Volumes and potential origins of crater dark floor deposits on Venus

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“Why should I care about dark-floored craters on Venus?”

The hypothesis that Venus was mostly resurfaced in a catastrophic volcanic event ~500-750 Mya [1, 2] relies on the observation that only **4%** of Venus’ ~940 craters are clearly **externally embayed** by plains volcanism. Alternatively, **dark floor craters may record** more continuous **volcanic resurfacing** if they are indeed resurfaced by lava flows [1, 3]. Here we **measure the volume of dark floor deposits** for a subset of Venus craters to test whether can be explained by **impact melt** retained within the crater, or if they suggest infilling by **volcanic flows** [4].

Dark floor area measurements

Crater dark floor areas are mapped and measured for 42 dark-floored craters using ENVI 5.5 (Fig. 1). Craters consist of those with central peaks visible in both SAR and DEM, and craters without visible central peaks (Fig. 6). Each dark floor area is mapped 5 times in order to constrain measurement error.

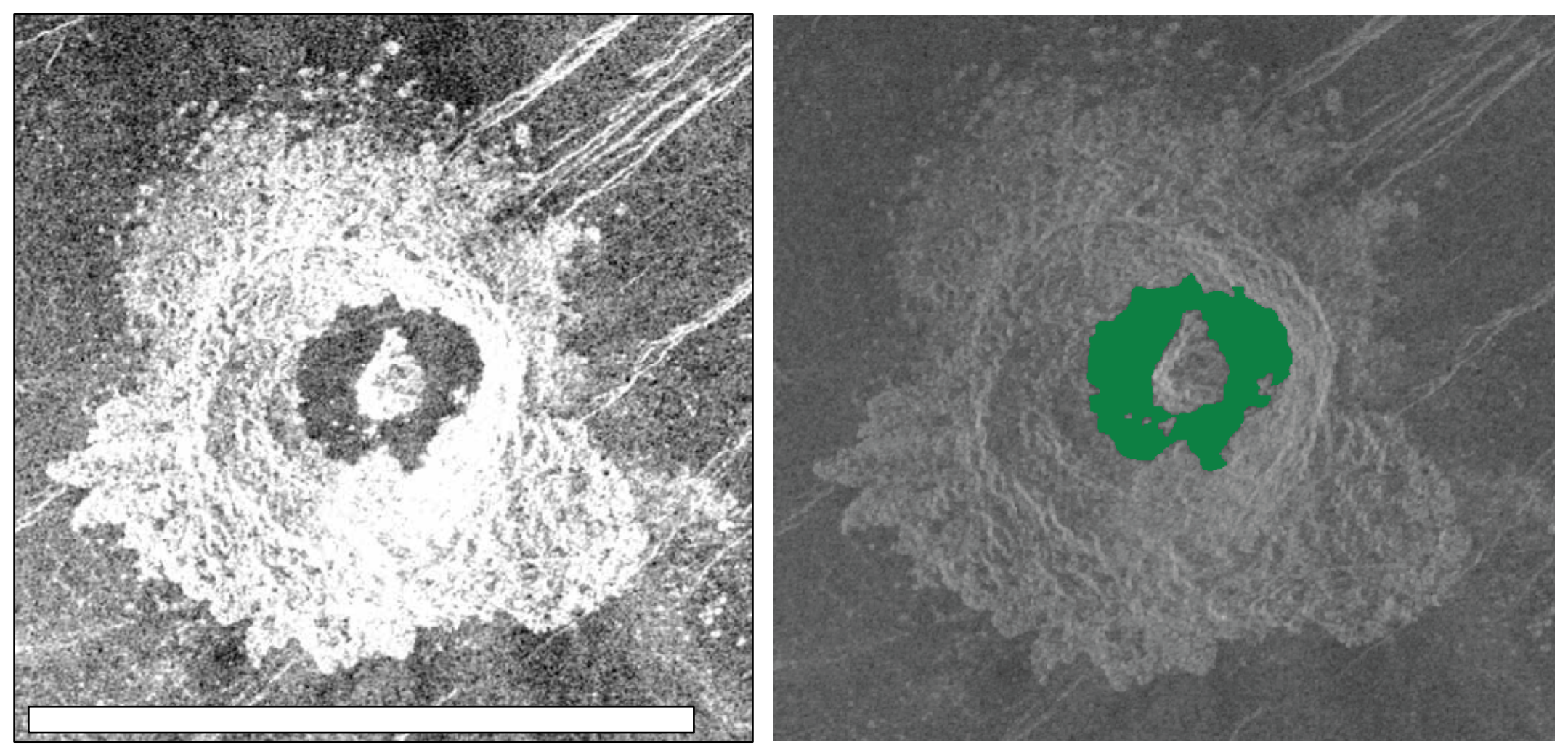

Figure 1: Magellan image of the crater Ma Shouzhen (left), with the dark floor area mapped in green (right). Scale bar on the left image is equal to 50 km.

