A Thermal Model and the Hermean Hollows: Constraints on Plausible Volatiles Involved in Hollow Formation on Mercury

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November 21, 2022

Abstract

We propose a thermal-fluid system model for hollow formation. A subsurface heat source (typically impact-related) produces volatiles from LRM and drives them to the surface. Volatiles generated through heating of LRM are likely S and S-bearing gases produced by thermal decomposition of sulfides heated by the impact process. C-bearing volatiles, such as CH4 and other simple organics, and potentially fullerenes within LRM, may also be involved in proposed thermal-fluid systems responsible for hollow formation.

A Thermal-Fluid System Model for Hermean Hollow Formation

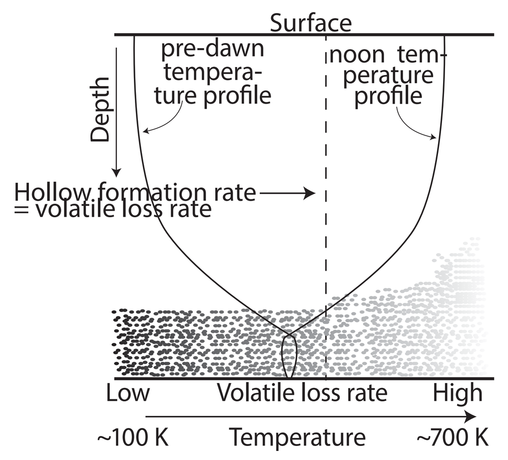
Introduction

- On Mercury, flat-floored depressions called hollows are observed nearly globally [1].
  - 97% of hollows are associated w/ impact craters.
  - 96% are within low reflectance material (LRM).
- Published models for hollow formation [1, 2]:
  - impacts exhume a buried volatile-rich layer
  - volatiles sublimates upon exhumation
  - growth ceases when insulating lag develops.

Hypotheses

H0: No volatile exists that is unstable at hermean surface/near-surface temperatures and stable under a lag deposit.

HA: Some such volatile exists that is unstable at hermean surface/near-surface temperatures and stable under a lag deposit.



Methods

- Calculate the loss rates of volatiles at subsurface and surface temperatures at different latitudes and longitudes on Mercury.

$$E_i = P_v \left(\frac{\mu_i}{2\pi RT}\right)^{\frac{1}{2}}$$

- Input temperatures derived from a thermal model.

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

Results

- Only elemental sulfur (S) and stearic acid (C18H36O2) have the appropriate characteristics to explain hollow formation in the published model framework in which a volatile-rich layer is exhumed and sequestered beneath an insulating lag deposit.
- Temperatures generated by impacts are sufficient to decompose sulfides quickly enough to account for hollow formation.

Discussion

We reject the published model framework for hollow formation on the grounds that development of a global or near-global S- or $C_{18}H_{36}O_2$-rich layer does not seem plausible. Other models for hollows, such as sulfide slag models, do not predict S or C18H36O2 as the hollow-forming volatile.

We propose a thermal-fluid system model for hollow formation.

- A subsurface heat source (typically impact-related) produces volatiles from LRM and drives them to the surface.
- Volatiles generated through heating of LRM are likely S and S-bearing gases produced by thermal decomposition of sulfides heated by the impact process.
- C-bearing volatiles, such as CH4 and other simple organics [3], and potentially fullerenes within LRM, may also be involved in proposed thermal-fluid systems responsible for hollow formation.

Conclusions

- Elemental sulfur (S) and stearic acid ($C_{18}H_{36}O_2$) would sublimate on the surface of Mercury at a sufficient rate to account for hollow formation and are capable of being sequestered under an insulating lag.
- Solar heating cannot decompose sulfides at rates sufficient to account for hollow formation.
- Temperatures achieved adjacent to magma bodies or impact generated melt could decompose Na2S at a rate sufficient to generate hollows, even at a depth of 1 km. MgS and CaS would decompose at lower rates, but could still contribute to hollow formation, especially immediately following an impact when temperatures are highest.

