IN SITU ANALYSIS OF ICE TABLE DEPTH VARIABILITY UNDER A ROCK AT THE PHOENIX LANDING SITE, MARS.
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Introduction: One of the major objectives of the Phoenix mission was to investigate the history of water in the Northern Plains, specifically by examining the characteristics of shallow ground ice. The global distribution of ground ice is consistent with diffusive equilibrium between the ice and atmspheric water vapor [1, 2]. Based on the assumption of a long-term global equilibrium, several theoretical studies have predicted variations in the depth of the ice table (the boundary between dry and ice cemented soil) at horizontal length scales ranging from 1000s of km to centimeters [3, 4, 5, 6]. These studies indicate that the ice table under decimeter-scale rocks is an important indicator of the history of water, locally and regionally.

Rocks cause a thermal perturbation to the subsurface that can affect the ice table in different ways. In the case of prevailing diffusive equilibrium, a rock creates a depression in the ice table [6,7]. Under warmer conditions, liquid water interactions (e.g. blowing snow melting on contact with a rock) might result in a “bump” or shallower ice hunder the rock. If no purturbation of the ice table is observed, this could incdicate that the rock was emplaced more recently than the ice. In the latter two cases, the ice is not in equilibrium with the current climate.

Here, we examine varitations in the depth of the ice table in the immediate vicinity of a rock, “Headless,” at the Phoenix landing site. We compare depth variations observed near Headless to simulations of the equilibrium ice table near similarly shaped irregular rocks and discuss implications for the current stability and dynamical history of the ice.

Excavations, Data, and Analysis Methods:

Excavation near Headless. Headless is a semi-tabular rock, roughly 10 cm in diameter and initially protruding ~3 cm above the soil surface. Its location on the flat shoulder of a polygon mound distant from other rocks offered the potential for a relatively uniform background ice table depth. Investigation of the Headless region began on Sol 68 with the excavation of the Neverland trench (Fig. 1). Neverland was subsequently expanded, and the robotic arm was used to slide Headless into Neverland on Sol 117. A series of digs between Sol 128 and 133 excavated soil beneath the initial position of Headless until mechanical resistance prevented further digging.

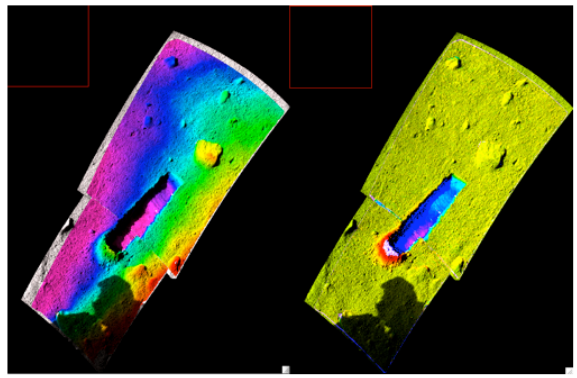

Fig. 1. Context images of Headless and the Neverland Trench overlain with color topography from (left) initial DEM and (right) difference DEM.

Data products. We measured trench depths using digital elevation models (DEMs) derived from Surface Stereo Imager (SSI) image stereo pairs. We differenced DEMs acquired prior to excavation from DEMs acquired after each stage of trench development. The resultant difference DEMs provided absolute trench depths with vertical uncertainties of $\pm$ 3 mm (Fig. 1).

We also employed a modified “pre-dig” DEM, in which the topography associated with Headless was removed (Fig. 2). By differencing this modified DEM with DEMs acquired on Sols 117 and 133, we were able to make detailed estimates of both the shape of Headless below the soil and the shape of the ice table immediately below the rock.

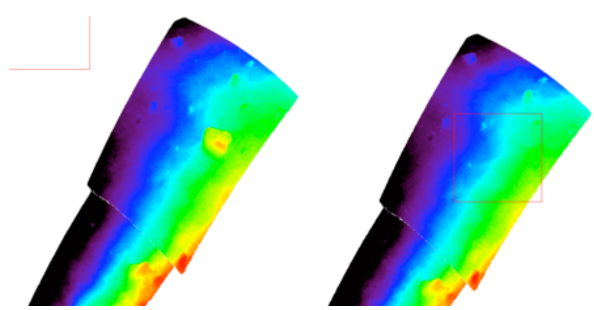

Fig. 2. Original “pre-dig” DEM (left), and modified DEM with Headless removed by interpolation (right).

Thermal simulations. Previously, [6] and [7] used two- and three-dimensional simulations of subsurface ice stability to investigate the effects of sub-meter scale rocks, variations in soil thermal inertia, and variations in albedo on the ice table *in diffusive equilibrium*. They predicted that rocks would depress the ice table by millimeters to 10s of cm in their immediate vicinity. To evaluate the hypothesis that the ice table reflects diffusive equilibrium, we utilize the numerical model described by [6] and [7] to examine the specific effects of irregular rocks whose shape approximates Headless.

