ICE AT THE PHOENIX LANDING SITE PART V: THE EQUILIBRIUM STRIKES BACK. M.H. Hecht, Jet Propulsion Laboratory, California Institute of Technology (michael.h.hecht@jpl.nasa.gov),

Introduction: Frozen water was observed in several forms in the course of the Phoenix mission: As a sheet of apparently pore-filled, impervious material underlying polygon interiors; as friable, "segregated" material at a polygon margin; as "globules" on the legs underneath the lander; and as ephemeral frost detected visually towards the end of the mission and indirectly as a transition across a frostpoint earlier in the mission. The diversity of observations gave rise to speculations by a number of investigators (including this author) of unusual disequilibrium processes. Here, some of those speculations are re-examined in sober hindsight, and it is suggested that more conventional equilibrium physics better describes the observed phenomena.

Segregated ice: Ice exposed directly below the lander by the jets and in the interior of polygons by the robot arm was particulate rich, as determined by spectroscopy and the rate of sublimation [1]. The likely mechanism of formation for such ice is pore-filling of loose soil by vapor diffusion and, indeed, microscopic [2] and chemical [3,4] properties of the sublimation till did not differ in any measurable respect from surface soil. Mechanically, this ice was well-cemented and could not be excavated by the robotic arm.

In contrast, ice excavated at the shoulder of a polygon, adjacent to a trough, was found to be nearly pure and was friable. Several chunks broke off during excavation and sublimed without leaving an observable residue. This "Dodo-Goldilocks" sample has been described as segregated ice, attributed to various recent formation mechanisms [1], and cited as evidence of past liquid water [5,6]. In practice, however, the purity of this ice is comparable to that of the Polar Layered Deposits (PLD) [7], which is generally attributed to accumulation by condensation and/or precipitation.

Mellon et al. 2009 [1] recently argued that the exposed pore-filled ice was representative of the bulk ice underlying the site, citing a rheological formalism to show that its properties (and *not* the properties of pure ice) were consistent with the observed polygon size [8]. However, obvservations by Byrne et al. of recent impacts in the northern plains using the HiRise and CRISM instruments [9] have indicated that the exposed ice is relatively pure, consistent with the Dodo-Goldilocks sample.

The question of which type of ice is characteristic of the subsurface is important because the Mellon et al. interpretation suggests formation by vapor diffusion only, while the Byrne et al. finding suggests formation by precipitation and/or condensation. It is argued here that the Dodo-Goldilocks sample is, indeed, more representative of the bulk ice at the Phoenix site, and the other exposed samples represent a centimeter-scale veneer of young, pore-filled ice.

The essence of the argument is summarized in Fig. 1. One dimensional models of the movement of the ice table due to climate change indicate that the equilibrium thickness of the soil blanket has been thinning in recent times as the climate has cooled [10]. Neglecting the effect of aeolian movement of soil, equilibrium would be maintained on a time scale of centuries by a process of vapor diffusion of water into the soil just above the ice table. This process suggests that *any* equilibrium ice exposed at the Phoenix site is likely to be particle-rich and pore-filled, but reveals no information about the underlying, older ice.

Fortuitously, Phoenix discovered a site, Dodo-Goldilocks (DG) that was significantly out of equilibrium, in the sense that the soil covering was only a few centimeters thick, whereas the southern orientation of the slope should have resulted in a sublimation blanket in excess of 10 cm thick [1]. Whatever the source of the disequilibrium (likely a slump, possibly triggered by winter CO_2 deposition), the response of the system would be for the ice table to retreat by a process of sublimation. In this unique location, the underlying ice would be exposed. This suggests that the the segregated DG ice is typical of the subsurface, in agreement with the Byrne et al. result.

While the rheological formalism of Mellon et al. argues for bulk pore-filled ice under the polygons, it is questionable whether the stress-strain relationship utilized in the model has sufficient fidelity to distinguish between the two types of ice. In practice, it is possible that climate cycles have left a stratified imprint within the ice, much as is seen on a larger scale in the PLD.

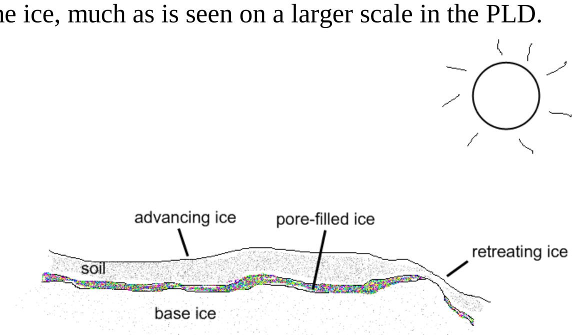

Fig. 1: Phoenix accesses young, pore-filled ice at all locations except Dodo-Goldilocks where a recent south-facing slope collaps has caused the ice to retreat, exposing older ice

Lander leg globules: Globules of frozen volatiles were observed to form on the Phoenix Lander leg and to change character during the mission, with some growing and others shrinking. [11,12]. The changes in size have led some researchers to conclude that the "droplets" liquefied during the mission. The explanation for this extraordinary claim is that the droplets consisted of eutectic brines, possibly derived from perchlorate salts discovered at the site [3].

