for 2 Myr, they would need to be covered with a lag that remains, on average, between 5 and 10 mm thick.

![Figure 2. Amount of horizontal ice loss over 2 Myr for two lag thicknesses, and for reference, our nominal value of horizontal trough migration of 60 km.](image)

If the trough wall has remained bare throughout its history (meaning lag removal rates are greater than or equal to lag generation rates), we calculate the age for which 60 km of horizontal migration occurs: 520 kyr (Fig. 3). For this to occur, lag removal rates would range from 0 to 7 mm/year, with a mean of 0.72 mm/year, assuming a dust content of 3% in the ice and a regolith porosity of 40%. Over this time, the total accumulation from [7] would be <500 m. The nominal observed accumulation since onset of trough migration (~700 m) could be reached if accumulation rates were 1.5 times higher (Fig. 3). Likewise, we could also match the overall trough migration if the troughs are slightly older (800 kyr) so there is more time for accumulation, and sublimation rates are lower as to keep the overall horizontal ice loss at around 60 km (suggesting a thin lag is allowed to form, reducing the maximum required lag removal rate in times of high sublimation).

**Conclusions:** Our results depend on how old the troughs are, however, we are finding a narrow window of allowable solutions. We can explain the trough migration paths with a nearly-bare trough wall surface for young ages (~500–800 kyr) and accumulation rates similar to that predicted by [7]. However, if initiation of trough migration occurred 2 Myr ago, the trough requires a lag to restrict sublimation, and we constrain the thickness of this lag to between 5–10 mm. In this ‘old-trough’ scenario, accumulation rates need to be less than previous predictions [e.g. 7,8].

Many of the observed trough migration paths only exhibit a couple jumps in slope, often exhibiting steeper slopes nearer to present day surface and shallowing out at a depth. This behavior is better matched by younger trough ages. Young ages are also favored because we can match the overall amount of migration using previous predictions of NPLD accumulation rates.

We will present our final solution space of ages, lag thicknesses and accumulations that reproduce the trough migration paths observed in SHARAD (e.g. Fig 1). The work of [2] demonstrates that there is diversity within the troughs, and the troughs formed in two generations separated by many hundreds of meters. With our model, we may also able to constrain the mass balances and conditions that lead to this diversity.

![Figure 3. Synthetic trough migration paths for 520 kyr of bare-ice sublimation and accumulation from [7].](image)

**References:**