GROUND ICE AT THE PHOENIX LANDING SITE: A PREFLIGHT ASSESSMENT. M. T. Mellon[1], R. E. Arvidson[2], F. Seelos[2], L. K. Tamppari[3], W. V. Boynton[4], P. Smith[4], and the Phoenix Science Team; [1]University of Colorado, Boulder, CO; [2] Washington University, St Louis MO; [3] Jet Propulsion Laboratory, Pasadena, CA; [4] University of Arizona, Tucson, AZ.

Introduction: One of the objectives of the Mars Scout mission, Phoenix, is to characterize the present state of water in the martian environment, in a location where water may play a significant role in the present and past habitability of Mars [1]. Given the generally dry and cold climate of Mars today any substantial amount of water is expected to occur in the form of ground ice (subsurface ice) within the regolith. The Mars Odyssey Gamma Ray Spectrometer has indicated abundant subsurface hydrogen and inferred ground ice at high latitudes [2]. Therefore, the Phoenix mission will be targeted to land in the northern high latitudes (approximately 65ºN - 75ºN) where ground ice is expected to be abundantly available for analysis [1].

The lander will be capable of excavating, sampling, and analyzing, dry and water-rich/icy soils. The location and depth of excavation necessary to achieve the goals of sampling and analysis of icy material become important parameters to assess. In the present work we ask two key questions: 1) At what depth within the regolith do we expect to find ice? 2) How might this depth vary over the region of potential landing sites?

Numerous lines of evidence can be employed to provide an indication of the presence or absence of shallow ground ice at the potential landing sites. For example geomorphology, neutrons, gamma rays, and theory each contribute clues to an overall understanding of the distribution of ice. Orbital observations provide information on a variety of spatial scales, typically 10's of meters (patterned ground) to 100's of kilometers (gamma rays). While information on all of these scales are important, of particular interest is how the presence and depth of ground ice might vary on spatial scales comparable to the lander and its work area. While ground ice may be stable (and present) on a regional scale, local-scale slopes and changes in the physical characteristics of soils can result in significant variations in the distribution of ice.

Antarctic Analog: Perhaps a useful analog to illustrate the potential complex distribution of ice with depth can be found in the Antarctic Dry Valleys. The Dry-Valley climate is similar to that of Mars in that it is generally cold and dry. While the Dry Valleys are warmer than Mars, liquid water is not believed to dominate the stability of ground ice, and vapor diffusion plays a key role. Ground ice is ubiquitous in the Dry Valleys below an "ice table", an icy-soil boundary above which is generally 10's of cm dry soil.

In areas of uniform soil and level surfaces the ice table parallels the surface, reflecting level isothermal planes within the subsurface. In areas of rough uneven surfaces and mixed rocks and soil the ice table forms as a similarly complex subsurface layer (Figure 1).

Figure 1. Ice-cemented soil (beneath the rock hammer) in Beacon Valley Antarctica, exposed from beneath a few 10's of cm of dry, rocky soil. The complex structure of the dry soil and the surface topography results in complex, undulating ice table [2].

Ice Stability: Both orbital observations and theoretical studies indicate an ice table overlain by dry soil should occur in the martian high latitudes [2, 3].

Indeed, orbital observations of hydrogen gamma rays are consistent with pure ice buried beneath relatively water free soil, below a depth of about 10-15 cm (depending on the soil density). This depth represents an upper limit; if the ice is diluted by soil, the ice table may in fact be shallower. Theoretical studies, assuming ground ice in diffusive equilibrium with the atmosphere, are largely consistent with this view (see below).

Diffusive equilibrium implies that the depth of the ice table is located at a depth where sublimation and diffusion to the atmosphere balance diffusion from the atmosphere and condensation on seasonal time scales.

Figure 2 shows a map of the theoretical ice-table depth for the northern hemisphere of Mars. This map includes the effects of geographic variations in elevation, albedo, and thermal inertia on the subsurface temperatures and atmospheric humidity. Within the 65ºN - 75ºN area targeted for landing, ice-table depths are typically several cm, slightly shallower than the depths inferred for pure ice from GRS data, but not inconsistent with dirty ice. In addition, effects of rocks and surface slopes on ground ice stability and the gamma-ray data help improve the consistency.

Slopes and Other Effects: Models such as those described above (both for interpreting orbital data and predicting ice-table depth) commonly assume a homogeneous soil surface, absent of slopes, rocks, and other variations in soil properties. However, as Figure 1 illustrates permafrost with heterogeneous characteristics exhibits more complex ice tables. In addition, martian surface observations at all the previous landing sites indicate heterogeneous soil characteristics is the norm, with some combination of rocks, dust, sand, and duricrust, as well as sloped surfaces to various degrees.