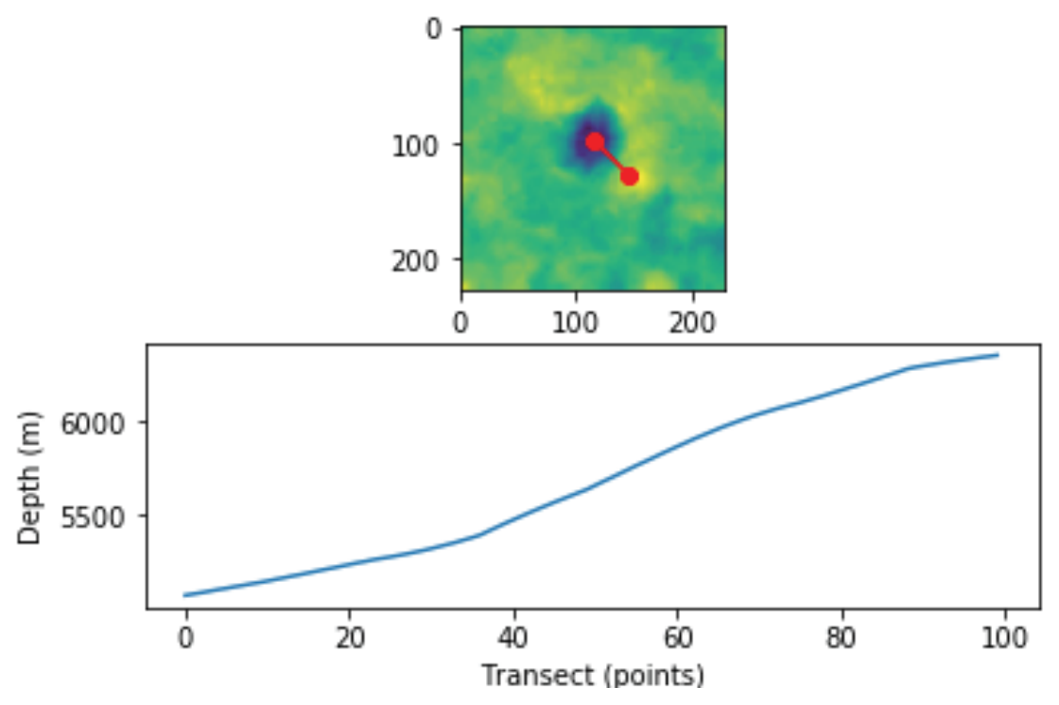

Figure 2: Depth measurement program [5] used to sample crater DEMs [3]. Pictured is the crater Carter.

Morphometric calculations

Crater morphometries are determined from the following sources:

Area measurement: See Fig. 1.

Radial depth measurements: See Fig. 2. Crater rim depths (d_r) and central peak heights (H_{cp}) are obtained through this method.

Empirical power-law functions: Using equations describing relationships observed by [6] and [7], we can utilize power-law functions for parabolic crater depth to estimate dark floor thickness (t), in addition to functions describing crater wall width (Ww) and central peak diameter (D_{cp}).

$$d = 0.4D^{0.3}$$

Equation 1: Power-law function describing crater depth, derived from measurements of 22 bright-floored craters with parabolas. From [6].

$$t = d - d_r$$

Equation 2: Dark floor thickness, produced by subtracting the crater rim depth d_r from the “fresh” crater depth d.

$$V = at$$

Equation 3: Dark floor volume before applying wall and central peak corrections, the product of the average dark floor area, a and the dark floor thickness, t.

Crater geometry corrections: We apply the functions described above to correct for the cross-sectional contribution of crater walls and central peaks, utilizing Ww, D_{cp}, and H_{cp} to obtain wall slope and central peak slope values θ and α (Fig. 3).

Crater cross-sectional geometry

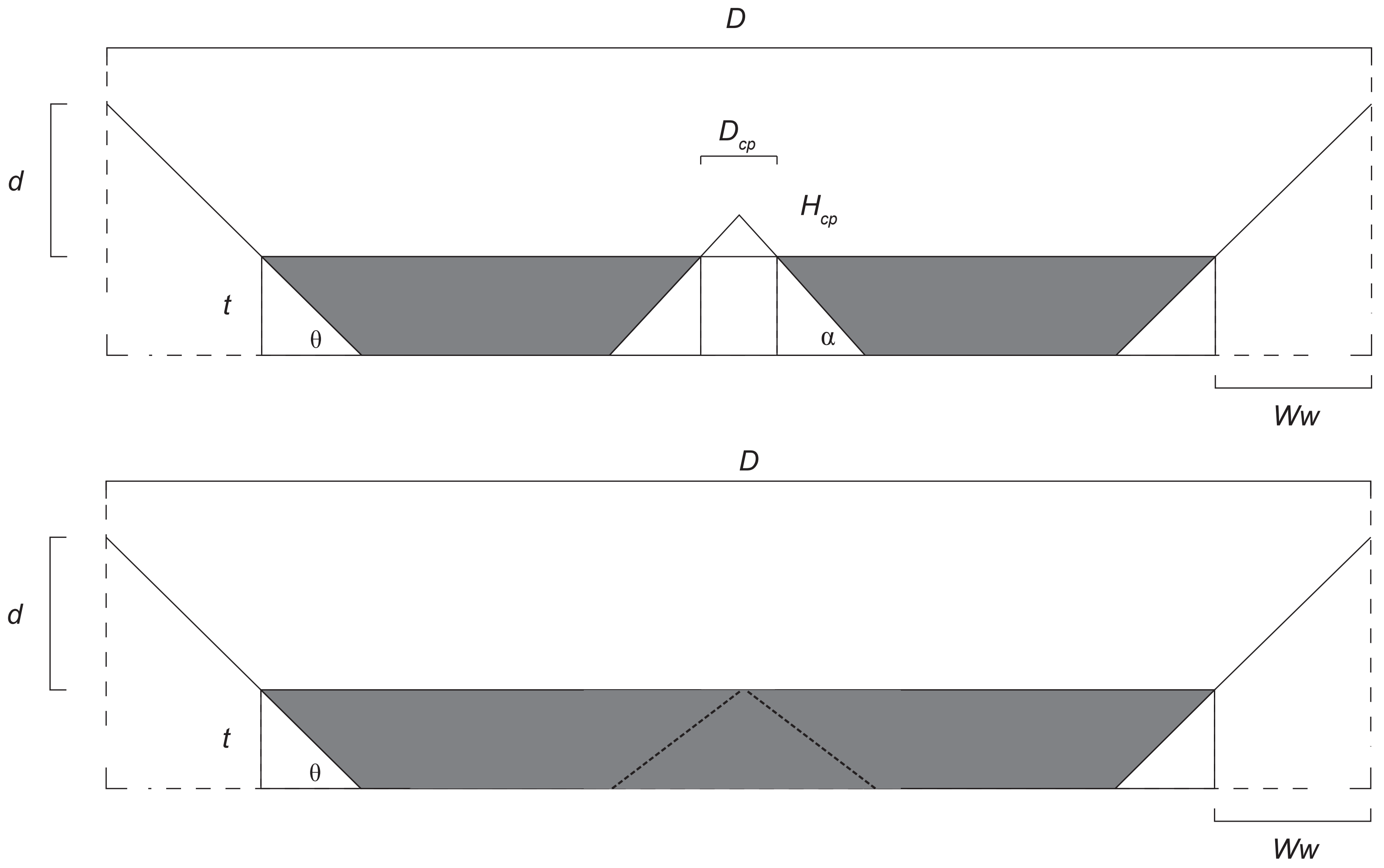

Figure 3: Idealized cross-sectional geometry of craters with observable central peaks (top) and craters without observable central peaks (bottom). For craters without observable central peaks, we make two endmember calculations where central peak heights are either assumed to be zero, or equal to the thickness of the dark floor deposit.

Impact melt volumes

Can impact melt account for the volume of dark-floored craters?

Croft [8] produced empirical functions relating transient crater diameter to the simple-to-complex transition diameter and rim diameter, based on terrestrial and lunar measurements (Fig. 4).

$$D_{tc} = D_Q^{0.15\pm0.4} D_r^{0.85\pm0.4}$$

Equation 4: Crater transient diameter D_{tc}, where D_Q is the simple-to-complex transition diameter, taken to be 3.5 km for Venus. D_r is the measured diameter of the crater. From [8], see Fig. 4.

Grieve and Cintala [9] related the amount of impact melt volume produced to the transient crater diameter, type of impactor, and impactor speed (Eq. 5).

$$V_m = cD_{tc}^{\ d}$$

Equation 5: Relationship of transient crater diameter D_{tc} to the amount of impact melt produced V_m. Constants c and d are dependent on impactor type (chondrite or comet) and impact velocity (15, 25, or 50 km/s), taken from [9].

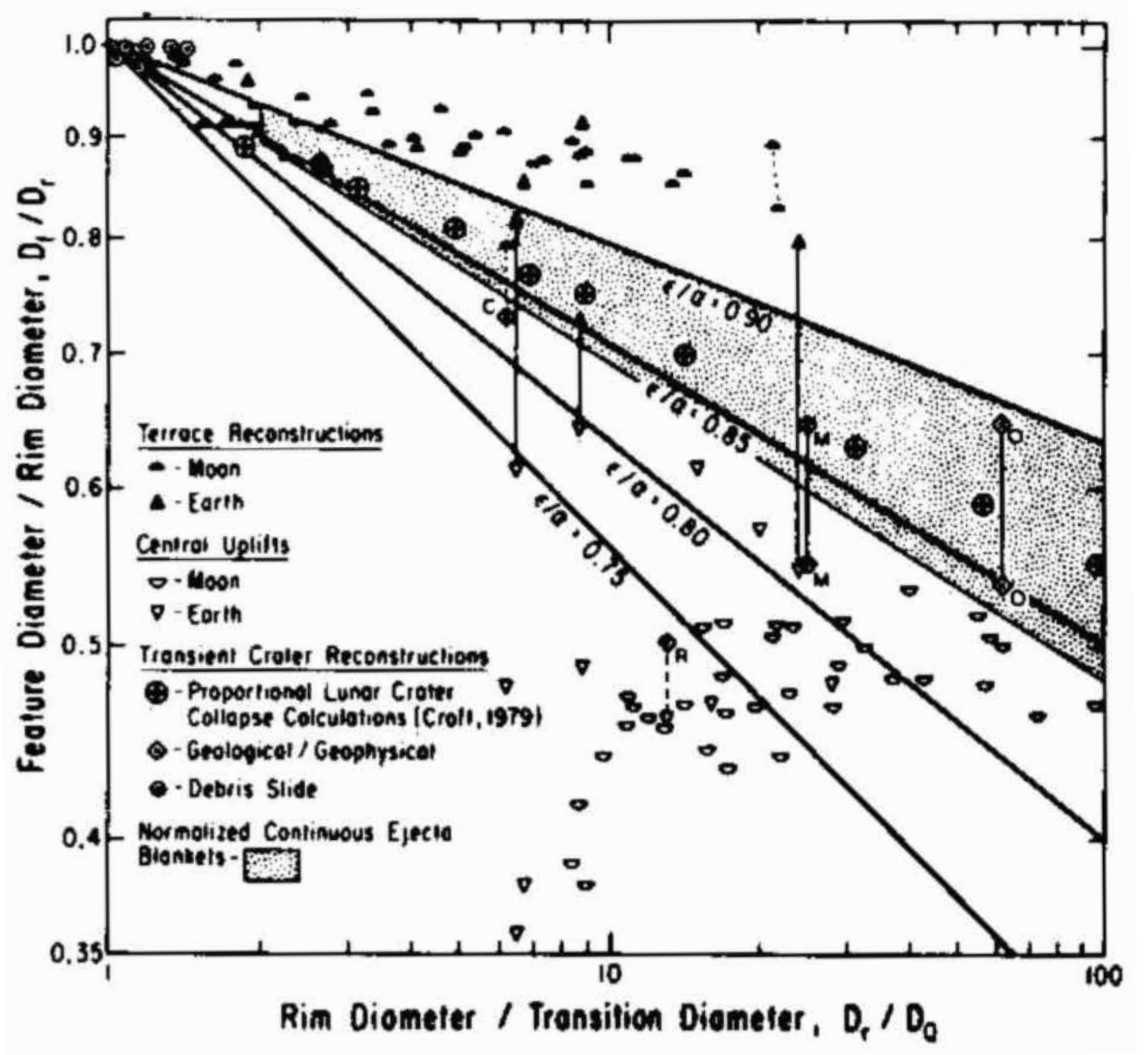

Figure 4: Estimations of transient crater diameter taken from terrestrial and lunar measurements of reconstructed terraces (filled points) and central uplifts (unfilled points). The resulting regression provides values for the mean, minimum, and maximum exponents in Eq. 4. From [8].

Volume error

In order to calculate error from our estimates of dark floor volume, we use an error analysis program written in R to compute a range of volumes for a given crater. The program calculates *n* number of volumes (for the purpose of this analysis, *n* = 1000) for a crater given the mean dark floor area values and standard deviations. Mean values and standard deviations for the wall width, *Ww*, and central peak diameter, D_{cp}, are also utilized in the program. The dark floor deposit thickness *t* is treated as constant for the purpose of the present analysis, but will be amended in future work.

Crater outflows

Impact melt is often observed outside of craters, where it is visible as highly radar-bright, lobate flows. We note other craters that have observable outflows, interpreting them as examples of impact melt exterior to the crater. Dark floor volumes calculated for these craters represent a minimal contribution of impact melt.

For craters with observable central peaks, we note that 16 craters have visible outflows, while 10 craters do not have visible outflows. For craters with no observable central peak, we note that 6 craters have visible outflows, while 10 craters do not have observable outflows.