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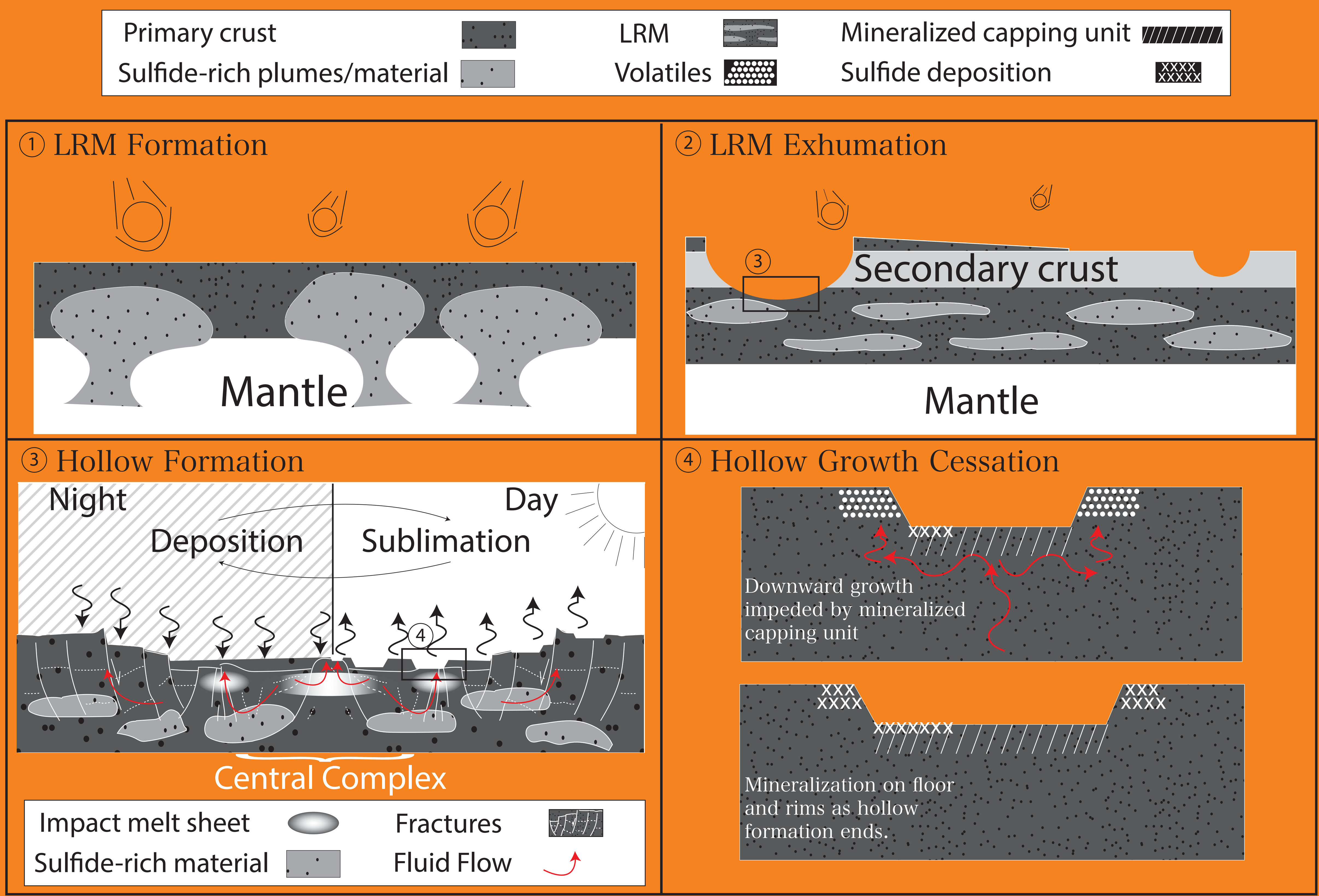
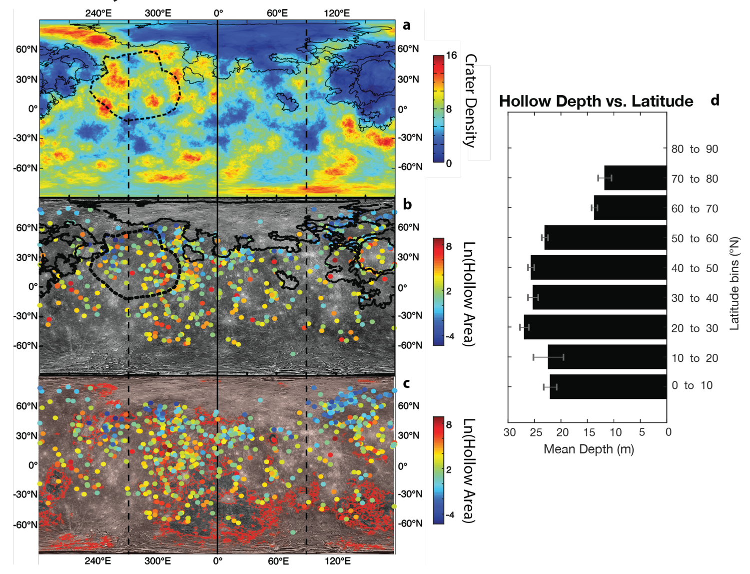
Hollow formation on Mercury cannot be explained by solar heating of sulfides. **Sulfides** can only be **responsible for hollow formation** if a **subsurface heat source** contributes to sulfide decomposition.



