PERMAFROST AND POLYGONS AT THE PHOENIX LANDING SITE. M. T. Mellon[1], R. E. Arvidson[2], M. C. Malin[3], T. L. Heet[2], H. G. Sizemore[1], M. L. Searls[1], M. T. Lemmon[4], H. U. Keller[5], and The Phoenix Science Team[6], [1]Laboratory for Atm. and Space Physics, Univ. of Colorado, Boulder, 80309, [2]Dept. of Earth and Planetary Sciences, Washington Univ., St Louis, MO, [3]Malin Space Science Systems, San Diego, CA, [4]Dept. of Atm. Sci. Texas A&M Univ., College Station, TX, [5]MPI for Solar System Research, Katlenburg-Lindau, Germany, [6]Earth.

Introduction: The Phoenix spacecraft landed in the northern high latitudes of Mars, in a region where water ice was expected to dominate the subsurface. Indeed, a key goal of the Phoenix mission was to examine this ice, its characteristics, and the high latitude environment [1]. Over time this ice has influenced the martian landscape at these latitudes and resulted in the development of periglacial landforms. Excavation by the spacecraft's robotic arm and descent thrusters exposed an abundance of ice.

Analysis of the subsurface distribution of ice and the periglacial landforms around the lander, provide important clues about the nature and history of the martian high-latitude climate and the history of water in this region. The Phoenix mission provides the first direct measurement of the depth of the ground ice and the first close up observations of the resulting periglacial geomorphology.

Polygonal ground formation: Polygonal patterned ground is perhaps the most common landform in terrestrial permafrost. It develops as a result of seasonal thermal-contraction cracking in cohesive, ice-cemented permafrost [2]. Winter cooling of the ground causes contraction and a build up of tensile stress. Slow viscous deformation relaxes some of the stress, but when this relaxation is insufficient brittle fracture occurs relieving stresses in the neighborhood of the fracture. At some distance from this initial fracture the stress is not relieved and a new fracture can form. In relatively isotropic permafrost a honeycomb network of fractures develops within the ice-rich surface layer.

In any one season a crack can open a few millimeters. Surface materials (liquid water in wet climates or dry soil in arid climates) can fill in the open crack forming a wedge, and subsequent summertime thermal expansion will result in incremental uplift of the central regions of the polygon. Thousands of years (or more) of polygon development and wedge growth can lead to decimeter-scale topographic relief.

The depth in the subsurface where tensile stresses are the highest corresponds with the depth of the ice table (the top of the cohesive ice-cemented layer) where the magnitude of thermal oscillations are the largest. Therefore, not surprisingly, the depth of the ice table below a blanket of dry soil can influence the formation and scale of polygonal ground [3].

Ice Rich Permafrost on Mars: Today, Mars is globally covered by a thick layer of permafrost, a soil layer where temperatures never exceed the freezing point of water. Water ice deposits within the permafrost are expected at middle and high latitudes based on theoretical stability [4] and spacecraft observations [5]. Prior to the Phoenix landing, ice rich deposits were expected to be found at depths as shallow as 2-6 cm below a layer of "dry" ice-free soil, based on a variety of observational and theoretical studies [6]. Ice found at these depths would reflect a condition of diffusive equilibrium with atmospheric water vapor at concentrations close to or slightly higher than that measured in the last few decades [7].

Depth of ice at the Phoenix Site: Ice-rich frozen ground was found to be widespread around and under the lander. During the entry, descent, and landing phase, descent thrusters stripped away approximately 5 cm of loose soils from under the lander exposing a resistant layer that roughly paralleled the original surface (Figure 1). Subsequent degradation of this material and formation of a friable soil lag during the course of weeks indicated an ice-rich composition.

Fig. 1 - A robotic arm camera image under the lander showing several areas of ice-rich material exposed by the descent thrusters. The exposed icy surface was named "Holy Cow." The view is to the south.

A dozen major excavations, or trench systems, by the robotic arm exposed the ice table in numerous locations in the workspace next to the lander. This icy layer was found below a layer of dry soil, as predicted. These trenches explored the permafrost in a variety of geomorphic contexts relative to the local polygonal patterned ground, including troughs, trough shoulders, and polygon interiors, as well as sloped and level ground. While the characteristics of the icy material varies, the dominant form observed was a matrix-supported ice-cemented soil, or pore ice.

