3D MAPPING OF MIGRATION PATHS OF MARS' NORTH POLAR SPIRAL TROUGHS.
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Introduction: Mars' north pole features a kilometers-thick ice cap (referred to as Planum Boreum) of mostly pure water ice [e.g., 1]. Most of the polar cap is made up of the North Polar Layered Deposits (NPLD), a series of stratigraphically continuous, sub-horizontal layers of ice with variable fractions of dust [2]. These layers provide records of variations in Mars' climate due to orbital forcing [3].

Mars' spiral troughs, shown in Figure 1, are unique features that expose the upper, fine-scale layers of the NPLD in visible images. On a larger scale, the Shallow Radar (SHARAD) instrument onboard MRO also reveals the presence of laterally continuous subsurface layers through observations of subsurface radar reflectors, which are due to changes in the dielectric properties of the icy layers – related to the dust content variability through time. Within the upper ~500 m of the NPLD, where the layers are normally continuous laterally, stratigraphic discontinuities begin at the bottoms of the current troughs and extend downwards into the stratigraphy. These discontinuities have been interpreted as bounding surfaces that record the boundary between erosion and deposition of ice at the trough sites during migration, e.g. one side erodes while the other receives deposition. Thus, these bounding surfaces likely preserve a record of the location of the change from erosion to deposition through time, during NPLD growth and trough migration. They have been referred to as trough migration paths (TMPs) [4, 5].

These TMPs suggest that the troughs have generally migrated northward, or upwind over time as the NPLD were deposited [4, 6]. Mars' katabatic winds, and their deflection from Coriolis forces, have been proposed to cause the spiral pattern of the troughs, and contribute to sublimation on the upwind (and generally poleward) side of the trough [7]. The stratigraphically-oldest troughs have migrated upwards of 100 km during the accumulation of up to 1 km of ice [5].

The migration of these troughs is powered by the mass balance of volatiles [8, 9, 10] and can provide insight into the variation of Mars' climate in the late Amazonian. Three independent processes have been suggested as the drivers of migration of the troughs: transfer of ice by wind laterally, insolation-induced sublimation, and atmospheric deposition of ices [8]. The slope of these migration paths in the subsurface can be used to determine the relative rate of these processes, and preliminary modeling of ice accumulation and sublimation by [9] was able to recreate the variable TMP slopes at two trough sites.

The presence of unconformities that vary in slope with depth in the subsurface radar stratigraphy belies climate changes that affect the ratio of forces, including a signature of a significant climate shift in Mars' recent history [10, 11]. Mapping of the TMPs will allow for exploration of variations in shape of the paths that act as a tracer for Mars' volatile mass balance conditions in the past.

Methods: Recently, a 3D SHARAD dataset has been compiled using observations from thousands of orbits [12, 13]. The use of this dataset provides clarification of the subsurface structure and allows us to observe the migration paths from all angles, regardless of the orbital geometry of the original 2D observations. We use the depth-corrected dataset, in which the radar delay times were converted to depths by assuming the real component of the dielectric constant of the subsurface is that of pure ice ($\varepsilon' \sim 3.15$), consistent with previous measurements of the bulk dielectric constant of the NPLD [1]. The pixel size of the 3-D depth-corrected dataset is ~20 m vertically and 475 m horizontally.

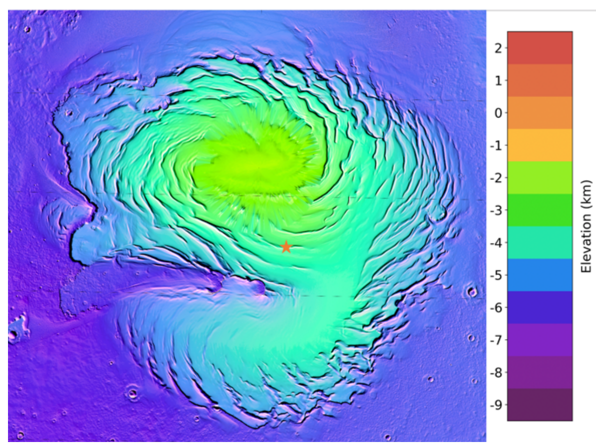

Figure 1: Topography of Planum Boreum as measured by the Mars Orbiter Laser Altimeter (MOLA), showing the spiral pattern of the troughs. An orange star marks the location of Trough 1 explored in this work at 86.5 °N, 13.8 °E.

