THE DISTRIBUTION AND VOLUME OF IMPACT MELT, CLEOPATRA CRATER, MAXWELL MONTES, VENUS.
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Introduction: The Cleopatra Crater is arguably one of the most interesting features on Venus. Located at approximately 65.9°N, 7.0°E (Figure 1), the crater sits on the eastern slope of the Maxwell Montes Mountain Range in Ishtar Terra. Cleopatra's outer rim is approximately 100 km in diameter. Its inner peak ring is approximately 50 km in diameter and is slightly offset west-northwest of the crater's center [1]. The eastern rim of the crater is cut by a channel (Anuket Valles), which feeds into an area of valleys and ridges. The valleys downslope of the channel are filled with material inferred to be melt from Cleopatra [2]. Anuket Valles itself is unusual because few channels on Venus incise and breach crater rims.

Cleopatra was first imaged in Venera 15 and 16 radar images. Radar images from the Magellan orbiter showed that fluid from Cleopatra had breached its rim and flowed downslope to fill many valleys. The channel, Anuket Valles, cuts through the rim, the crater wall, the peak ring, all the way to the radar dark crater floor.

Method: To determine the volume of melt that flowed out of Cleopatra crater, we mapped the downslope region of filled valleys east of the crater (Figure 2). The base map was the Magellan SAR left look global mosaic (75 m per pixel); elevations were from both the Magellan altimetry global mosaic and the Magellan stereo digital elevation model (DEM) [7]. The JMARS web interface was also used for visualizing the region.

Extents of the melt fill were mapped onto the Magellan SAR image. The valleys containing fill were segmented into rectangles. To calculate the fill volume, we estimated the shapes of the valleys using the DEM of nearby areas, as the DEM does cover the filled valleys, and Magellan altimetry does not have adequate spatial resolution. To model the shapes of the valleys, we used DEM elevation profiles across comparable valleys on the northern, southern, and western regions of Maxwell Montes. After removing regional gradients, we found that the valleys were basically symmetrical with slopes of ~6° on both east and west facing sides. The volume of each rectangular area was calculated then as a triangular prism model. The volumes of Cleopatra crater, inside and outside the peak ring, were calculated from simple geometry.

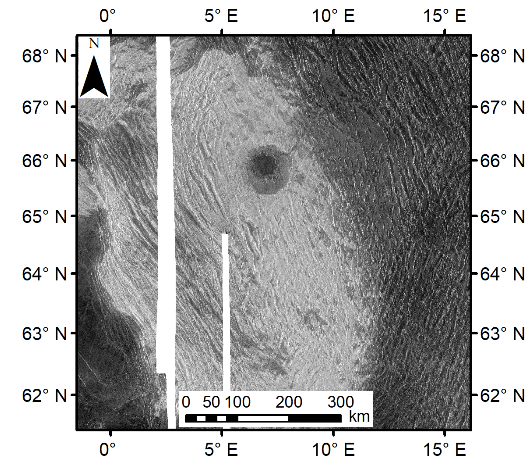

Figure 1. Regional image showing longitudinal and latitudinal position of Cleopatra on Maxwell Montes.

Expected volumes of impact melt from the Cleopatra impact were calculated from the equations of [4] (esp. 12 & 18), assuming (as he did) an impactor with a density of 3320 kg/m^3 travelling at a velocity of 17,000 m/s [4]. A final crater diameter of 100 km (like Cleopatra) implies a transient crater diameter of ~75 km. We calculated the melt volume for such an impact for granitic and basaltic target rocks on Venus, using Venus' surface gravity and temperature (740K), and a range of thermal gradients (dT/dz). Melt volumes were calculated for impacts at both 45° (most probable) and 90° (vertical) for Venus. The thermal properties of the target rocks and typical impactor are from [4,6].

Results: *Volume of valley-fill melt:* The east and west facing slopes of the region were at an average of 6°, and the total volume of the lava fill was approximately 4500 km^3.

Volume of Cleopatra: The volume of the crater from the rim to the outer ring floor was approximately 7850 km^3. Inside the peak ring to the inner floor of the crater, the volume was approximately 1800 km^3.

Melt volumes from crater scaling: The estimated melt volumes for granitic and basaltic rocks on Earth and Venus are given in Table 1.