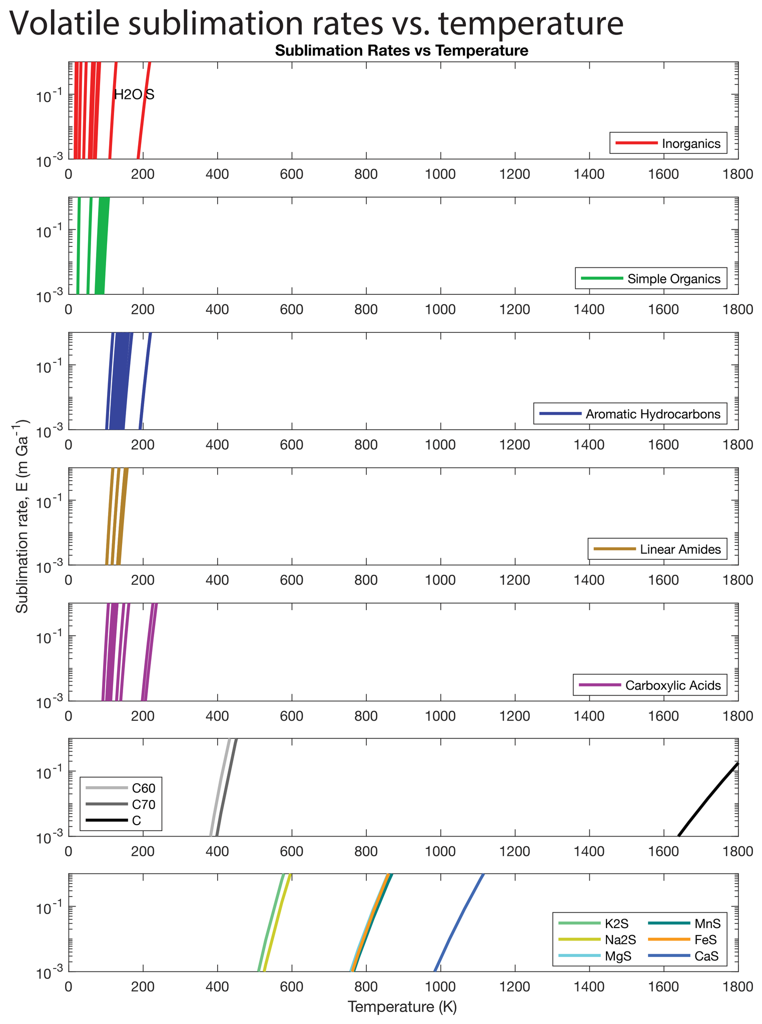
Link to abstract

Supporting Information and Figures

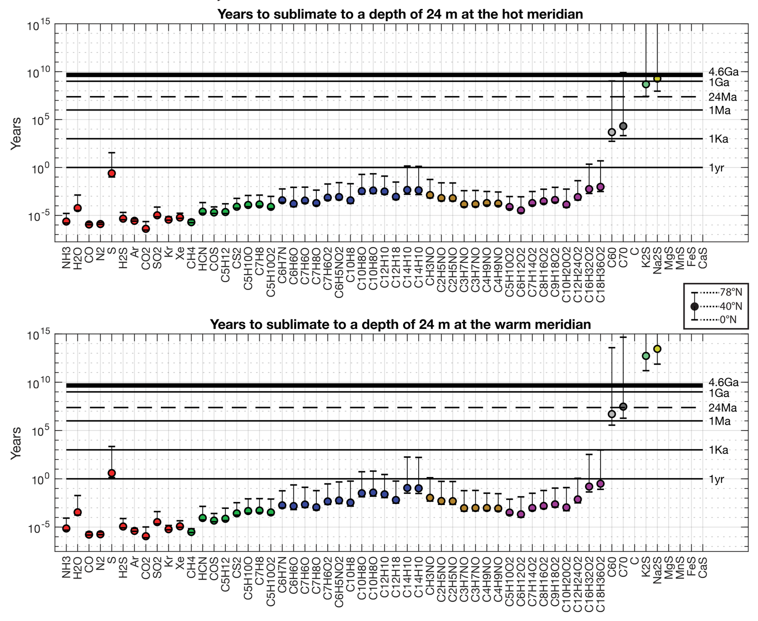
Distribution, areal extent, and depth of hollows on Mercury.



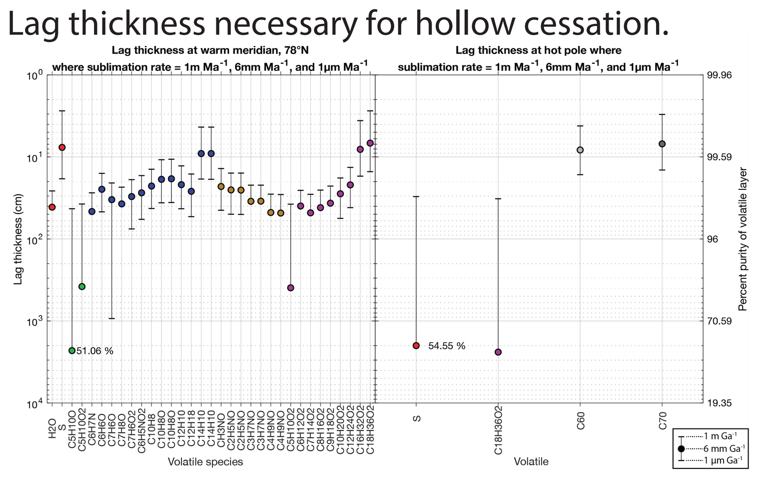
Volatile sublimation rates vs. temperature



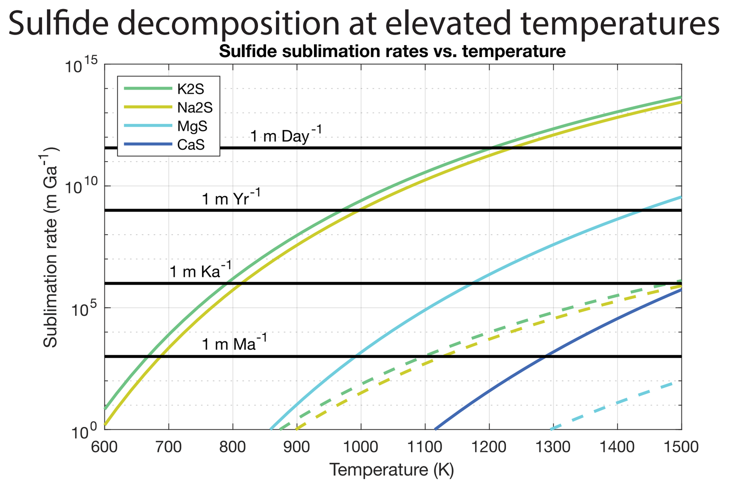
Time necessary for hollow formation.



Lag thickness necessary for hollow cessation.



Sulfide decomposition at elevated temperatures



References:

[1] Thomas, R.J., et al. (2014) *Icarus*. **[2]** Blewett, D.T., et al. (2013) *JGR: Planets*. **[3]** Blewett, D.T., et al. (2013) *JGR: Planets*.