A THERMAL MODEL AND THE HERMEAN HOLLOWS: CONSTRAINTS ON PLAUSIBLE VOLATILES INVOLVED IN HOLLOW FORMATION ON MERCURY. M.S. Phillips¹, J. E. Moersch¹, ¹Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996-1526 (mphill58@vols.utk.edu).

Introduction: Mercury hosts features unique in the solar system that were first observed in Mariner 10 images and described as bright crater floor deposits [BCFDs, 1]. Images from the MESercury Surface, Space Environmet, GEOFchemistry, and Ranging (MESSENGER) spacecraft have revealed that BCFDs are sub-kilometer-scale, flat-floored, rimless depressions with typical depths of 40-50 m and an average areal extent of 129 km² [2]. These features have become known as hollows to distinguish them from morphologically similar structures such as pyroclastic vents and pits related to collapse due to magma evacuation from a near-surface chamber [2, 3].

Background: Hollows are nearly global in extent, though some spatial variability has been noted. They are more extensive at equatorial latitudes and on slopes with equatorial aspects than at higher latitudes and on slopes with anti-equatorial aspects [2]. The apparent preference of hollows to form at equatorial latitudes and on slopes with equatorial aspects suggests a thermal control on formation, and that may be a temperature-related curbing of hollow formation at high latitudes. The apparent dependence on temperature combined with the morphology of hollows has led previous workers to suggest that hollows form via sublimation.

It was posited [3, 4] that the hollow-forming volatile is likely sourced from a hermean surface unit called low reflectance material (LRM) because hollows almost exclusively form in this unit [96%, 2, 5]. It was further noted [4] that sulfur or sulfides are likely candidate materials because of the volatility and high abundance of sulfur on Mercury [6, 7]. The suggestion that sulfides play a role in hollow formation has also been made by several other workers [2, 5, 8-11].

Here, we consider the stability of plausible hollow-forming volatiles at subsurface and surface temperatures at different latitudes and longitudes using a thermophysical model to infer the stability of volatiles as a function of depth, time, and latitude.

Methods: There have been several thermophysical models of Mercury formulated in past studies [e.g., 12, 13-16]. Similar to past models, we consider heat conduction in the vertical dimension, and use the 1D time-dependent heat equation [17]:

\[ \frac{\partial \rho}{\partial t} = \frac{k}{\rho c_p} \frac{\partial^2 T}{\partial z^2} \]

Eq. 1

Where \( \rho \) is density, \( c_p \) is the specific heat capacity, and \( k \) is the effective thermal conductivity.

We allow \( \rho \) to vary with depth \( z \), \( c_p \) to vary with temperature \( T \), and \( k \) to vary with \( z \) and \( T \). Our resultant temperature profiles were used to calculate sublimation rates of various volatiles (Fig. 1, horizontal-axis) with the Hertz-Knudsen equation:

\[ N_i = P_e \left( \frac{2 \pi \mu K T}{\pi \mu K T} \right)^{1/2} \]

Eq. 2

Where \( N_i \) is the number of molecules of volatile \( i \) sublimated per square meter per second; \( \mu \) is the mass of volatile \( i \) (in kg); \( K \) is Boltzmann’s constant (m² kg s⁻² K⁻¹); \( T \) is the temperature (in K); and \( P_e \) is the temperature-dependent vapor pressure (in Pa).

Results: We find most volatiles would be unstable at hermean subsurface temperatures over the age of the planet (Fig. 1). However, sulfur, sulfides, and fullerenes (hollow molecules of carbon that form a tube or closed mesh) would be stable in the subsurface but unstable at daytime surface/near-surface temperatures. Of these volatiles, we suggest that sulfides (with a possible contribution from fullerenes) are most likely responsible for hollow formation for the following reasons:

1) The high association of hollows with both craters and the LRM suggests that both are necessary for hollow formation. Sulfides (and fullerenes) require temperatures somewhat higher than Mercury’s daytime surface temperatures to account for thermal decomposition (or sublimation) at a rate fast enough to account for the size of typical hollows. Temperatures achieved adjacent to magma bodies or impact generated melt could decompose sulfides at a rate sufficient to generate hollows (Fig. 2). 2) Hollowing is more common and extensive within craters than in their proximal ejecta, consistent with areas that would experience the most post-impact heating. 3) Sulfur is more unstable than sulfides at ambient subsurface temperatures, so it is less plausible that a global hollow-sourcing layer of sulfur was maintained over Mercury’s geologic history than a sulfide hollow-sourcing layer. 4) Non-crater-related hollows are typically associated with other heat sources, e.g., lava flows and pyroclastic deposits, further suggesting that some additional heat source is necessary for hollowing. 5) Sulfides (and fullerenes) have a plausible geochemical and spatial association with Mercury’s LRM. 6) Sulfide spectral characteristics are more consistent with spectroscopic observations of hollows than sulfur [5, 9]. 7) Ca (and Na) in Mercury’s exosphere have a conceivable link to hollows [18].
Our conceptual model for hollow formation is presented in Figure 3.


Figure 1: The stability of volatiles on the surface and subsurface of Mercury at the warm pole. Colors correspond to the compound classes in table 4. Note that sulfides are represented by their cation because these are the rate limiting factors in the thermal decomposition reaction. a) Time in years it would take to sublimate (or thermally decompose) each substance to a depth of 50 m. Lines are drawn at 1 yr, 1 Ka, 1 Ma, 1 Ga, and 4.6 Ga to facilitate interpretation. The circle marker represents latitude 55°N, the upper bar is 78°N, and the lower bar is 0°N. At 78°N sulfur would sublimate at ~50 m Ga⁻¹. At the equator Na₂S would take ~3 Ga to sublimate to a depth of 50 m. b) At the equator Na₂S would take ~3 Ga to sublimate to a depth of 50 m.

Figure 2: Time in years it would take to sublimate (or thermally decompose) fullerenes and sulfides to a depth of 50 m at various constant temperatures in K. Temperatures shown by numbers left of the curves, increasing in increments of 100 K. For example, at 900 K, Na₂S and C60 could create a 50-meter-deep hollow in < 400 Ka.

Figure 3: Model for hollow formation. 1) Primary graphite crust, space weathered to produce fullerenes, is underlain by a buoyant sulfide-rich layer. 2) Layers are mixed via impact gardening and rapidly buried by secondary crust production. 3) LRM is excavated by impacts and hollowing occurs through thermal decomposition of sulfides (and perhaps some contribution from sublimation of fullerenes) in the locally elevated thermal environment (indicated by light-toned gradients below crater). 4) Growth of hollows continues through solar heating after impact area has cooled, imparting a latitudinal dependence on the areal extent of individual hollows.