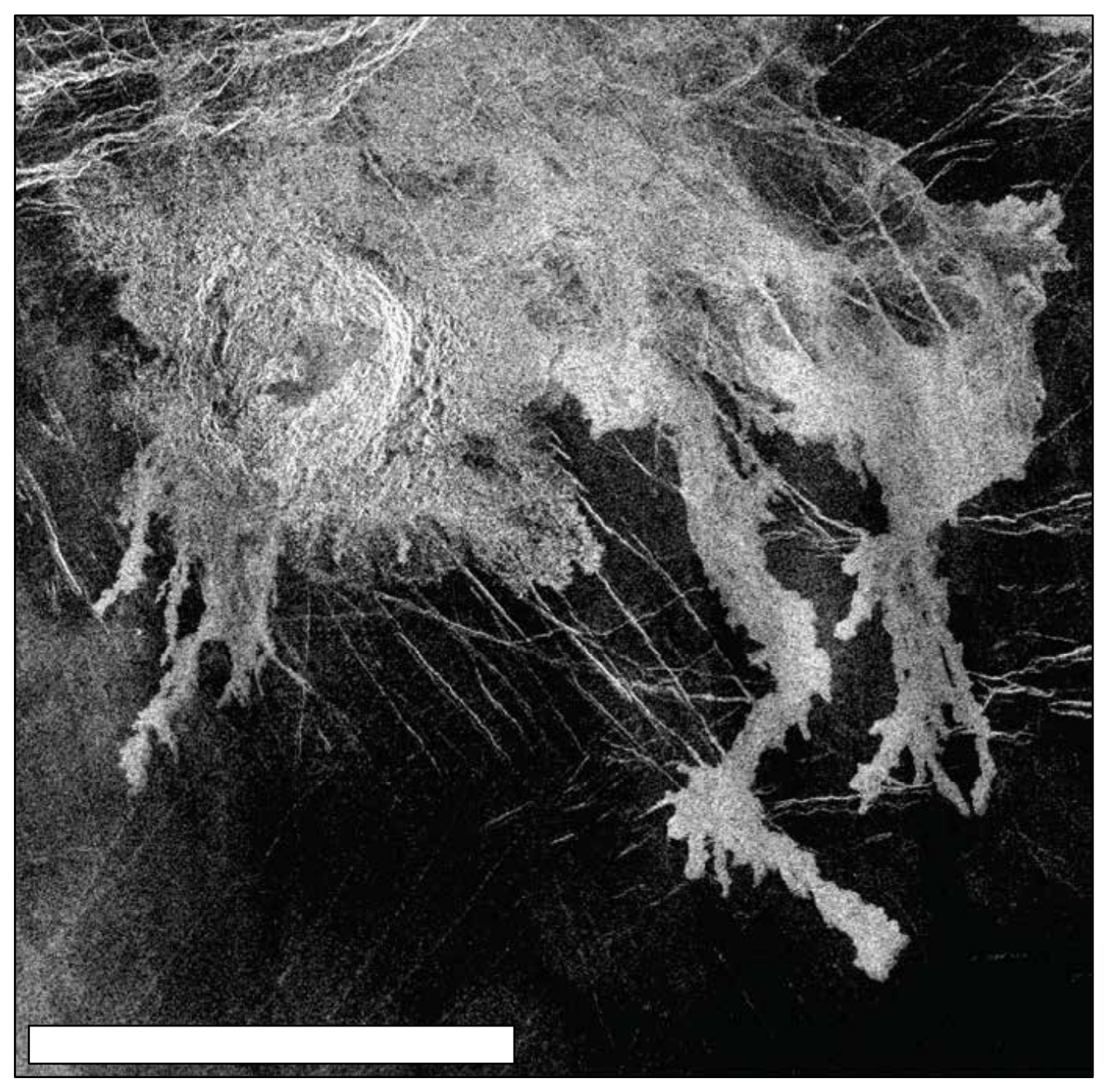

Figure 5: Magellan image of the crater Halle, with outflow visible extending to the SE and NE of the image. Scale bar is equal to 50 km.