A survey of the depth of the ice table in each excavation showed that this depth varies from as shallow as

1.6 cm to deeper than 16 cm. Typically, depths are close to 5 cm with most in the range of 3-7 cm. The shallowest depth corresponds to a small deposit of light-toned dirty ice (ice with very low soil content), though some of the icy soil (matrix-supported pore ice) deposits are similarly shallow. At the deepest depths excavated, the robotic arm did not confidently expose water ice. These trenches occurred on the shoulder of a polygon trough close to the lander - digging deeper to locate the ice table was limited by the lander and robotic arm geometry.

Analysis of ice table depths relative to local surface slopes indicates that equatorward facing surfaces exhibit deeper ice table depths than poleward facing surfaces. This trend and the magnitude of the ice table differences are consistent with ground-ice stability models, assuming diffusive equilibrium with atmospheric water vapor. Other variations in soils properties such as thermal conductivity and thermal inertia also play a role in the depth of the ice table.

Polygonal Ground at the Phoenix Site: The landscape around the Phoenix spacecraft is dominated by polygonal patterned ground (Figure 2). These patterns generally consist of a central mound and perimeter trough. Trough-to-trough spacing (polygon "diameter") is around 3-5 meters from the landers point of view. Orbital imaging confirms the 5-m-scale pattern and indicates a larger 20 m scale pattern is also present in the immediate area. The size of the polygons is intimately linked to the depth of the ice table.

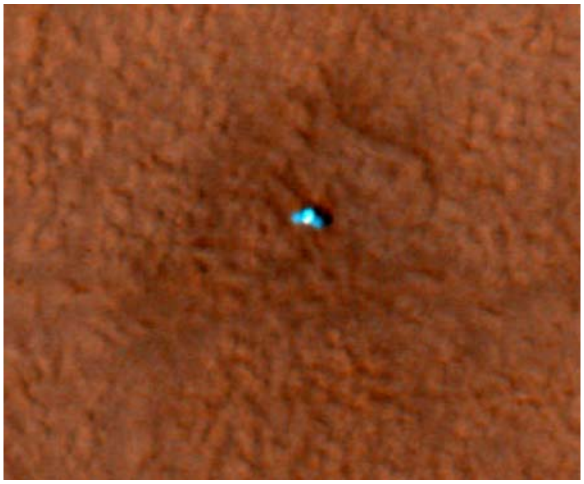

Fig. 2 – The Phoenix lander on the surface of Mars as viewed from orbit by HiRISE. Approximate 5 m scale polygonal patterns ubiquitously cover the surface. Zoomed out, larger 20 m patterns are also evident.

The shape of the central mounds in plan view varies widely from equilateral (almost circular) to elongated. Troughs are quite variable in depth relative to the central mounds, ranging from a few centimeters to about 15-20 cm. Despite this variability, troughs and trough slopes appear symmetric along compass directions, indicating an absence of insolation control.

Small centimeter-scale furrows are observed within some of the troughs, and a few appear to crosscut existing central mounds. Furrows indicate the consumption of surface soil by an open subsurface fracture and are common in Antarctic sand-wedge polygons.

Surface rocks are observed to be heterogeneously distributed over the polygonal landscape, with statistically higher concentrations of rocks in the polygon troughs. Additionally, there is a marked absence of aeolian bedforms and vetifacts, suggesting the surface has experienced significant and ongoing cryoturbation.

Polygon Evolution and the Martian Climate: The polygonal patterns and their morphology as seen by the Phoenix lander are complex. Polygons are not simply arrays of equilateral semi-hexagonal forms, but complex mixes of superimposed scales seen from orbital imaging and lander imaging.

The variability in trough depth suggests present day troughs are observed at a wide range of developmental stages. Shallow troughs are less developed, either due to becoming inactive in the past or being younger and just beginning to form. The small furrows observed around the lander are similar in form to furrows observed in Antarctic sand-wedge-polygon troughs where surface fines are falling into active open cracks in the ice-cemented ground below the surface. In addition, finite-element modeling shows that for an ice-table at nominally 5 cm below the surface small ~5 m polygons should form in the current climate [3].

These observations and the comparisons with numerical models are consistent with present-day polygon forming activity. Rock sorting, the absence of aeolian features, and the complex superposition of sizes indicate a long history of polygon development. The superposition of polygon scales from 3 m up to 20 m suggests long-term changes in the environment. These changes could be in the form of differences in the depth of the ice table over time which would be linked to changes in the atmospheric humidity and ground temperatures as has been predicted from orbital oscillations. Changes in the mean ground temperature can also play a role by altering the rheologic properties of the ice-rich permafrost.

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