MODELING DEVELOPMENT OF MARTIAN SUBLIMATION THERMOKARST LANDFORMS. Colin M. Dundas[1], Shane Byrne[1] and Alfred S. McEwen[1], [1]The University of Arizona, Lunar and Planetary Laboratory, 1541 E. University Blvd., Tucson, AZ 85721 (email: colind@lpl.arizona.edu).

Introduction: Thermokarst landforms form when ice is lost from ice-rich permafrost, causing surface subsidence. As such, they not only indicate the past presence of ice but also carry information about the nature of the ice table. Removal of pore ice from self-supporting regolith will cause little if any collapse; the formation of large subsidence features indicates that ice content exceeded the natural regolith pore space.

Thermokarst landforms on Mars were first suggested based on Mariner and Viking Orbiter images [e.g. 1-2]. Recent work has focused on depressions commonly found in Utopia Planitia and south of the Hellas basin [3-7]. The smaller of these depressions are often discrete scallops with relatively steep pole-facing scarps and shallow equator-facing slopes (Fig. 1), which can be up to hundreds of meters across and tens of meters deep. In places many interacting features give rise to more complex surfaces. These landforms have been proposed as thermokarst. Several authors have proposed sublimation models [3, 5-7], while others have argued that these landforms are indicative of melting in a past Martian climate [4].

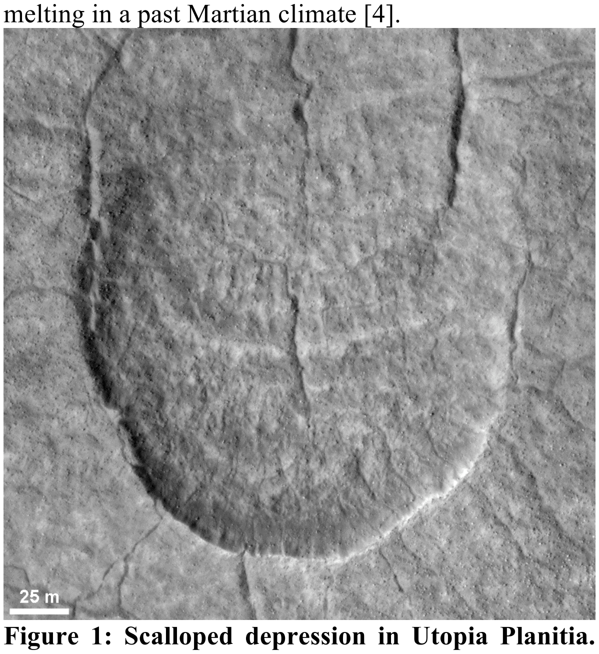

Figure 1: Scalloped depression in Utopia Planitia. (Subsection of HiRISE image PSP_001582_2245. Light is from the left and north is up.)

Model: We have developed a model for landscape evolution of Martian features during ice loss via sublimation. This model is derived from standard concepts of ice stability subject to vapor diffusion. Ground ice is stable when the annual-average water vapor pressure at the top of the ice table equals that in the near-surface atmosphere, resulting in no net diffusive transport [e.g. 8-10]. Models based on this concept have generally been successful in predicting the global distribution and depth of Martian ground ice [8-10]. A lag of dry regolith stabilizes ice by reducing the amplitude of temperature variations at the top of the ice table; due to the nonlinear dependence of vapor pressure on temperature, this reduces the average vapor pressure. Too-shallow ice will have high peak temperatures and a high average vapor pressure, driving net diffusion away from the ice table and loss of ground ice.

Here we apply similar principles at the landform scale. We use a 1-D thermal model to generate look-up tables (LUTs) for vapor density difference as a function of surface slope, orientation, and ice table depth. By assuming a diffusion coefficient, these can be converted into ice loss rates. We use a diffusion coefficient in the range experimentally determined by [11].

This LUT is used to model landscape evolution, given some initial topography, depth to ice, excess ice content, and thickness of pore ice above excess ice. Pore ice sublimation does not cause surface collapse. Removal of excess ice leads to deflation, changing the surface slope and orientation and influencing the future evolution rates. Excess ice is assumed to have some regolith content, such that a lag thickens over time; the lag is also allowed to evolve through diffusive mass movement with slope-dependent diffusivity, commonly used in other landscape models [e.g. 12].

