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 mountains 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]. The origin of the valley fill melt is not clear – was it entirely impact-generated melt, or could it include impact-related volcanic rock? We start investigating the question by measuring the volumes of valley fill melt and of Cleopatra itself.

Method: To determine the volume of melt filled the valleys outside Cleopatra crater, we mapped the downslope region east of the crater (Figure 2). The base map was the Magellan SAR left look global mosaic (~75 m / pixel) [5]; 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.

Measured Melt Volume. To calculate the volume of melt outside Cleopatra, we first mapped the valleys, downhill of the crater and Vallis, that had flat floors. These areas were segmented into rectangles (Fig. 2). To calculate the volume under these rectangles, we determined the shapes of nearby valleys that were not filled and assumed that the filled valleys had similar shapes. The shapes of unfilled valleys were estimated using the DEM of nearby areas (north, south, and west of Cleopatra), as the DEM does cover the filled valleys, and Magellan altimetry does not have adequate spatial resolution. After removing regional slope gradients, we found that unfilled valleys were basically symmetrical, with slopes of ~6° on both east- and west- facing sides. The volume under each rectangular area was calculated then as a triangular prism with slopes of that 6°.

Theoretical Melt Volume. An anticipated volume of impact melt from the Cleopatra impact can be calculated from impact cratering theory and empirical relations. We applied the relationships developed in [4] (equations 12 & 18), using the assumptions of an impactor density of 3320 kg/m^3, and a velocity of 17,000 m/s [4]. Using those relations, a crater of diameter 100 km (like Cleopatra) formed from a transient crater of ~75 km diameter. 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). The thermal properties of the target rocks and typical impactor are from [4,6].

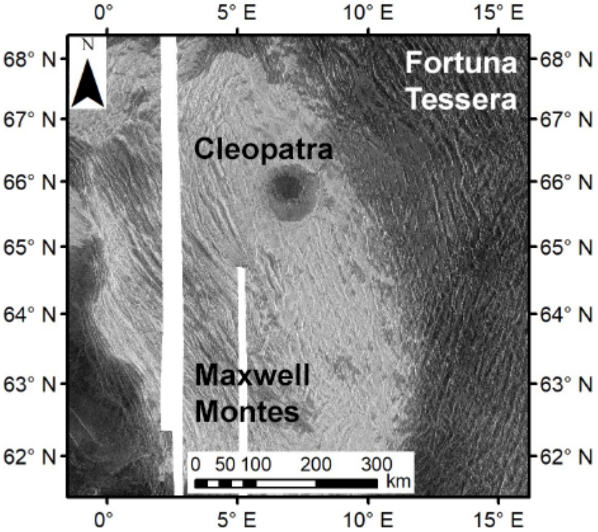

Figure 1. Maxwell Montes and Cleopatra crater. From Magellan left-look SAR global mosaic. Melt from Cleopatra flowed east and north to fill valley in Fortuna Tessera.

Results: *Volume of valley-fill melt:* We calculate the volume of each segmented rectangle (Fig. 2), for slope angles of 6°, summed them. The inferred total volume of the valley fill is approximately 4500 km^3.

Melt volumes from theory: Calculated volumes of impact melt from a crater of Cleopatra's size are given in Table 1, for granitic and basaltic target rocks, and for Earth and Venus.

Volume of Cleopatra: The interior total volume of Cleopatra crater, from the rim to the depths of the outer ring floor, is approximately 7850 km^3. Cleopatra is deeper inside its peak ring than outside; the volume of that deeper portion inside the peak ring is approximately 1800 km^3.

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.

Geology: Impact melt deposits usually have rough surfaces, from the abundance of rock fragments in impact ejecta. From the Magellan SAR images, the filled valleys below Cleopatra have relatively smooth surfaces. A few craters on Venus, e.g., Wu Hou, have

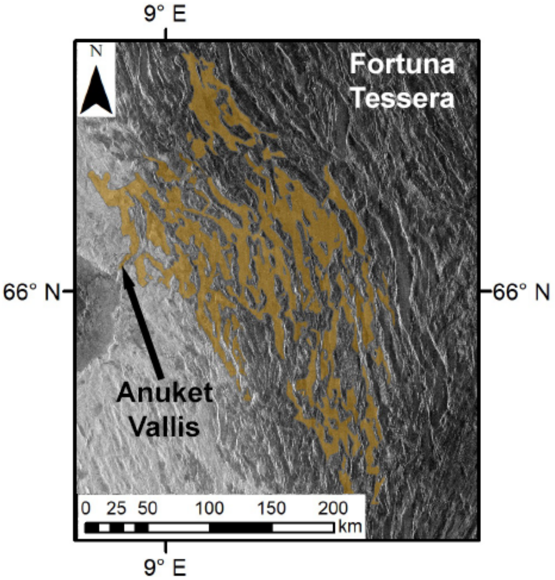

Figure 2. Melt-filled valleys, in brown, east and downhill of Cleopatra Crater. Valley fills were fed through Anuket Vallis.

smooth (SAR-dark) material outside of their rough ejecta. This smooth material could be melt that flowed out from the rock-rich ejecta, and this 'filtering' scenario is possible for Cleopatra impact melt. However, there is no obvious sign at Cleopatra of rough, rock-rich impact ejecta.

Volume: The channel at the crater rim could reasonably have 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, 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] for a 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 that should be 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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