Discussion: Questions to consider are whether the geology and the volume of the valley-fill are consistent with the geology of typical impact crater melt, as well as the volume of melt produced by a crater like Cleopatra.

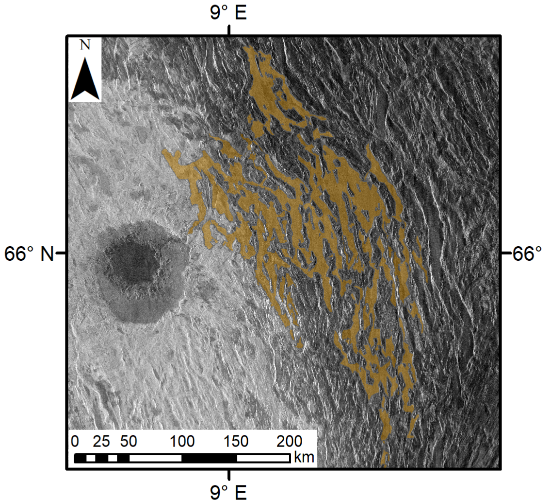

Figure 2. Melt-filled valley floors (brown) east of Cleopatra Crater.

Geology: Impact melt is usually rough as it is mixed with fragments of rock. From the radar images, we see that the fill has a relatively smooth texture. A few craters on Venus, for example the Wu Hou crater, are surrounded by rough impact ejecta, with a smoother and radar dark material on the outside. One assumption could be that the impact melt was partly molten and then deposited the rougher and fragmented parts as it continued to flow downslope. If the fill that occupies the valleys east of Cleopatra is impact melt from the crater, then it would have had to be extensively filtered. The valley-fill next to Cleopatra, however, does not show any remnants of larger rock fragments.

Volume: The channel at the crater rim most likely started there, initiated by melt overflowing the crater rim, and so the fluid that created it would have been at or near the edge of the crater. This implies that Cleopatra was initially full or nearly full of melt. If the crater floor inside the peak ring were at the elevation of the floor between the rim and peak ring (the annulus), then volume of valley fill would have filled the crater to a depth of ~0.6 km. The crater rim is approximately 1 km above the floor of the annulus, so the crater would have been approximately half-full of impact melt. If the crater wall had a low spot, it is possible that the melt could have topped that low spot, and eroded through the rim to allow crater to drain. A possible simplification of this scenario is that Cleopatra was not so deep as it is now. There is evidence that the floors of large Venus craters have subsided significantly as the heat of impact dissipates [8]. In this case, the crater would have been filled more than the above estimate, so its melt could have been high enough to breach the crater rim and flow down to fill the valleys. Since then, the melt that remained inside the floor would have cooled down, causing the crater floor to subside to the level it is presently.

Table 1. Calculated Impact Melt Volumes:

Planet	Target Rock	dT/dz (K/km)	Impact angle (°)	Melt Volume (km^3)
Earth	Basalt	25	45	5000
	Granite	25	45	8500
Venus	Basalt	25	45	6000
	Granite	25	45	14000
	Basalt	5	45	5000
	Granite	5	45	9000
	Basalt	25	90	11000
	Granite	25	90	26000
	Basalt	5	90	8000
	Granite	5	90	15000

Calculated from equations 12 & 18 of [4]. 100 km diameter final crater; 75 km diameter transient crater. dT/dz is geothermal gradient; 90° impact angle is vertical. Surface temperatures: Earth, 287K; Venus, 740K. Thermal parameters from [4,6].

Conclusion: From our calculations, the volume of the valley-fill melt is comparable to the total impact melt produced by a Cleopatra-sized crater assuming the target material was basalt, had a low geothermal gradient, or was impacted at a 45° angle. This would imply that all or almost all the impact melt produced by Cleopatra flowed out of the crater, which is unlikely. The volume of the fill, however, is about a third to a quarter of the total melt produced if the target material was granitic, although that is not definitive. This is also consistent with a 90° impact angle and a higher geothermal gradient. This implies that about half the volume of melt produced could have cut through the crater rim and flowed out of the channel, which is a more reasonable assumption. The volume of the fill is large enough that it suggests that the target material was granitic, had a higher geothermal gradient, or that it was impacted at a more vertical angle. Either one or a combination of these conditions would be a more probable answer.

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