INFLUENCE OF TEXTURAL AND TOPOGRAPHIC VARIABILITY ON SUBLIMATION OF BURIED ICE: IMPLICATIONS FOR NEAR SURFACE ICE STABILITY IN ANTARCTICA AND MARS. D.E. Kowalewski[1], G.A.Morgan[2], D.R. Marchant[3], J.W. Head III[2]; [1] Dept. of Geosciences., UMass, Amherst, MA 01003; [2]Dept. Geol. Sci., Brown Univ., Providence, RI 02912; [3]Dept. of Earth Sci., Boston Univ., Boston, MA 02215.

Introduction: The McMurdo Dry Valleys of Antarctica have commonly been used as an analog for Mars; analogies are due in part to the regions hyper-arid and cold climate as well as its abundance of similar-appearing microscale and macroscale morphological features such as gullies, lineated valley fill, and polygons [eg. 1,2,3]. With the recent direct observations of water ice on Mars from the NASA Phoenix lander and MRO Satellite images [4], a complete understanding of the physics of buried-ice preservation in Antarctica is becoming increasingly important in helping to model the stability and age of buried ice deposits on Mars.

Geological Setting: Beacon Valley, Antarctica is an ideal site for investigating the preservation of ancient ice buried beneath a variety of surface deposits and morphologies [5]. The Mullins Valley alpine glacier, which occupies a tributary valley to Beacon Valley, is a slow-moving-to-stagnant cold-based glacier. Its capping sublimation till is composed of dolerite-and-sandstone clasts set within a sand-rich matrix (Dolerite Till). Collectively, the till is approximately 10 to 15 cm thick in the upper ablation zone and thickens to ~50 cm towards the terminus of the glacier. The top 10 cm is slightly oxidized [6]. In-situ overlying ashfall deposits at the terminus have been dated at ~7.9 Ma [7]. Alternative methods for determining the chronology of the glacier include: cosmogenic nuclide dating of surface rocks, integrated flow from synthetic aperture radar interferometry, numerical glacial modeling, and direct dating of atmospheric gases within the ice [eg. 7-9]. Polygons at the till surface mature with increasing distance down glacier.

In some portions of central Beacon Valley, stagnant, buried glacier ice is derived from an ancient advance of Taylor Glacier, an outlet glacier from the East Antarctic Ice Sheet, up into Beacon Valley, rather than from expansion of Mullins Glacier. The remnant stagnant lobe ice is protected by a ~50-cm thick, silt rich sublimation till (Granite Drift) with clasts of dolerite, sandstone, and granites; the latter are not native in Beacon Valley. Here the polygons are fully mature and troughs can reach 2-3 meters in depth.

Methods: Vapor flux in sublimation till is governed primarily by two mechanisms: molecular diffusion of vapor in pore spaces and advection of air through the material. Other forces influence vapor transport, including osmotic pressure and non-isothermal vapor flux, but it has been reported that Fickian diffusion processes dominate transport in extreme cold environments [10-12]. Our vapor-diffusion model does not specifically track vapor density beyond saturation (as may occur with the formation of hoar frost), but results can be used to infer times when secondary ice would likely form in pore spaces within the Mullins till. Such secondary ice would decrease till porosity, which would tend to retard vapor diffusion. Given the very dry soil conditions of Mullins till (in comparison with seasonally wet and frozen tills with dynamic active layers in Arctic regions, [e.g., 13,14]), phase changes associated with the development of minor pore ice would not significantly alter the thermal profile of till in Beacon Valley. The molecular diffusion of water vapor in the till can be expressed using Fick's Second Law.

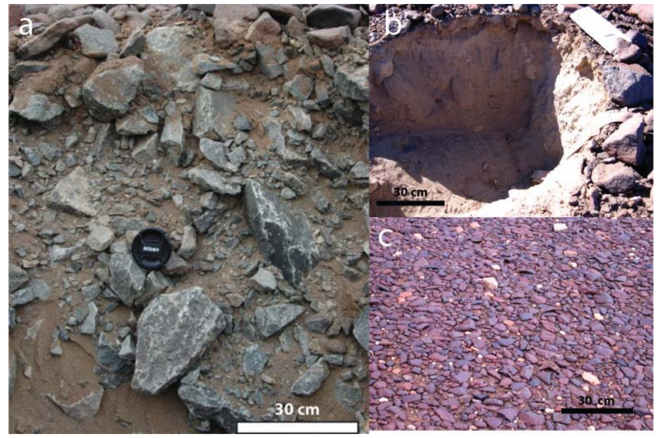

Fig. 1. Till and surface textures in Beacon Valley. a) Dolerite Till of fresh dolerite clasts and minimal sands. b) Granite Drift with a silt and sand rich matrix. c) Desert Pavement displaying interwoven and highly weathered clasts.

To understand better the physical and environmental factors that foster long-term ice preservation, we developed a 2D model using COMSOL Multiphysics software to calculate the rate and spatial variability of vapor diffusion from the buried-ice surface to the atmosphere. Unlike previous 1-D models [6,15], we here incorporate the effects of textural and topographic variability in modulating ice sublimation. As input we incorporate physical characteristics of the overlying debris and meteorological data from installed HOBO™ sensors. The latter capture changes in solar radiance, relative humidity, soil temperature, and soil moisture in polygon centers and troughs.

