INITIATION AND GROWTH OF MARTIAN ICE LENSES. H. G. Sizemore[1], A. P. Zent[2], and A. W. Rempel[3]. [1]Montani Consulting (HC 64 Box 176 Hillsboro WV, hgsizemore@gmail.com), [2]NASA Ames Research Center (Moffett Field CA, aaron.p.zent@nasa.gov), [3]Univeristy of Oregon (Department of Geological Sciences, University of Oregon, Eugene OR, rempel@uoregon.edu).

Introduction: Excess ground ice, or ice that exceeds the pore volume of its host soil, has been observed at several locations on Mars. Data from the Mars Odyssey Gamma Ray Spectrometer (GRS) indicates that ice occupies >90% of the regolith by volume over large regions of the high latitudes (>50^o) in both hemispheres [1]. Thermal and optical observations of fresh impact craters also indicate the presence of relatively pure sub-surface ice at mid-latitudes [2]. At the Phoenix landing site (68^o N), trenching activities primarily revealed ice that was pore-filling. However, excess ice (98-99% water by volume) was found in the Dodo/Goldilocks trench complex [3].

The origin of excess ice at its various locations is not well understood. Excess ice cannot be cold-trapped from atmospheric water vapor. Its presence implies either bulk deposition or *in situ* segregation of pre-existing pore ice. Here, we employ numerical simulations of climate and soil-ice interactions to place quantitative constraints on the growth of segregated ice lenses throughout the northern latitudes. We discuss where and how ice lenses may contribute to observations of excess ice.

Numerical Models:

Climate model. We use the climate model described by Zent [4] to simulate the evolution of temperature and ice-table depth, z_i, at latitudes north of 55^o over the past 10 Ma. The model tracks temperatures in the upper 30 m of regolith based on Laskar et al. [5] orbits, and defines z_i assuming diffusive equilibrium with the atmosphere. Because atmospheric water vapor density at high latitude is buffered by the polar cap, ice-table depths and ice temperatures predicted by the model are very sensitive to assumptions about the fate of the residual cap at high obliquity. Here, we assume that the cap remains a source of H_2O vapor at all times. We use results from the Ames GCM to guide our assumptions about meridional vapor transport. Temperature profiles and ice-table depths produced by the climate model provide the initial conditions for simulating ice segregation.

Lens initiation and growth model. We have developed a numerical model that tracks temperatures, phase partitioning, and pressures at grain-grain contacts in a soil that is fully ice and water saturated. We assume that premelted films at the ice-mineral boundaries grow and shrink in place under diurnal and seasonal forcing when no lens is present. We rigorously test for lens initiation, and make order-of-magnitude estimates of subsequent lens-growth rates. The premelting physics employed in this model is based on mass and energy conservation equations developed by Rempel [7]. For simplicity, the soil-water-ice system is assumed to be gas and solute free.

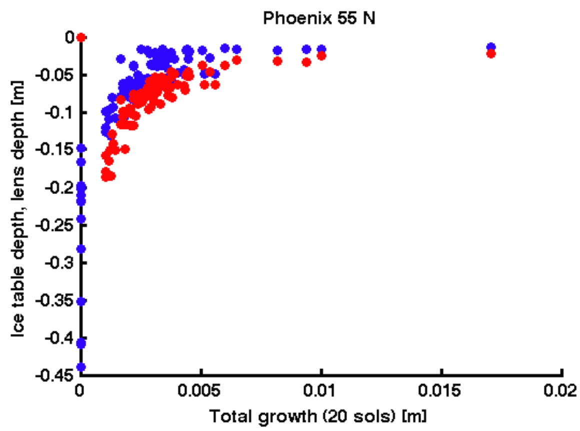

Figure 1. Ice table depth (blue) and lens initiation depth (red) at 55^o N during the past 1 Ma. All data shown are from 20-sol simulations beginning at $L_s = 90^o$, with $\Delta T_f = 0.5$ ^{o}C.

Soil paramartization. We define the thermal conductivity and heat capacity of soils in both numerical models based on published values for silt and clay minerals [8, 9] and analysis of the soil at the Phoenix landing site [10]. In the lens initiation model, we define additional soil characteristics using four empirical parameters:

1) $\Delta T_f = T_m - T_f$ is the freezing point depression caused by inter-molecular forces at grain-water boundaries;

2) k_o is the ice-free soil permeability;

3) β describes ice saturation as a function of temperature ($S_i = 1 - \theta^{\beta}$, where $\Theta = \dfrac{T_m - T}{\Delta T_f}$);

4) and α describes the reduction of permeability with reduced temperature ($k = k_o \theta^{-\alpha}$).