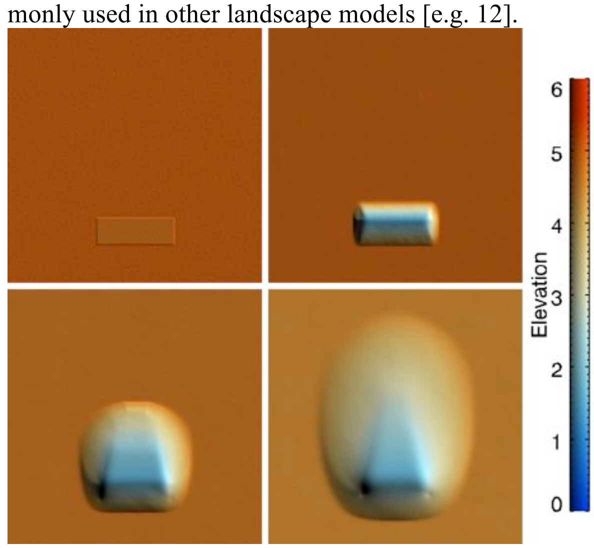

Figure 2: Modeled scallop development after 0, 20k, 100k and 250k Mars years. Domain size is 400 m.

Results: We have modeled the evolution of landforms given an initial disturbance to a surface otherwise near equilibrium. Fig. 2 shows an example of development of a scallop under conditions typical of the northern mid-latitudes. The model initially has a large thickness of excess ice covered by a lag that places it at the approximate equilibrium depth. The lag is partially removed over a rectangular region and the surface allowed to develop.

The area with a reduced lag rapidly deepens, and the equator-facing slope extends northwards and shallows. The result after 250,000 Mars years is a depression with form similar to classic pole-oriented scallops. The topography resembles that of a small scallop from a digital elevation model derived from HiRISE images (Fig. 3). Scallop size depends on several factors, including the initial disturbance size, mass wasting rate, and the regolith content of the excess ice.

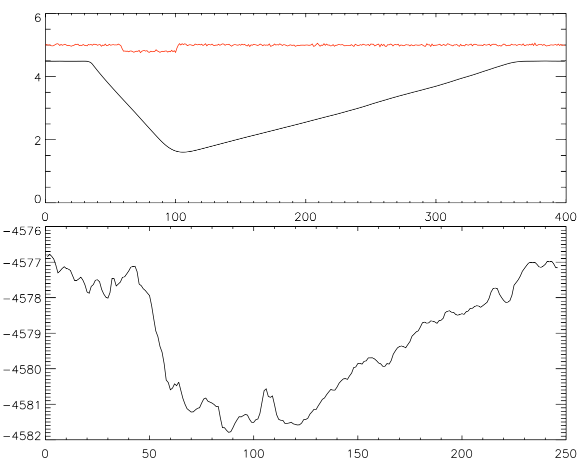

Figure 3: Top: model axial profile, with initial topography in red. Bottom: Profile of a simple scallop from a HiRISE DEM. Axis scales differ somewhat;, the general nature of the scallop is reproduced.

Discussion: Initial results indicate that scalloped depressions with morphologies very similar to those observed can develop from disturbances for some initial conditions. This suggests that scalloped thermokarst morphologies can develop through sublimation alone, and that melting is not required to explain these features. If sufficient excess ice is present, scallops could form entirely by sublimation without invoking additional erosional mechanisms.

The initial disturbance by removing regolith is arbitrary. A more likely mechanism is an initial lag in equilibrium with the climate for some set of orbital parameters; as these conditions change, the equilibrium thickness on different slopes could change by varied amounts, driving differential sublimation and potentially runaway destabilization in some cases. Impacts provide another possible source of initial instability.

Our model has some limitations driven by the need to make it computationally tractable. LUTs incorporate self-shadowing by slope facets, but not by other slopes. Additionally, under conditions where ice is aggrading, we assume that it fills the pore space immediately above the ice table, whereas in some conditions it may partially fill pores through a larger volume [e.g. 13]. These simplifications are required to use LUTs rather than modeling unique shadowing and ice-table conditions at each point. The second is partially mitigated by studying conditions where ice loss is the major process; note that aggradation does not affect the topography. The model run in Fig. 2 used constant orbital parameters, but in fact they vary over similar timescales; this will alter the final morphology and might leave observable morphological signatures. Other limitations include a lack of eolian erosion or deposition and of a mechanism to regenerate excess ice.

In addition to scalloped depressions, HiRISE observes other potential thermokarst landforms. At several northern plains sites, craters appear to have expanded, producing a shallow-sloping funnel into the central crater. We also observe non-pole-oriented depressions similar to scallops; if the thermokarst model applies to these features, some additional process is required to affect the orientation of these features.

Multiple processes have been suggested to form excess ice on Mars, including migration of thin liquid films, deposition of vapor in microfractures, or burial of snowpack [see 14]. The ground around scallops has abundant boulders [5]. This indicates that a recent snowpack is unlikely, since there has been insufficient time for impacts to redistribute boulders evenly across the scalloped regions.

Conclusions: We have demonstrated that a purely sublimation-driven process can generate scalloped depressions with scale and morphology similar to features observed on Mars. If this is the sole driving process for scallop formation, substantial thicknesses of excess ice (at least as much as the scallop depth, up to tens of meters) are required in scalloped terrains.

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