EXCAVATION OF SUBSURFACE ICE ON MARS BY NEW IMPACT CRATERS. S. Byrne[1], C.M. Dundas[1], M.R. Kennedy[2], M. Mellon[3], D. Shean[2], I. Daubar[1], S. Cull[4], K.D. Seelos[5], S. Murchie[5], B. Cantor[2], R.E. Arvidson[4], K. Edgett[2], A. McEwen[1], T. Harrison[2], L. Posiolova[2], F.P. Seelos[5] and the HiRISE, CTX and CRISM teams. [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ; [2]Malin Space Science Systems, San Diego, CA; [3]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO; [4]Department of Earth and Planetary Sciences, Washington University, St. Louis, MO; [5]Applied Physics Laboratory, Johns Hopkins University, Laurel, MD. **Correspondence:** shane@lpl.arizona.edu

Introduction: Theoretical results [1-7] and observational evidence [8-11] indicate that high-latitude terrain on Mars contains large quantities pore-filling ice buried beneath a desiccated regolith. Although the models themselves differ in detail, they all show a sharp transition from regions where ice is currently stable to those where it is not. The modeled extent and depth of this buried ice is sensitive to the long-term global average water vapor concentration in the atmosphere. The position of the mid-latitude boundary between regions where buried ice is stable and where it is not is particularly sensitive to this quantity.

Current models suggest a value of 20 precipitable microns (pr μm) best agrees with the observational evidence from the neutron spectrometer aboard Mars Odyssey in a global sense [3]. This required long-term average is higher than the currently observed annual averaged water vapor of 14 pr μm [12] (which itself may need to be revised downward by a factor of 1.5 [13]). An accurate determination of where buried ice transitions from stable to unstable would help greatly in constraining this long-term average of martian atmospheric water. Unfortunately the neutron spectrometer cannot detect ground ice deeper than a few decimeters. This, coupled with the low resolution nature of this device, means that this mid-latitude boundary cannot be accurately determined from these data alone.

Here we report on natural probes of the martian subsurface which have 'detected' ice in this critical mid-latitude zone. New impact craters discovered in the Context Camera (CTX) dataset, and not present in previous imagery, occur in this latitudinal zone. In five such cases (with latitudes spanning 43.3° to 55.6° N), these impacts have excavated bright material which in High Resolution Imaging Science Experiment (HiRISE) data have a brightness and color consistent with water ice (see Figure 1). Real-time collaboration between instrument teams allowed for a coordinated investigation of these features.

Bright material composition: This bright material appears in both the ejecta (Figure 1) and floors (Figure 2) of these new craters. These craters are typically a few meters in diameter, excavate to several decimeters and have associated bright material a few meters across. We examined hyperspectral data acquired by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) for spectral evidence of water ice. Four of the five sites have bright material which occupies less than 10% of a CRISM pixel (~18m in size) and showed no spectral evidence of water ice. However, one site (depicted in Figure 1) had a large enough bright deposit to occupy a significant fraction of a CRISM pixel. Spectra from this site show clear water-ice absorption features at 1.25, 1.5 and 2 μm.

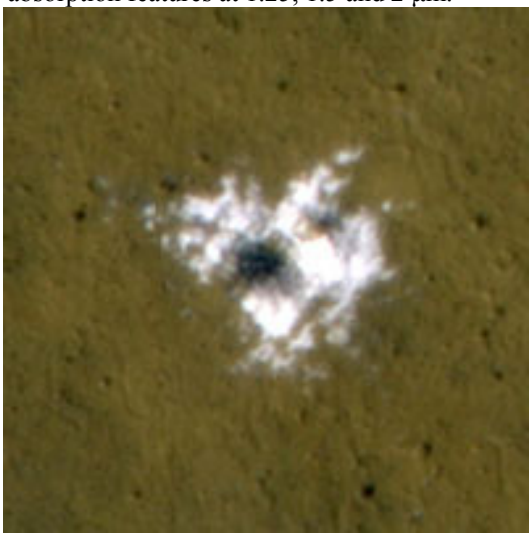

Figure 1. HiRISE false color image PSP_010625_2360 of a new crater (formed between 1/26/2008 and 9/18/2008) with associated ice deposit. Image is 50m across. Site 3 in figure 3.

Exposed surface ice is not stable at the latitudes of these sites (43.3°-55.6° N) and would be expected to sublimate. We are monitoring these sites and have seen this ice both shrinking in area and fading. Figure 2 shows an example of icy material in craters of an impact cluster. Bracketing CTX images confirm this particular cluster formed between June and August 2008 (L_s 81-111). The two craters containing the bright blue material are 5-6m across and shadow measurements indicate depths of ~70cm. Figure 2 shows these ice patches fading to background color and albedo over the course of several months and they are essentially indistinguishable from background terrain in recent images (at L_s 180 and 187, not shown here).

