Constraint on Hollow Formation from Reflectance Spectra. Yichen Wang[1] and Zhiyong Xiao[2], [1] School of Earth Science, China University of Geosciences (Wuhan)(ycwang@cug.edu.cn; xiaozhiyong@mail.sysu.edu.cn); [2] Planetary Environmental and Astrobiological Research Laboratory, School of Atmospheric Sciences, Sun Yet-Sen University.

Introduction: Hollows are irregularly-shaped small rimless shallow depressions on Mercury that are usually associated with high-reflectance haloes (Figure 1A) [1,2,3]. Hollows are likely formed by loss of volatile-bearing phase in surface materials via possibly sublimation process, and they are possibly still activate [3,4,5]. Hollows are a key window to understand the composition and evolution of volatiles in Mercury, which hold important information about the origin and evolution of Mercury.

It is still unclear about how volatiles are lost to form hollows, and the locations where volatiles begin to loss are not resolved. The negative topography of hollows are caused by the volatile loss (Figure 1A), as gravitational unstable in the wall induce further collapse, recede, and lateral growth of hollow walls. High-resolution images of hollows show the spatial relationship between the interpreted embryo hollows and fully-developed hollows (yellow arrows in Figure 1), indicating that hollows start to form as small depressions and continual volatile loss formed the large hollows that have flat floors [3,4,6]. Therefore, the embryo hollows are active surfaces where volatiles are lost.

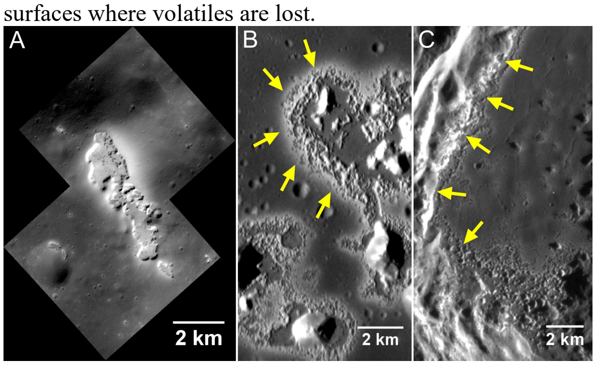

Figure 1. Growth direction of hollows. (a) High-resolution image of a hollow at 115.36°E, 43.05°N showing remnants of the collapsed hollow-wall on the high-reflectance hollow floor (EN1058851700 and EN1058851701M, 9.1 m/pixel). (b) Hollows around the central peak of the Eminescu crater. The large central hollows have flat floors, and they are boarded with smaller depressions that are located in the center of the high-reflectance haloes (yellow arrows). The base image is from EN0221282712M. (c) Hollows along the border of the crater wall and floor of the Balanchine crater. Embryo hollows are visible towards the center of the crater, while large hollows with flat floors are located close to the foot of the crater wall (yellow arrows). The base image is from EN1022827014M.

There is no consensus in previous studies about the possible nature of volatiles that formed the hollows. Hollows are uniformly formed in low-reflectance materials on Mercury, a terrain that is enriched in both C and S as constrained by the XRS and NRS of the MESSENGER mission. However, both certain sulfides [1,5,7] and C were interpreted as the source volatiles. Reflectance spectral data in visible-to-near-infrared wavelengths are used to deduce the nature of the volatiles, but different results in terms of possible absorption features were noticed. Blewett et al. [1,2] and Vilas et al. [5] extracted reflectance spectral data for entire hollows (i.e., both halos and floors) and suggested that the volatile substances should be sulfides based on the sulfide-like shallow absorption feature at 500–600 µm. Assuming the possible absorption features at 500–600 nm on Mercury is caused by Cas and MgS, Thomas et al. [6] performed correlated study of reflectance spectral data with high-resolution monochrome images to investigate the possible reflectance spectra of different parts of hollows, and they believed that the volatile species lost from the hollow floor should be MgS and CaS. Referring to the study of Murchie et al. [8], Blewett et al. [3] further proposed that graphite could be the volatile candidate, ascribing the 500–600 µm absorption feature to carbon. Lucchetti et al. [9] studied the reflectance spectra for three hollows and noticed a possible absorption feature at ~750 nm, suggesting that sulfides alone cannot explain the spectrum behavior of hollows. Comparing with reflectance spectra of standard minerals suggest that bedrock-forming minerals, such as pyroxenes, should be responsible of the ~750 nm absorption feature [7].

A fundamental question about the formation mechanism of hollows is the true reflectance spectra of volatiles. The widely-accepted scenario of hollow-formation is volatile loss, and both the bright halos and hollow floor materials should be depleted in volatiles compared to the original source materials. Otherwise, hollows should be continuing growing, which is inconsistent with the constant hollow depths and halo deposition. We attack this paradox by performing detailed observations for different parts of hollows. By assuming different scenarios of volatile content in hollow deposits, our current knowledge of possible volatiles forming hollows are discussed.

