MODELING THE DEPTH TO THE BASE OF LUNAR H₂O AND CO₂ VOLATILE STABILITY ZONES. H. A. Danque¹ and K. M. Cannon¹, ¹Colorado School of Mines, Golden, CO, USA. hdanque@mines.edu

Introduction: Volatiles in lunar polar cold traps are of interest for science and are targets for potential In-Situ Resource Utilization (ISRU). Current research is generally focused on identifying the presence of volatiles and in defining their spatial extent [1, 2]. There is a body of work examining the depth to the top of volatile stability zones [3, 4]. However, more research is needed to define the depth to the base of volatile stability zones for water and other volatiles identified in the LCROSS mission [5]. The depth to the base of a given volatile’s stability zone will change with a crater’s size and infill history.

The water ice stability zone exists where regolith surface temperatures are below ~110 K [6], or where regolith subsurface temperatures are below ~145 K [4, 7]. The CO₂ stability zone has a upper temperature of ~50 K [6]. Volatiles may exist in lunar regolith as discrete grains of ice, adsorbed onto regolith grains, or as layers of relatively pure ice [8].

This work explores a hypothesis that volatiles may sublimate from the base of cold traps where lunar heat flow destabilizes buried icy volatile mixtures. The sublimated volatiles may redeposit near the base of each volatile’s stability zone. This process may concentrate volatile species at predictable depths that correspond to a particular volatile’s subsurface stability temperatures. This mechanism of volatile separation would be akin to a natural fractional distillation process using the processes of cryogenic sublimation and redeposition.

Methods: Here, we calculate two-dimensional (2D) thermal models of regolith and icy regolith mixtures to define shapes of volatile stability zones under PSR cold traps. We use the finite element solver in the Python Library for Inversion and Modelling in Geophysics (pyGIMLi) [9]; thermophysical properties of lunar regolith, megaregolith, and water ice along with a range of boundary conditions. We develop synthetic crater profiles, modify them based on topographic diffusion rates, and examine the thermal effects of infill [10]. We choose an upper boundary condition for the model outside the cold trap of 160 K, which is the average temperature at 1 m depth for latitudes of ~75 degrees [11]. The upper boundary condition of water ice models is 110 K [6], and for CO₂ it is 50 K [12]. The lower boundary condition depends on the subsurface heat flux from the mantle and crustal radioactive sources [13]. The representative regolith thermal conductivity is 0.023 W m⁻¹ K⁻¹ [14], and megaregolith thermal conductivity is 0.2 W m⁻¹ K⁻¹ and the heat flux is .018 W m⁻² [15]. We calculated a thermal gradient of 0.09 K/m for the lower boundary condition from the heat flux and the megaregolith thermal conductivity assuming linearity in the model space. The low-temperature regolith heat capacity function is from [15]. The regolith density function is from [13].

Results: We model a lunar crater with a 1.5 km diameter and calculate 2D temperature profiles (Figures 1-4). Most of the model space has properties consistent with a megaregolith layer that extends from the base of surficial regolith at ~5-20 meters to 2-3 kilometers below the surface [16].

The initial model is a 3.5 Ga old impact crater shortly after reaching thermal equilibrium. It has a PSR temperature of 110 K and a thick volatile stability zone because of the relatively high thermal conductivity of megaregolith (Fig. 1).

With a PSR temperature of 50 K the water stability zone is much larger and extends under the adjacent illuminated regions (Fig. 2).

The crater model is filled with regolith to a thickness consistent with topographic diffusion until the present. The low thermal conductivity regolith infill acts as a blanket to elevate temperatures below the crater. The
new base of water ice stability is at or above the original surface of the crater (Fig. 3).

Figure 3. Filled crater with PSR temperature of 110 K.

If low concentrations of ice exists in the regolith fill, it could be sublimated from the base of the fill zone at or above the original crater floor. Cold trapping temperature conditions exist for volatiles to redeposit and accumulate at depths corresponding to each volatile’s subsurface stability temperature. This work assumes the volatiles behave independently during sublimation and deposition. The base of CO2 ice stability will be at a shallower depth than the water ice stability depth (Fig. 4).

Figure 4. Filled crater with PSR temperature of 50 K.

Discussion: The model results support the hypothesis that an icy regolith mixture has the potential to sublimate from the base of stability zones in craters that have significant infill. The models indicate that the base of the stability zones become shallower than the original crater surface, volatiles may remobilize and redeposit. With “warmer” PSRs H2O would potentially remobilize in craters of a size for efficient topographic diffusion and ~3.5 Ga years or more of infill (Fig. 3).

Where a PSR is cold enough to trap CO2 it may offset the blanketing effects of regolith and prevent water ice from remobilizing (Fig. 4). However, CO2 and other volatiles with similar stability temperatures may be sublimated from the regolith fill between the original crater floor and base of stability in the infilled crater.

Conclusion: This work examines a hypothesis for subsurface volatiles have the potential to remobilize to predictable depths. This will modify subsurface volatile concentration by reducing the concentration in sublimation zones and increasing the concentration in redeposition zones. This work proposes a natural cryogenic volatile distillation process in craters with significant regolith infill and sufficient time to allow sublimation and deposition to modify volatile concentrations.

Acknowledgments: We are grateful to Caleb Fassett for conversations that allowed appropriately diffused topography to fill synthetic craters.

References: