# VOLUMES AND POTENTIAL ORIGINS OF CRATER DARK FLOOR DEPOSITS ON VENUS.

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**Introduction:** The surface of Venus has 940 craters which corresponds to relatively recent (300 to 1000 Ma, average of ~500 Ma) resurfacing [1, 2]. Two resurfacing mechanisms have been proposed to explain the present surface state of Venus: so-called "catastrophic" resurfacing, which posits that the majority of Venus (excepting the highland tessera terrains) was resurfaced in a single geologic event at around 500 Ma, and "equilibrium" resurfacing, which holds that different regions of Venus have been resurfaced at different times in the past 500 million years [1, 3]. These hypotheses hinge on the number of volcanically modified craters. Approximately 4% of craters are clearly volcanically embayed, supporting the "catastrophic" hypothesis [1]. However, several studies [4, 5, 6] recognize craters as having radar-dark floors. Dark-floored craters are generally shallower than bright-floored craters [4, 5] and have been interpreted to indicate either plains volcanism or volcanism within the crater [4, 6].

Impact melts, or the products of vaporized rock due to the great pressures and temperatures of the impact event, are also suggested as possible sources of crater dark floors [6, 11]. Due to Venus conditions, impact melts are expected to be greater in volume, faster, and more cohesive than impact melts elsewhere in the solar system, suggesting them as a possible candidate for material that would fill the interior of a crater, however, this has been contested by the observation that few "fresh" craters as indicated by the presence of impact parabolas have dark floors [6, 11].

*Hypotheses.* If the dark floor volume is greater than the calculated impact melt volume, dark floor material must be explained by invoking processes other than impact melt generation, i.e. embayment by volcanic plains or volcanism within the crater [6]. If the dark floor volume is less than the calculated impact melt volume, then impact melt generation may explain the entirety of material within that particular crater's dark floor.

**Methods:** We calculate two separate values for a given crater: dark floor volumes and impact melt volumes. We use Magellan Cycle 3 left-looking synthetic aperture radar (SAR) imagery, and measure crater depths from DEMs processed by stereo data from [7], which have a spatial resolution of ~ 1 km. The available data from [7] encompasses about 20% of the surface of Venus and numbers 62 craters.

*Dark floor volumes.* To estimate the volume of crater dark floor deposits, we employ an idealized model of crater morphometry (Fig. 1).

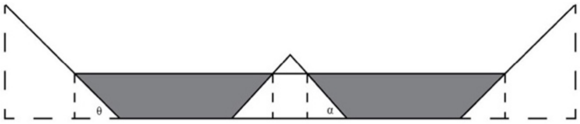

**Figure 1.** Dark floor model of crater morphometry. θ and α are angles correcting for the sections of the crater central peak and wall slope that would lie underneath the areal extent of measured dark floors.

We first measure the areal extent of crater dark floors using ENVI, converting the area in pixels into km$^2$. We compute an average rim-to-floor crater dept from 360 radial topographic profiles for a given crater, as described in [8].

We subtract the measured depth from a "fresh" crater depth derived from empirical measurement of Venus impact craters given by [4] to calculate dark floor thickness. We take the product of this thickness and the measured dark floor area to gain a general sense of the volume of the dark floor deposit, however, we need to make corrections based on crater morphometry (Fig. 1). We divide each crater into two categories: those with observable central peaks and those lacking observable central peaks. We measure central peak heights for those in the first category using the same method for measuring depths, as detailed in [8].

$$\alpha = tan^{-1}\left(\frac{t+h_{cp}}{r_{cp}}\right) \qquad (1)$$

Eq. 1 determines the slope of a central peak structure, where $\alpha$ is the central peak slope, $t$ is the thickness of the dark floor deposit, $h_{cp}$ is the measured height of the central peak, and $r_{cp}$ is the radius of the central peak derived from a power-law function of Venus central peak diameters from [9]. For craters with no observable central peak, we calculate two end-member estimates: a maximum dark floor volume that treats the central peak volume as negligible, and a minimum dark floor volume where the height of the central peak is equivalent to the thickness of the dark floor deposit.

Eq. 2 calculates the base length of the portion of the central peak underlying the dark floor deposit, $b_{cp}$. Eq. 3 provides the cross-sectional area of the central peak portion underlying dark floor deposits, $a_{cp}$. We make similar corrections for the contribution of the crater wall slope based on a power-law function of Venus crater wall width measurements made by [9]. Those corrections are excluded here for brevity.

$$b_{cp} = \frac{t}{\tan\alpha} \qquad (2)$$

$$a_{cp} = \frac{1}{2} b_{cp} t \qquad (3)$$

*Impact melt volumes.* Eq. 4 (from [10]) uses lunar and terrestrial impact craters to relate the simple-to-complex transition ($D_Q$), observed diameter ($D_r$), and transient crater diameter (or diameter at the time of impact, $D_{tc}$):

$$D_{tc} \cong {D_Q}^{0.15\pm0.4} {D_r}^{0.85\pm0.4} \qquad (4)$$

$D_Q$ is assumed to be 3.5, an average of the range of expected Venus values derived in [2].