To evaluate the effects of local surface slopes, we estimate the ice table depth for north-south facing slopes by offsetting the latitude by the amount of the slope. While not entirely correct, this approach gives us a zero-order approximation of the ice-table depth on a sloped surface (Figure 3). In general, for an average soil for these latitudes, the ice table may become excessively deep only for large equatorward slope and lower latitude.

Rocks can also effect the ice-table depth by drawing heat into the subsurface and generally warming the bulk soil on an annual average. Higher temperatures in the subsurface will cause ice to become less stable and the ice table will recede to deeper depths. Rocks can also cast shadows (depending on the time of day) reducing insolation and allowing ice to become more stable and the ice table to become shallower within the shadowed area.

Similarly, variations in the thermophysical properties of the soil will cause variations in the ice-table depth. Higher thermal inertia soils are warmer on a seasonal average, than are lower thermal inertia soils. The result is that the ice table will be deeper in the higher thermal inertia case.

References: [1] Smith P. et al., *LPSC XXXV* (2004); [2] Boynton W. V. et al, Science, 297, 81-85, (2002); [3] Mellon M. T., W. C. Feldman, and T. H. Prettyman, *Icarus* in press (2004)

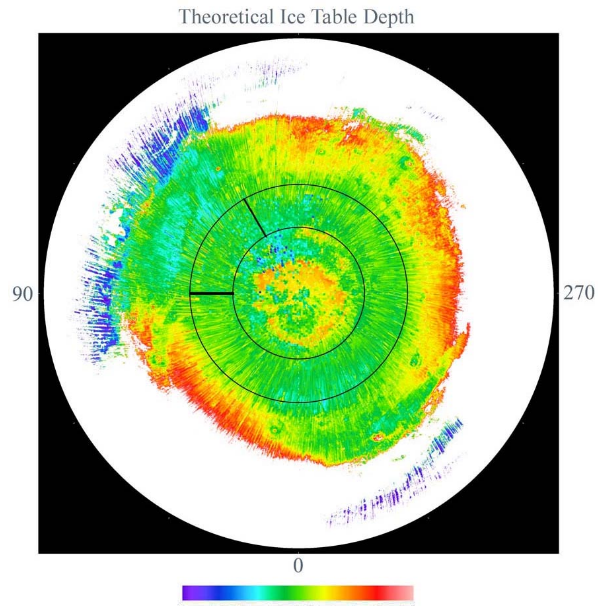

Figure 2. A polar orthographic projection of the depth of the ice table assuming geographic variations in the properties of the surface and diffusive equilibrium with an atmosphere containing 20 pr um of atmospheric water. This amount of water and the assumption of diffusive equilibrium are consistent with observations of epithermal neutrons (ground ice) in the southern hemisphere [3]. Latitudes 65º and 75º are highlighted, as well as a longitude zone where particularly high hydrogen abundance is indicated. (Large depths over the polar cap are an artifact of the high cap thermal inertia and assuming soil surface.)

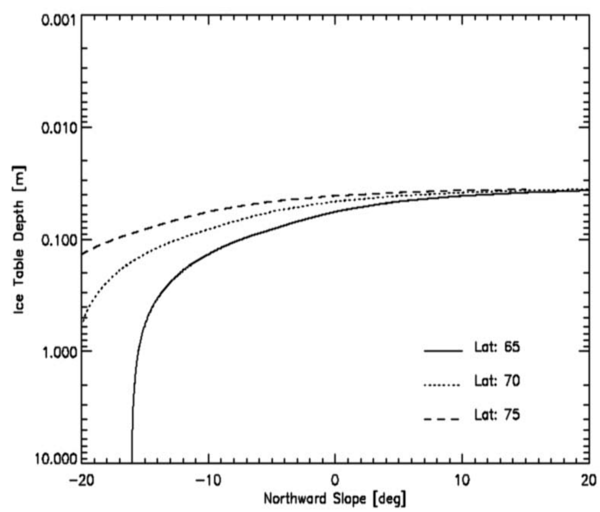

Figure 3. Ice-table depth as a function of surface slope for average soil properties (albedo of 0.25 and thermal inertia of 250 J m^{-2} K^{-1} $s^{-1/2}$) and elevation (-4500 m) representative of the latitudes 65º to 75º N.