To better constrain the texture of sublimation tills, and monitor the impact of desert pavements on vapor diffusion, we ran a series of in-situ diffusion experiments whose aim is to capture the diurnal variation of Nitrogen isotopes in the top 30 cm of sediment. The real-world results may be of considerable importance to the Mars community as similar laboratory experiments have been conducted using standard glass beads [10] and crushed dolerites, without the requisite geologic complexity, to simulate Mars sediments.

Discussion, General Conditions and Sublimation Rates: Given current environmental conditions in Beacon Valley the sublimation model predicts a net-annual ice loss of ~0.06 mm in central Beacon Valley (Taylor Glacier ice) and at the terminus of Mullins Glacier. About 88% of this loss occurs during the austral "summer" months, (October – March) with January loss (0.02 mm) being ~33% of the annual total. Model results also show a transient, net gain in secondary ice accretion during August and September, when heightened atmospheric vapor densities lead to reverse vapor gradients.

Spatial Deviations in Sublimation Rates and Potential Relations to Age and Maturity: Spatial variation in rates of ice sublimation is demonstrably related to the development of surface troughs at the margin of contraction-crack polygons. Based on the Marchant et al. conceptual model [16], initial sand-wedge deposits at polygon troughs tend to increase net-annual ice sublimation, due to their overall high values for porosity (up to 45%) relative to that for pristine Granite Drift at polygon centers (~30%). However, as troughs deepen, they experience colder-than-average microclimate conditions due to local solar-radiation shielding from polygon margins. The reduced temperatures act to suppress ice loss at the base of troughs, thereby forming a negative feedback that prevents runaway ice loss. The negative feedback also constrains maximum relief between polygon troughs and centers. Our model predicts similar rates of sublimation for polygon centers and troughs for much of the Taylor Glacier ice, suggesting an equilibrium state for a mature polygon profile. A difference in sublimation rates between the polygon center and trough would suggest either a recent shift in climate conditions or an immature polygon surface. The later would be prominent in younger landscapes and thus suggest a younger ice age. A similar relationship might exist for buried ice deposits on Mars.

Role of Salt Cemented Layers and Desert Pavement: The addition of near-surface salts [17] and rocky desert pavements, modeled independently as distinct reductions in near-surface porosity, yield substantially reduced rates of ice sublimation. Assuming a scenario in which a 50-cm thick section of Granite drift contains a salt-cemented horizon at 10-15-cm depth (with a porosity of 20%) and 75% coverage with a rocky desert pavement would decrease rates of sublimation by 60%. If desert pavement is found to be rare on Mars, especially in regions where ice has been confirmed in the Northern Plains, the likelihood of high concentrations of salts in the martian regolith [4] could substantially decrease the rates of deposition or sublimation of ice.

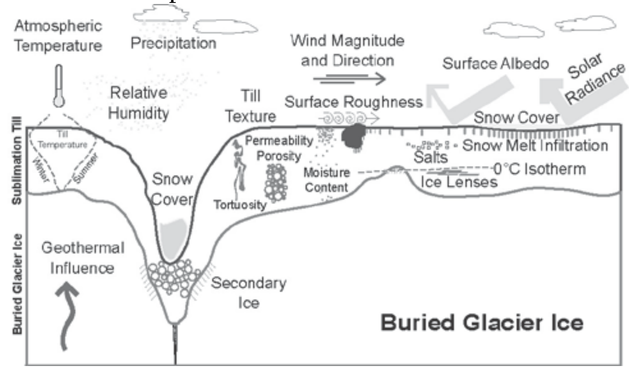

Fig. 2. Factors that influence vapor flux through the till and the sublimation rates of subsurface ice.

Summary: Surface textures, topography, and the presence of salt layers demonstrably alter sublimation rates in the McMurdo Dry Valleys. Studies of these systems offer insight into buried-ice preservation in similar environments on Mars [5].

References: [1] Malin and Edgett, *Science*, 325, 1674, 2009; [2] Head et al., *EPSL*, 241, 663, 2006; [3] Levy et al., *Icarus*, 201, 113, 2009; [4] Smith et al., *Science*, 325, 58, 2009; [5] Marchant and Head, *Icarus*, 192, 187, 2007; [6] Kowalewski et al., *Ant. Sci*., 18(3), 421, 2006; [7] Marchant et al., *LPSC Abstract 2007 Meeting*, 2007; [8] Sugden et al., *Nature*, 376, 412, 1995; [9] Rignot et al., *GRL* 29(12), 10.1029, 2002; [10] Hudson et al., *Jour. Geophys. Res. Planets*, 112(E5), 2007; [11] Chevrier et al., *GRL*, 34(2), 2007; [12] Chevrier et al., *Icarus*, 196(2), 459, 2008; [13] Beyer et al., *Ant. Sci*., 11(4), 387, 1999; [14] Bockheim and Hall, *S. Afr. Jour. Sci*., 98(1-2), 82, 2002; [15] Hindmarsh et al., *Geografiska Ann*., 80A(3-4), 209, 1998; [16] Marchant et al., *GSA Bull*., 114(6), 718, 2002; [17] Bao and Marchant, *Jour. Geophys. Res. – Atm*, 111(D16), 2006.