Thermal models, reported on by *Dundas et al.* (this conference), predict several centimeters of sublimation over this timeframe. Our interpretation of the

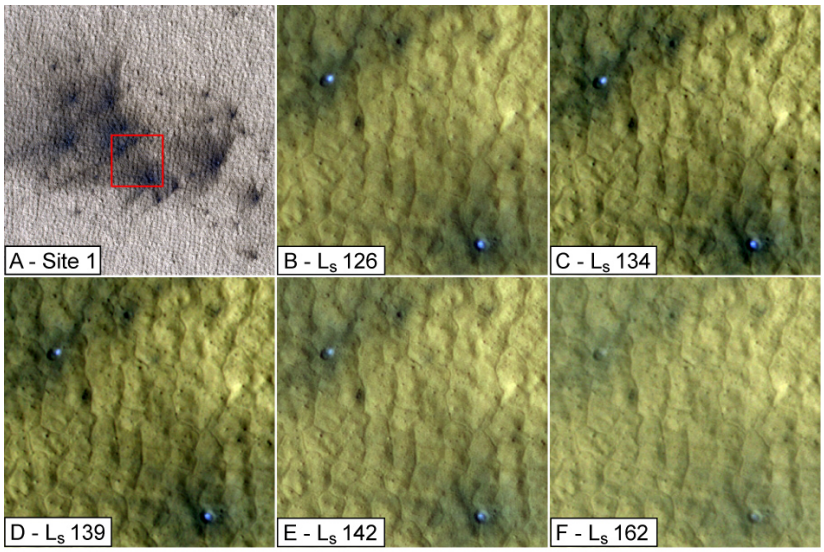

Figure 2. Series of HiRISE false color frames PSP_0xxxx_2265, where xxxx are orbit numbers 09978, 10189, 10334, 10400 and 10901. Each band in each image has been scaled by the brightness of undisturbed nearby terrain outside the crater cluster. Each frame (apart from A) is 75m across. Bright blue spots visible in B within small craters fade with time until they are barely discernable (F). Subsequent images show no evidence of ice at all. Site 1 in figure 3.

fading of this material is that a sublimation lag is forming. The amount of sublimation, coupled with the lag thickness required to mask ice at visible wavelengths, implies extremely low dust concentrations of <0.001 by volume (multiple uncertainties in this estimate will be discussed at the conference). If this dust cover were partially derived from airfall then the dust concentration of the ice would be lower. The ice exposed at this site is not pore-filling ground ice but rather is relatively pure and is at least several cm thick.

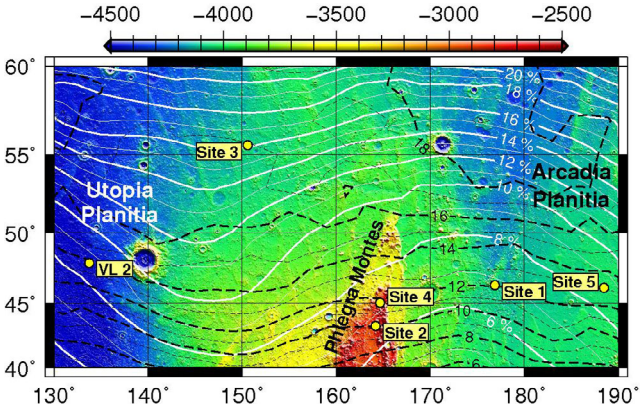

Figure 3. Locations of ice-excavating craters in Utopia and Arcadia Planitia. Viking lander 2 indicated on left. White and black contours are the modeled ice content of a lower layer and its burial depth (g cm^{-2}) [11].

Massif Aprons and Polygons: Two of these sites impact on the flanks of aprons surrounding massifs in the Phlegra Montes region (see Figure 3). These aprons have previously been interpreted as lobate debris aprons (LDAs) [14], recent radar evidence has shown LDAs in other regions to be composed of ice [15] to within 10 meters of the surface (rendering the term 'debris aprons' incorrect). These craters suggest ice-rich material within 1m of the surface; however, morphologic differences mean these aprons may not be the same class of feature discussed by [15]. Polygons visible at sites 1 and 5 may be currently forming from thermal contraction cracking of this near-surface ice.

Implications for models: Comparison of the depths of these craters with modeled depths to stable ground ice is encouraging. Four of the five sites are within ~0.1° latitude of the boundary which encloses terrain expected have ground ice in the upper meter. Site #3, at 55.6°N is comfortably within the region expected to have ground ice. For the example shown in figure 2, the expected depth to ground ice is close to 84cm [3] while the crater depth is 65-70cm. This particular model uses an average water vapor concentration of 20pr μm and these new data are so far consistent with this value or perhaps one slightly higher. This contrasts with the current observations of average atmospheric water vapor of ~14pr μm [12] or ~10pr μm [13]. Thus the ground ice exposed here is probably in the process of retreat from a previously larger extent perhaps due to recent variations in the argument of perihelion [6].

We will report on these discoveries as well as constraints from new mid-latitude impacts which do not currently expose ice and discuss comparisons with current ice-stability models and their implications.

References: [1] Mellon and Jakosky, JGR, 1993. [2] Mellon and Jakosky, JGR, 1995. [3] Mellon et al., Icarus, 2004. [4] Schorghofer and Aharonson, JGR, 2005. [5] Aharonson and Schorghofer, JGR, 2006. [6] Chamberlain and Boynton, JGR, 2007. [7] Schorghofer, Nature, 2007. [8] Boynton et al., Science, 2002. [9] Feldman et al., Science, 2002. [10] Mitrofanov et al., Science, 2002. [11] Feldman et al., JGR, 2005. [12] Smith, Icarus, 2004. [13] Fouchet et al., Icarus, 2007. [14] Squyres and Carr, Science, 1986. [15] Holt et al., Science, 2008.