THE DEPTH OF ICE INSIDE THE SMALLEST COLD-TRAPS ON MERCURY: IMPLICATIONS ON AGE AND ORIGIN

L. Rubanenko[1], E. Mazarico[2], G. A. Neumann[2] and D. A. Paige[1], [1]Department of Earth, Planetary and Space Sciences, UCLA, LA, CA 90095, [2]NASA Goddard Space Flight Center, Greenbelt, MD, USA (liorr@ucla.edu)

Introduction: Volatiles may be trapped inside permanently shadowed regions (PSRs) cast by topographic features near the poles of Mercury [1, 14, 20]. Evidence for the presence of water ice inside these cold-traps was remotely sensed in RADAR [9], reflectance [12] and visible imagery [3]. More recently, evidence for the presence of ice inside smaller craters (~ 1 km) and micro cold-traps ($1-10$ m) was found using data obtained by the Mercury Laser Altimeter (MLA) [6, 16]. Here we constrain the thickness of these small deposits in order to learn about their age and deposition method. We consider two types of topographic features: small craters ($3-15$ km) and micro cold-traps ($1-10$ m) cast by the unresolved topography.

Measuring the Ice Depth Inside Small Craters: We begin by identifying small, simple craters on the Mercury Dual Imaging System (MDIS) global basemap. Then, we measure the crater elevation along a south-north profile on the gridded MLA polar map. Overall we measured 1003 craters between latitudes $75°-86°$, where the most reliable MLA data is found. Figure 1 shows the craters depth/diameter (d/D) distribution on Mercury decreases between latitudes $75°-78°$ (where ice should not accumulate according to thermal models) and latitudes $83°-86°$ (where ice should accumulate), as shallower craters replace deeper craters. The mean d/D decreases from 0.106 ± 0.036 in latitudes $75°-78°$ to 0.086 ± 0.034 in latitudes $83°-86°$. As the mean crater depth in low latitudes is ~ 400 m, this decrease implies a mean infill of order $10-100$ m.

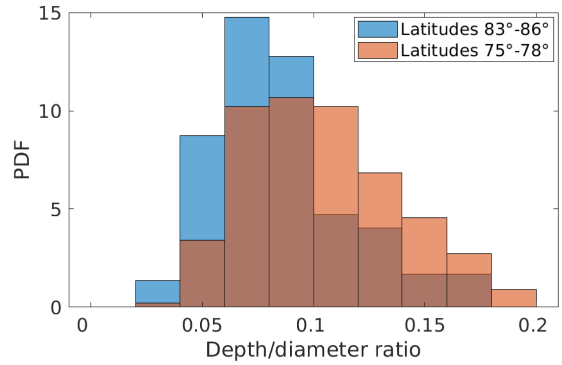

Figure 1: The d/D distribution in two latitude rings. Craters become shallower in high latitudes, where ice is expected.

Constraining the Ice Depth Inside Micro Cold-Traps: Micro cold-traps form in permanent shadows cast by small, often unresolved, topographic features. A common way to describe the topography at these scales is to use random Gaussian surfaces [e.g. 2, 5, 8, 10, 19]. This artificial realization has a Gaussian slope distribution and a power-law power spectrum. The degree of roughness is given by the slope RMS at the slope scale, σ_s. Higher σ_s corresponds to smaller lateral scales; the slope distribution on scales > 1 km has $\sigma_s \sim 5°$, while the slope distribution on scales $\sim 1-100$ m has a higher $\sigma_s \sim 20°-10°$ [2, 15]. To first order, the thickness of ice inside a cold-trap is limited by the depth of the *permanent shadow volume* (PSV) it occupies. To calculate the PSV depth we employ a 3-D illumination model [17]. First, we find the transient shadow depth; the vertical distance between the surface and the shadow that covers it. Then, we calculate the depth of the permanent shadow by finding the temporal minimum of this shadow. We demonstrate the shape of these PSVs in Figure 2 (a), which shows a cross section through the topography (black line) along with the modeled maximum possible ice depth (blue line). Models predict the scale of ice deposits in micro cold-traps on Mercury is $1-10$ m ($\sigma_s = 20-15°$) [16, 18]. As an example, we show the shadow depth CDF of a random surface with $\sigma_s = 20°$ (Figure 2). We find the maximum median ice thickness covering this surface to be a few decimeters.

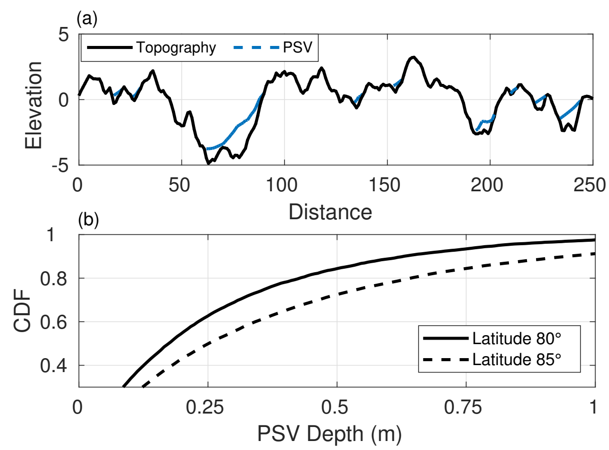

Figure 2: The maximum possible ice thickness inside micro cold-traps on Mercury modeled on a rough random surface with $\sigma_s = 20°$ (lateral scale ~ 1 m).

Discussion: Above we showed small craters near the pole of Mercury become shallower with latitude. If this infill is due to accumulation of ice, we estimate its thickness to be $10-100$ m. This implies a net delivery rate of a few meters per Ga, in accord with previous theoretical [11, 13] and observational [7] estimates. Recently it was shown ice may be trapped inside micro cold-traps on scales $1-10$ m [16]. We may constrain the maximum thickness of these deposits to be a few decimeters. At these scales, impact erosion is expected to dominate over accumulation [4]. However, the fact these deposits are still present leads us to believe they were latterly emplaced. Recent impact models suggest the turnover rate in the first few decimeters is $10^{-6}-10^{-7}$ yr^{-1} [4]. If these models are correct, we can constrain the age of these deposits to be $\sim 10^7$ years, comparable to modeled comet impact rate [11].

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