Andersland and Ladanyi [11] compiled measurements of these parameters in 33 terrestrial soils. We have focused our numerical experiments on three of these, Chena Silt, Inuvik Clay and Tomokomai Clay, with the goal of spanning the parameter space of freezing properties in heave-susceptible materials on Earth. We use values of k_o, β, and α corresponding to

Chena Silt as a best approximation of soil at the Phoenix landing site. We allow ΔT_f to vary from 0.006 to 1°C for the Phoenix soil, in order to make a zeroeth order approximation of the effects of deliquescent soils observed by the Phoenix and Curiosity spacecraft.

Results and Discussion: To date, our simulations have produced three primary results: 1) Lens initiation – the unloading of particle-particle contacts by thermomolecular forces at a given soil horizon – may be a common process in the shallow Martian regolith. It is nearly ubiquitous in our simulations and occurs at depths ranging from a few to 18 cm, at temperatures as low as 245 K. However, we do not observe lens initiation at depths greater than 20 cm, in any soil at any latitude (Fig. 1). 2) The dominant soil property controlling the rate of lens growth is the freezing point depression, ΔT_f (Fig. 2.). In typical clays, ΔT_f is large (>0.1 °C) and macroscopic lens growth (mm to cm over several sols) is possible. In silts, ΔT_f is small (<0.01 °C) and macroscopic growth is not possible unless unique Martian soil chemistry depresses the bulk melting temperature by > 0.1°C. 3) The maximum growth of Martian ice lenses is limited by the available reservoir of mobile water, which we implicitly assume lies between the depth of lens initiation and the ice table. During epochs of peak growth (e.g., midsummer at -629 ka), in soils with large ΔT_f, a nascent lens may exhaust its supply of mobile water in several sols.

Implications for mid-latitude craters. Our results indicate excess ice observed on the floors of fresh mid-latitude craters is unlikely to be exposed segregation ice formed in a manner analogous to terrestrial ice lenses, because this ice occurs at pre-excavation of depths > 40 cm, twice the maximum depth at which we see lens initiation. However, at the majority of fresh crater sites that have been studied in detail, ice exposures are seen only on crater walls and ejecta. This suggests complete excavation through a layer of excess ice [2], which is not inconsistent with our results.

Implications for Phoenix. The depth (~4 cm) and approximate thickness (mm to cm) of the excess ice in the Dodo/Goldilocks trench are a good fit with our numerical results, provided that the bulk melting temperature in the Phoenix soil is depressed by > 0.1 °C.

Generally speaking, the particular properties of Martian soils will determine if ice lenses play a major or very minor role in the stratigraphy of the ice-rich regolith. *If Martian soils exhibit freezing behavior similar to Chena Silt, in situ segregation likely does not contribute to any of the observed excess ice.*

However, if some characteristic of the Martian soil depresses the bulking melting temperature by > 0.1 °C *without substantially changing the physics at play*, then it is easy to envision a scenario in which diffusive equilibrium with the atmosphere buffers the source region on timescales of years or more and single or multiple ice lenses contribute to long-term inflation of the soil. In this scenario, accumulation of centimeters of excess ice at depths between 5 and 20 cm would be possible in a few thousand years or less. Depressing the bulk melting temperature by 0.1 °C is a modest requirement in soils with concentrations of magnesium perchlorate of order 1 wt%; ΔT_f in an equivalent concentration $Mg(ClO_4)_2$ solution is ~ 2.5K. Thus, there is a fundamental ambiguity in interpreting our results that points to a need for 1) an extension of the mass and energy conservations equations on which this work is based to account for the full effects of deliquescent salts, and 2) targeted laboratory studies of soil freezing at temperatures appropriate to Mars, with and without salts.

References:

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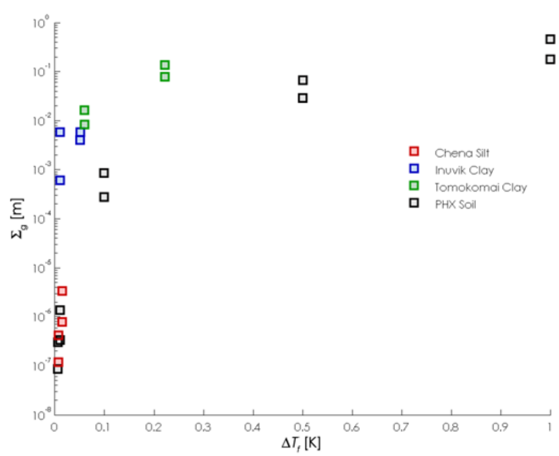

Figure 2. Maximum annual lens growth exhibits a strong dependence on the bulk melting temperature in the host soil. Data shown are from year-long simulations a 70° N latitude.