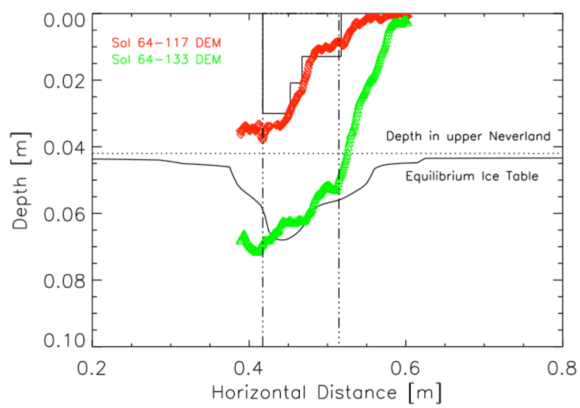

Fig. 3. Transects of DEMs approximating (red) the shape of Headless below the soil and (green) the underlying ice table and entrance ramp of the Pet Donkey trench. Vertical dashed lines indicate the horizontal extent of Headless visible at the soil surface. Solid lines represent an irregular rock and the corresponding ice table predicted by ice-stability simulations. Horizontal distance increases radially outward from the spacecraft.

Results and Discussion:

Our analysis of difference DEMs indicates that (1) the ice table under Headless is deeper than in adjacent areas (i.e. the ice table is depressed) and (2) on transects radial to the spacecraft, millimeter-scale variations in the depth of the ice table depression correspond to the shape of the overlying rock. Both of these results are consistent with predictions from ice-stability simulations ([6], [7], and Fig. 3) and support the hypothesis that the ice is currently in equilibrium with atmospheric water vapor. Additionally, the correspondence between small depth variations and the shape of the rock indicates that the diffusive equilibrium inferred from global data sets (specifically, TES thermal inertia and GRS neutron fluxes) is extensible to very small length scales (mm to cm).

It should be noted, however, that the total effect of Headless on the local ice table is subtle. Rocks are not the dominant source of ice table depth variability in the Phoenix workspace. Depths measured in the 12 workspace trench systems range from 1.6 cm to 16 cm, with the deepest ice occurring on the steepest equatorward slopes, and shallower ice occurring under flat or poleward sloping areas [8]. This correlation suggests that slope is the dominant source of depth variability, while small rocks – and possibly soil variations -- provide secondary modifications.

Consistent with its size, Headless depresses the ice table by a maximum of 3 cm below the farfield depth of ~4 cm. The area of the depression is quite small, corresponding to a limited portion of the rock that protruded ~3 cm below the soil surface. Analysis of DEM transects azimuthal to the spacecraft was complicated by loose soil tailings and incomplete "grooming" of the trench (removal of this loose soil). However, these azimuthal transects indicate that the background ice table slopes downward to the east of Headless. Ice stability simulations indicate that a similar effect could result from a local increase in soil thermal inertia, possibly due to grain cementation. Initial insertion of the Thermal and Electrical Conductivity Probe (TECP) into the soil above the region of depressed ice to the east of Headless produced surface cracking not observed elsewhere in the workspace, and tends to support this interpretation. However, TECP measurements do not indicate significant variation in soil thermal inertia between trenches.

The observation of a depression in the ice table under Headless allows us to make two strong statements about the dynamical history of ground ice at the Phoenix landing site. First, diffusion is likely the primary mechanism mobilizing water in the shallow regolith in the current epoch. Locally shallow ice beneath the rock might indicate recent water transport via thin films or liquid water [7], but is not observed. Second, the apparent equilibrium between ground ice and the atmosphere is a long term phenomenon (>10^3 yr). A recent shift in climate conditions would likely cause the magnitude of the ice table depression associated with the rock to deviate from theoretical predictions [7]. Again, this is not observed. Taken together, the range of ice table depths measured at the Phoenix landing site and the detailed behavior of the ice table near Headless argue strongly for a prevailing equilibrium between ground ice and atmospheric water, and indicate that physical models of ground ice employed for the past four decades are largely appropriate.

References: [1] Mellon M. T. et al. (2004) *Icarus* 169, 324-340. [2] Feldman W. C. et al. (2008) in *The Martian Surface: Composition, Mineralogy, and Physical Properties,* J. F. Bell, ed. [3] Mellon M. T. & Jakosky B. M. (1993) *J. Geophys. Res*. 983345-3364. [4] Aharonson O. & Shorghofer N. (2006) *J. Geophys. Res.,* Vol. 111, E11. [5] Banfield J. (2007), [6] Sizemore H. G. and Mellon M. T. (2006) *Icarus* 185, 358-369. [7] Sizemore et al. (2009) *J. Geophys. Res., in press*. [8] Mellon et al. (2009) *LPSC XL*.