The volume of impact melt produced, $V_m$, is calculated using Eq. 5 (from [11]). Constants *c* and *d* are derived from a regression for Venus impact craters, and vary with impactor material and impact velocity; in our initial case we use a 15 km/s chondritic impactor. We can then directly compare impact melt volumes to obtained dark floor volumes (Fig. 2).

$$V_m = c{D_{tc}}^{d} \qquad (5)$$

**Results:** Of the 62 craters examined, 54, or 87% contained some amount of dark floor material. This is greater than the number of dark floored craters previously reported of 32/74, or 43% [12] and 33/94, or 35% [4]. This may be the result of differences in criteria for “dark-floored”, where in this study any deposit of dark material was included. If these materials are indeed volcanic deposits, that would represent a doubling of craters potentially affected by late stage infilling.

The calculated depths range from 141 to 1305 m and volume of materials ranges from 0.06 to 1242 km$^3$ of material, comparable to depths reported by [5] and [12], supporting earlier conclusions that the dark floored craters contain additional materials and validating our measurement methodology.

We have compared our corrected crater dark floor volumes with our calculated impact melt volumes for two separate groups: craters with (Fig. 2) and without (Fig. 3) observable central peaks. Seven of the 29 craters with observable central peaks and 7/33 have dark floor volumes that fall above the central impact melt volume regression. These initial results suggests the volume of impact melt formation can completely comprise dark floor materials. However, we stress that this analysis assumes that all impact melt stays within a crater, which has been shown not to be the case (making calculated melts maximum values).

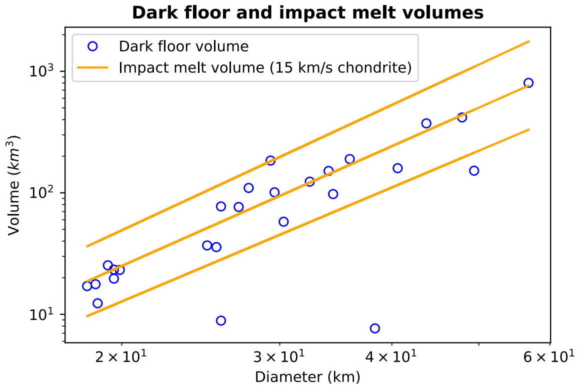

**Figure 2:** Corrected dark floor volumes and impact melt volumes. Central orange line is the regression of Eq. 6.

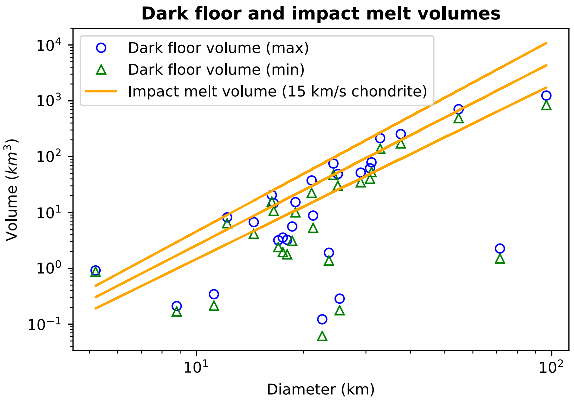

**Figure 3:** Corrected dark floor volumes and impact melt volumes, for craters with no observable central peaks. Blue circles are maximum volume dark floors (negligible central peak assumed) and green triangles are minimum volume dark floors (central peak height assumed to equal dark floor thickness).

**References:** [1] Schaber G. G. et al. (1992) *JGR, 97,* 13257. [2] McKinnon et al. (1997) in *Venus II, U. of Arizona Press*, 969. [3] Collins G. C. et al. (1999) *JGR, 104*, 24121. [4] Sharpton V. L. (1994) *GSA Spec. Pap. 293,* 19. [5] Herrick R. R. and Rumpf M. E. (2011) *JGR, 116*, E02004, doi:10.1029/2010JE003722. [6] Wichman R. W. (1999) *JGR, 104*, 21957. [7] Herrick R. R. et al. (2012) *EOS, Trans., AGU, 93*, No. 12, 125. [8] Perkins R. P. and Gilmore M. S. (2018) *LPSC XLIX*, #1513. [9] Herrick R. R. and Phillips R. J. (1994) *Icarus, 111*, 387. [10] Croft S. K. (1985) *PLPSC XV*, C828. [11] Grieve R. A. F. and Cintala M. J. (1992) *Meteoritics, 27*, 526. [12] Herrick R. R. and Sharpton V. L. (2000) *JGR 104*, 20245.