We mapped trough migration paths by tracing the unconformities in the reflectors between the high and low sides of troughs, as described in [4, 5], using the Seisware geophysics interpretation software. From the 3-D dataset, we created "artificial" 2D radargrams that are perpendicular to the trough strike to minimize distortion of the migration paths due to oblique viewing geometry. With these perpendicular orientations, the

TMPs were mapped using the discontinuities in the radar reflector surfaces. These were made by mapping on sample cuts where the path was most obvious, with an average spacing of 4.5 km. Then, using the SeisWare horizon tool, a median smoothing and interpolation was applied to create the final full path.

Here, we show our preliminary 3D mapping of the migration path associated with a trough located at 86.5°N, 13.8°E (referred to as Trough #1 in [9]).

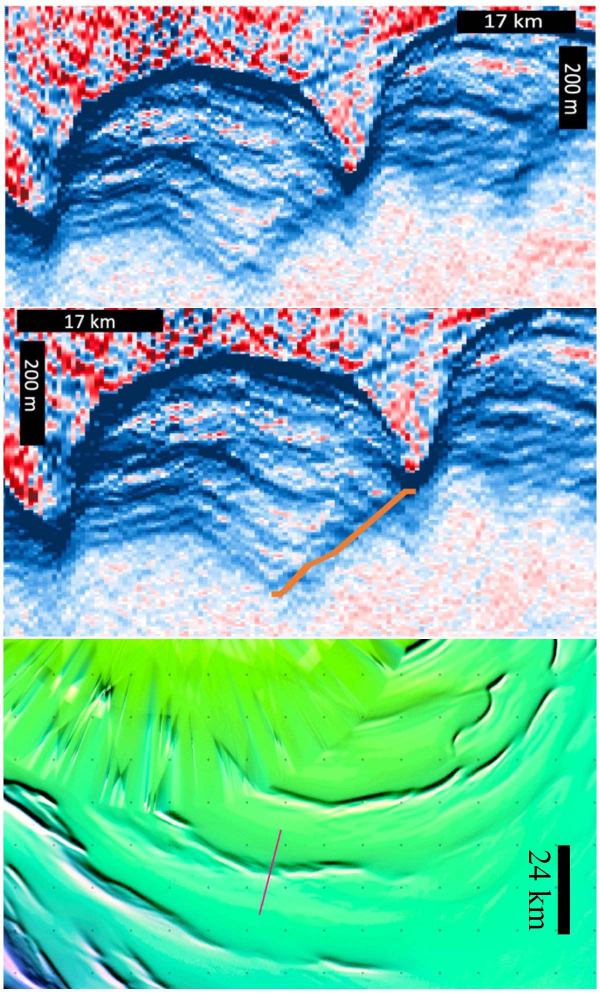

Figure 2: Interpretation of TMP. (Top) A radargram created from the 3D dataset perpendicular to the trough. (Middle) Radargram from the 3D dataset perpedicular to the trough with interpretations of the mapped trough migration path in orange. (Bottom) location of this radargram path in plan view over MOLA hybrid topography-hillshade basemap.

Preliminary Results: We find that the migration path for Trough 1 is 17.6 km long and at its greatest depth 450 m below the surface. The TMP is of consistent length laterally to the trough, for the region thus far mapped.

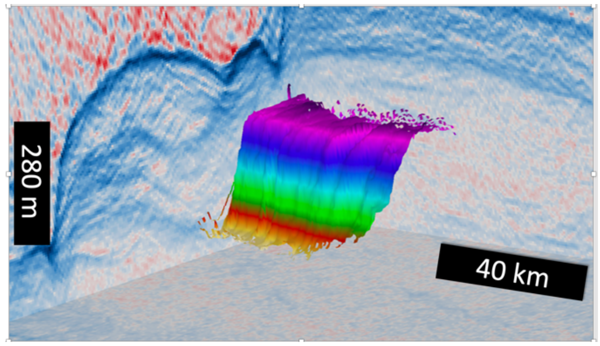

Figure 3: Migration path of Trough 1 as mapped and displayed in the 3D SHARAD dataset using SeisWare geophysics interpretation software.

Future work: We will apply this same methodology to various troughs to look for patterns in trough migration path behavior across the NPLD. We will then model the ice mass balance conditions needed to create the measured migration paths following the techniques outlined in [9]. This work will elucidate patterns in Martian trough evolution, and corresponding climatic conditions (specifically the accumulation and ablation of ice) at Mars' north pole.

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