Results and Discussion

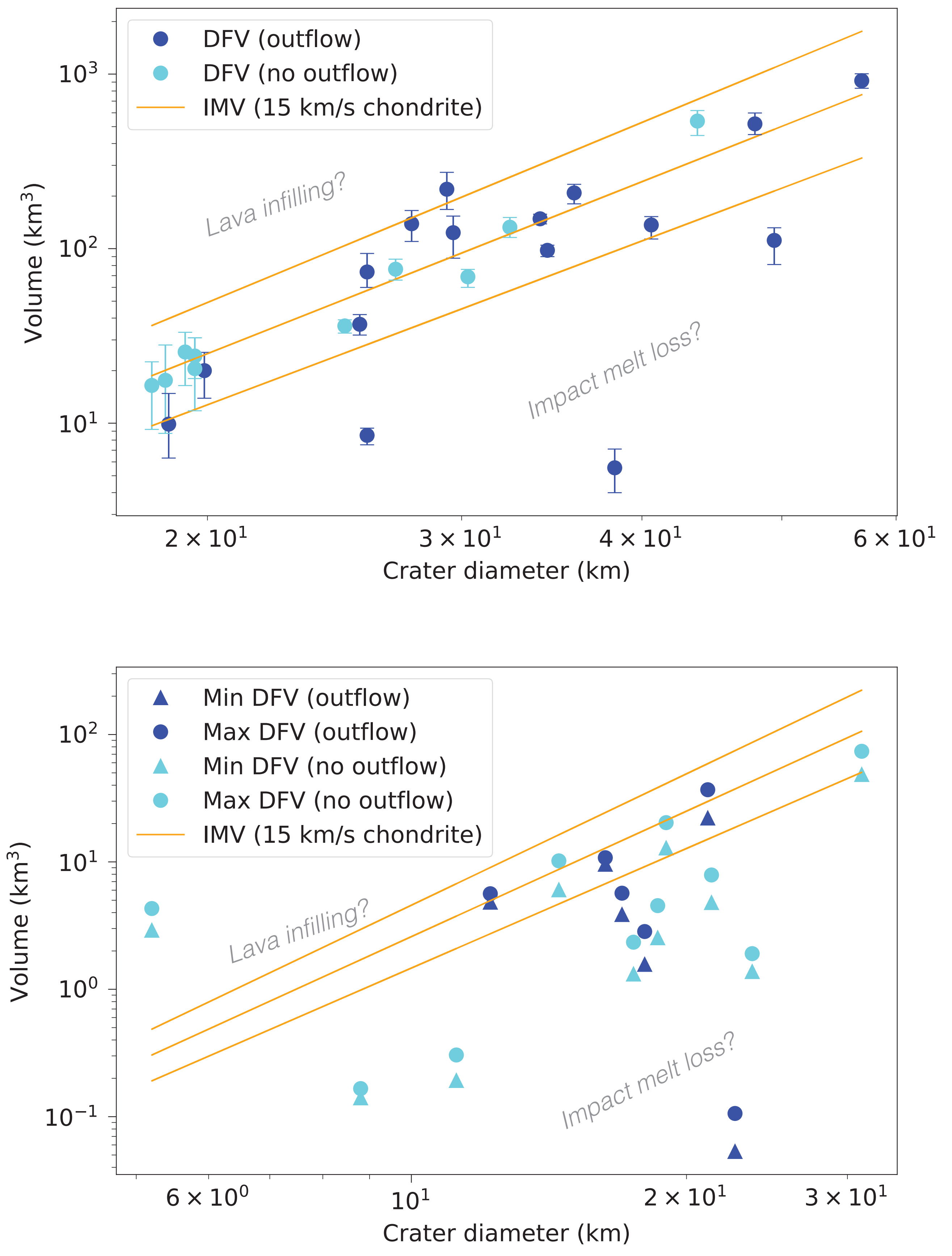

Figure 6: Calculated dark floor deposit volumes for 26 craters with observable central peaks (top) and for 16 craters without observable central peaks (bottom). DFV stands for dark floor volume, IMV stands for impact melt volume calculated using Eq. 5. The middle IMV regression is derived from the mean value of the transient crater diameter from Eq. 4, while the top and bottom regressions are the minimum and maximum exponential values in Eq. 4.

We divide our calculated dark floor deposit volumes into three categories, indicating the degree to which we are confident that a dark floor deposit volume is evidence of possible resurfacing affecting a crater: dark floor volumes that indicate resurfacing, dark floor volumes that do not indicate resurfacing, and ambiguous cases indicating potential resurfacing.

Two of our 42 craters have mean dark floor deposit volumes that lie above the maximum impact melt volume regression. Six craters without visible outflows have mean dark floor deposit volumes that lie below the minimum impact melt volume regression. Our 2 mean dark floor deposit volumes that lie above the maximum impact melt volume regression we interpret as being indicative of resurfacing that has affected a crater, likely through infill of volcanic flows from the plains or inter-crater volcanism. If the material comprising the dark floor deposit is definitely impact melt, we interpret the 6 mean dark floor deposit volumes that lie below the minimum impact melt volume regression as indicating craters that have experienced no resurfacing or inter-crater volcanism. The other 34 dark floor craters represent ambiguous cases where the crater may have experienced some resurfacing or inter-crater volcanism, though further work is needed to constrain impact melt volumes from observed areas (Fig. 6).

In addition to impact melt outflow measurements being beyond the scope of this study, our work assumes that for dark floor volumes that fall under an impact melt volume regression, at least some impact melt contributes to the dark floor volume. While it is again beyond the scope of this study to quantitatively scale the likely contribution of impact melt to dark floor volume, we speculate that it is more likely for dark floor deposit volumes below the lower impact melt volume regression to have a greater contribution of impact melt volume than for dark floor deposit volumes that lie just underneath the mean impact melt volume regression, for example.

As only 2 craters have mean dark floor deposit volumes that exceed maximum calculated impact melt volumes, we argue that resurfacing is minimal-to-modest in our population of 42 craters.

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