Method and data: The Mercury Dual Imaging System (MDIS; [10]) 8-bands and 11-bands WAC data were used for spectra analysis. All high-resolution MDIS NAC data (<10 meter/pixel) were used for perform morphology study. All the data were processed following a standard pipeline using the USGS ISIS3. The K-S model is used for the photometric calibration [11].

We selected 8 craters for spectra extraction, where large expanses of hollows are developed on the crater floors. NAC and WAC data were used together to determine the spectral extraction units. Sub-units for spectra extraction were divided into hollow floor (i.e., HF), crater floor (i.e., CF; surface regolith), halo, and mixed terrains (e.g. both hollow floor and halo are observed).

Results: The reflectance spectra of all the hollow can be classified into two end-members, HF and CF. HF is composed by depleted materials where volatiles are lost due to hollow formation. CF represents regolith developed from host materials that hollows can be formed, i.e., a combination of volatiles and their country rocks. HF has the flattest (bluest) spectral slope, a distinct and deepest 750-nm absorption characteristic (with spectral shoulders at 630 nm and 830 nm), and a downtrend of reflectance at the wavelength larger than 830 nm, e.g., red curves in Figure 2. CF is typical low-reflectance materials on Mercury, the spectra exhibit red slopes and no clear obvious features (Figure 2). Bright Haloes are fine-grained materials [6,12] with no absorption feature, which is essentially the same with that of CF but having a higher reflectance (Figure 2). The spectra of entire hollows that contain both floor and halo show a wide range of differences in terms of both spectral slope and absorption features, which are a combination of the two end-members (CF+HF; Figure 3).

Discussion and Conclusion: Our results suggest that reflectance spectra of hollows extracted in previous works are mixed spectra for the two end-members, (i.e., HF mixed with haloes, or HF mixed with haloes and CF). The reflectance of volatiles cannot be extracted from the surface materials.

Lag deposit on hollow floors can be regarded as degassed bedrocks (i.e., HF here), and the spectral features suggest that they may be composed by pyroxene-bearing debris [9] that are coarser than typical mercurian regolith [12].

Volatiles are not directly lost from either the surface or hollow floor. Morphological study (e.g., Fig. 1) suggests that volatiles may be dispersed from the hollow wall. The small cross-sectional area of hollow wall and low resolution of spectral data prohibits a reliable extraction of the reflectance spectra of the host rocks.

Expose of subsurface volatile-rich materials is required to initiate hollow formation. Our observations show for swarms of hollows on crater floors (e.g., the bright crater floor deposits [1]), cooling fractures in impact melt provide conduits for hollow formation.

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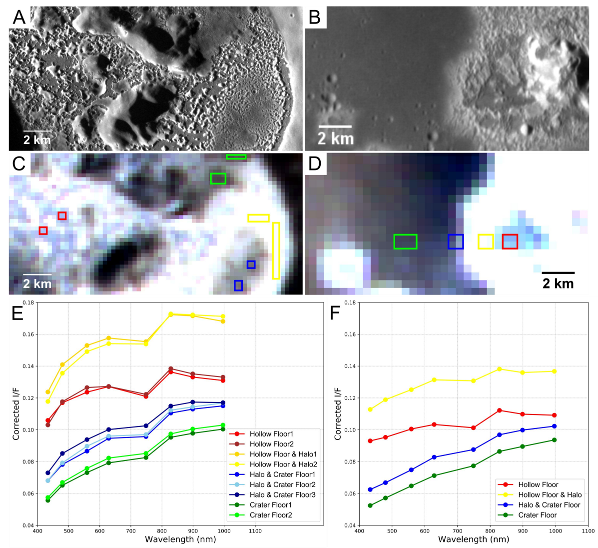

Figure 2. Examples of reflectance spectra for different components of hollows. (a) and (b) are hollows on the floor of the Kertesz and Eminescu craters, respectively. (c) and (d) show locations where reflectance spectra are extracted. The base color mosaics have R=996 nm, G=750 nm, and B=433 nm. Boxes with different colors represent different extraction units (Red: HF; Yellow: HF mixed with haloes; Blue: haloes mixed with CF; Green: CF). (e) and (f) show the reflectance spectra extracted.

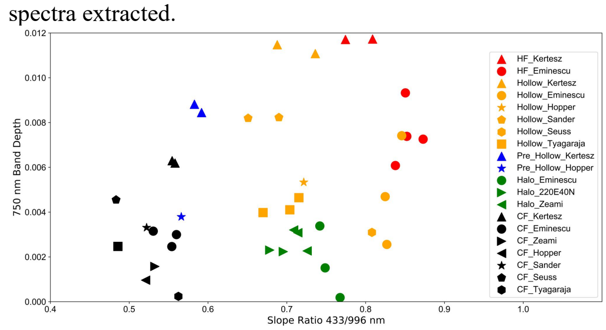

Figure 3. Characteristics of reflectance spectra for different components of hollows. The slope ratios of between reflectance at 433 and 996 nm [13] are plotted in the x-axis; and the absorption depths at 750 nm (distance between the reflectance of 750 nm and the connection of the 630 nm and 830 nm spectral shoulders) are plotted in the y-axis.