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Stability of Mid-Latitude Excess Ice on Mars over 10s of Millions of Years

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1. Introduction

Excess ice (higher water abundances than can fit into the pore spaces of the regolith) is now known to be common in the northern mid-latitudes of Mars. Thermokarstic features such as expanded craters [8] and scalloped depressions [3] point to the presence of high ice contents at these latitudes, and new impacts have directly exposed and excavated very pure water ice down to 38°N [2]. Radar sounding by the Shallow Radar (SHARAD) instrument onboard the Mars Reconnaissance Orbiter has detected dielectric interfaces that have been attributed to the bottom of excess ice sheets in both Arcadia Planitia [1] and Utopia Planitia [7]. Craters across Arcadia Planitia exhibit a terraced morphology due to layers in the subsurface that have been associated with the same ice layer detected by SHARAD [1].

Both Arcadia and Utopia deposits (Figure 1) each hold ice volumes on the order of 10s of thousands of km^3. Using independent measures of layer thicknesses from the terraced craters in Arcadia [1] and layered mesas in Utopia [7], the SHARAD studies were able to constrain the dielectric constants to ~2.5, consistent with excess ice and low dirt contents in the upper decameters of the surface. The thicknesses measured for the ice are 30-80 m across Arcadia Planitia and 80-170 m in Utopia Planitia.

Crater counting of expanded secondary craters in Arcadia Planitia suggests this ice is at least 10s of Myr old [8]. During this time, Mars has had many excursions through low obliquities, when low latitude ground ice is expected to be transported to the poles. Replenishment of this ice from the atmosphere in subsequent higher-obliquity epochs will only create pore-filling ice. Here, we model excess ice stability over 20 Myr of Martian orbital solutions [4] to investigate if it is reasonable to expect excess ice to be preserved for this long, and if so, the conditions necessary to reproduce the observed distribution, thicknesses and dielectric constants of these excess ice deposits.

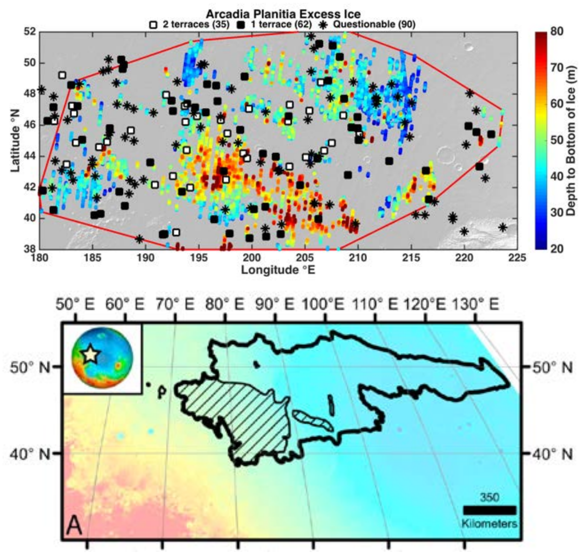

Figure 1: Maps of excess ice sheets in the mid-latitudes of Mars. The top plot is a modified map from [1] of radar reflectors (colored dots) and terraced craters (B/W markers) in Arcadia Planitia. The bottom map is from [7] and shows the extent of radar reflectors (diagonal lines) in Utopia Planitia.

2. Thermal Modeling

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 (e.g. conductivity, density, specific heat), which we use to model a surface porous regolith layer, which we assume is a sublimation lag deposit, atop excess ice. Within this lag deposit, we allow for the resupply of ice into the pore-spaces at and below its equilibrium depth (where $\rho_{vapor} \leq \rho_{atmos}$). We assume no retreat of the excess ice sheet when there is pore-filling ice in this lag as it can choke off diffusive exchange of vapor.