There are several conspicuous problems with the brine model. For one, it is not clear how the putative brine-forming salts might have been concentrated (they are found at <1% in the soil) and splashed onto the legs. The lander jets purportedly extracted the salts from the ice, in which environment they would have been completely hydrated and therefore would not have swelled on the lander legs. Even with complete dehydration (a slow process), absorption of water to the eutectic would result in a radius increase of less than 25%. The interpretation is further compounded by the low resolution of the data – the largest globules are less than 10 pixels across, and the images suffer from JPEG compression artifacts.

A simpler explanation is that the globules are merely water frost. Renno et al. estimate that the temperatures on the struts are between 200-220K [12], while Zent et al. *measure* a daytime frostpoint of 215K [13] at the site. Thus frost condensation is entirely plausible. Condensing water vapor would be attracted to the coldest points on the struts. Low emissivity of the metal struts and conduction of heat from the deck suggests that those cold spots would initially be soil contaminants and eventually would be the ice itself. Hence globules would tend to nucleate on soil aggregates and grow. Higher albedo globules (lower particle fraction) would tend to be colder and "cannibilize" darker droplets, as observed. The changing character of the globules is further encouraged by intermittent illumination through gaps in the solar panels (Fig. 2), causing inhomogeneous heating.

Fig. 2: Globules on the Phoenix robot arm illuminated by a patch of sunlight through a solar panel window. Imaged on sol 89. (Photo credit: JPL/NASA)

Vapor equilibria and frost: While frost was not visually observed until late in the mission, the humidity sensor on the Thermal and Electrical Conductivity Probe (TECP) routinely measured the transition above the frostpoint at night [13]. At night, the TECP measured humidity consistent with the frostpoint of ice at the measured temperature, indicating equilibrium with ice at the soil surface. In the daytime, humidity was found to saturate at just above 1 Pa, and it was variously suggested that this represented all the available water [14], an adsorption isotherm in the soil, or a hydration phase transition of magnesium perchlorate [13]. It was further noted the atmospheric temperature lagged the drop in humidity in the evening, and it was speculated that this might represent a adsorption property [13] or even a liquid brine transition [15].

A simple equilibrium explanation of the observed phenomena is that water vapor establishes an equilibrium with the coldest available surface. Since diffusion through the soil is rapid, the cold trap during the daytime is the surface of the ice, several centimeters below the surface. The temperature of this surface is estimated to be 210K-215K [13], corresponding to a saturation vapor pressure of 1Pa, in agreement with the daytime limit. The lags are likely due to the more rapid cooling of the surface relative to the atmosphere (better radiative coupling) or the presence of shadows on the surface creating local cold traps before sunset that sap water vapor from the boundary layer.

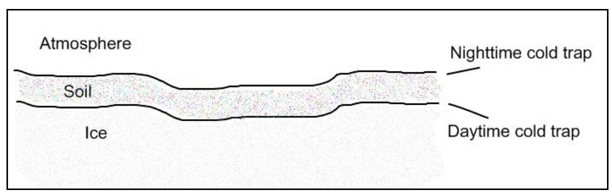

Fig. 3: Water vapor traps at the coldest accessible surface, which is the soil surface by night and the ice table by day. At dawn and dusk a wave of moisture moves through the soil

References: [1] M. Mellon et al (2009), *JGR 114*, doi:10.1029/2009JE003417 [2] W. Goetz et al (2009), *JGR 114, in final revision* [3] M. H. Hecht et al. (2009), *Science* **325,** 64 [4] S. Kounaves et al (2009), *JGR 114*, doi:10.1029/2009JE003424 [5] P. H. Smith et al. (2009), *Science* **325,** 58 [6] C. Stoker et al., (2009), *JGR 114, in final revision* [7] R. J. Phillips et. al (2008*), Science* **320**, 1182. [8] M. Mellon et al (2008), JGR **113**, E00A23 [9] S. Byrne et al. (2009) *Science* **325**, 1674 [10] A. Zent (2008), Icarus 196, 385 [11] M.-P. Zorzano et al. (2009), Geophys. Res. Lett., 36, 20 [12] N. Renno et al. (2009), JGR **114**, E00E03 [13] A.P. Zent et al. 2009, JGR **114,** J. Geophys. Res., doi:10.1029/2009JE003420 [14] J. Whiteway et al., (2009), *Science* **325,** 68 [15] V. F. Chevrier et al. (2009), *Geophys. Res. Lett.*, 36, L10202.

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