We calculate the annual-average saturation vapor densities at each depth and orbital solution. We model atmospheric water vapor conditions following the obliquity-dependent scheme of [6]. When $\rho_{vapor} > \rho_{atmos}$ at the excess-ice table, and there is no pore-filling ice within the lag deposit, ice is lost at a rate that is dependent on the vapor diffusivity of the regolith, the difference between the vapor density and atmospheric vapor content, and the depth of the ice table. When the excess 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 [5].

We allow the ice sheet in the model to start infinitely thick to quantify the total ice retreat that could occur to the present-day. After the simulation, we introduce a bedrock layer at the depth observed [1,7] and calculate the dielectric constant of the material between that and the surface for comparison to observations (2.5 +/- 0.28 for Arcadia Plantia [1] and 2.8 +/- 0.8 for Utopia [7]).

3. Results

We find that there are final model stratigraphies consistent with the dielectric constants (Fig. 2a) of Arcadia Planitia and Utopia Planitia, while also yielding total ice retreats (Fig. 2b) on the same order of magnitude as the present-day thicknesses of ice. This suggests it is reasonable for the ice to be preserved over 10s of Myr. To match the dielectric constants, the ice likely needs to have maintained some porosity (~25-35%) and relatively low dirt contents (~3%). This ice is protected by its growing lag deposit, which our models predict reaches meters in thickness (Fig. 2c).

4. Summary and Conclusions

Excess ice is common across the Martian mid-latitudes. The ice sheets in Arcadia Planitia and Utopia Planitia have been observed to be widespread, clean (excess ice), and porous based on radar studies [1,7]. This is most consistent with buried snowfall. Here, we demonstrate that such ice could be on the order of 10s of Myr old, much older than obliquity cycles and possibly the North Polar Layered Deposits, and is consistent with the ages calculated by [8]. The ice must have formed thicker than currently observed to account for retreat during times of low obliquity and would be protected by a growing lag deposit containing transient pore-filling ice.

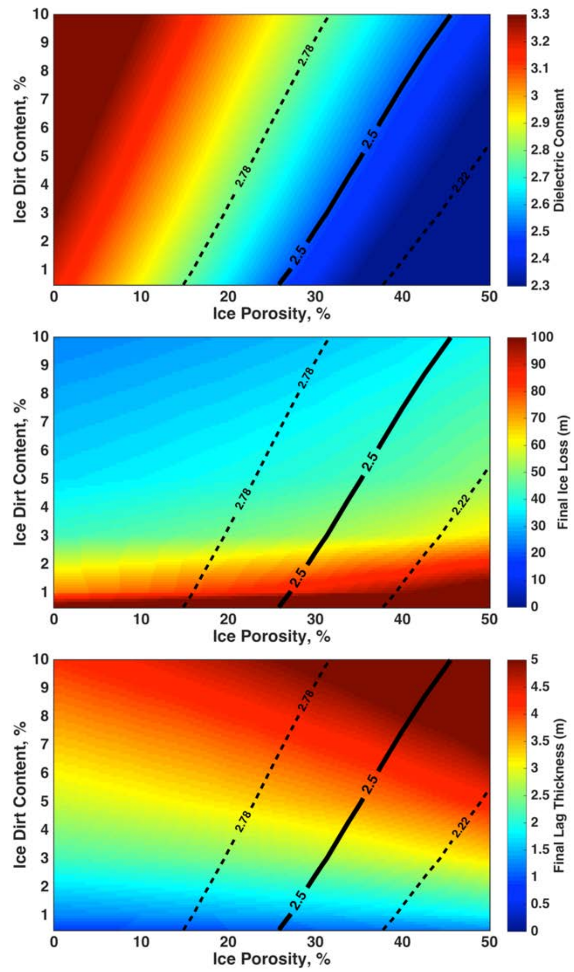

Figure 2: Results for 45°N in Arcadia Planitia (thermal inertia of 196 J m^{-2} K^{-1} $s^{-0.5}$ and albedo of 0.24). The top plot shows the dielectric constant associated with the final stratigraphy outputted by the models for a range of ice porosities and dirt contents. The final amount of ice loss and lag deposit thickness are shown in the middle and bottom plots.

References

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