EMBAYED CRATERS ON VENUS: HOW DO THEY CORRESPOND TO THE CATASTROPHIC AND EQUILIBRIUM RESURFACING MODELS?

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Introduction: The style and rate of resurfacing on Venus is among the key problem in the geologic history of this planet. There are two alternative models of resurfacing. The first is the model of catastrophic resurfacing [1]. It states that at some specific point (say, ~500 Ma ago) the entire surface of Venus was renewed and the observable population of crates began to accumulate. The model of equilibrium resurfacing [2] states that both endogenous processes (volcanism and tectonics) and exogenous impact cratering acted in a balanced way and that it is unnecessary to call on major cataclysms involving either volcanism or tectonism to explain the observed geological history of Venus.

Both models are based on two observations thought at the time of Magellan to characterize the Venus crater population: (1) the spatial distribution of craters may be indistinguishable from complete spatial randomness and (2) only a small proportion of craters is modified by volcanic flows and/or tectonic structures. The spatial randomness of the distribution of craters had been tested in different ways and by different groups of researchers [2-4]. A careful geologic analysis of the morphology of craters revealed that only ~6.2 % of the Venus craters are embayed from outside and 9.6 % of the craters are tectonized [1]. These characteristics of the distribution and morphology of the craters place some constraints on the model of equilibrium resurfacing and are the starting points of the catastrophic resurfacing model.

Limits of the equilibrium model: Phillips et al. [2] describe the parameters of the equilibrium model under the restriction of spatially randomly distributed craters. The craters considered as dimensionless points and the successive and randomly distributed resurfacing events have been modeled as two-dimensional circular areas. These areas could either completely cover (erase) the craters or did not affect them. The model predicts that the craters remain to be randomly distributed if the diameter of the resurfacing areas is either smaller than about 4^o (~420 km) or larger than about 74^o (~7700 km). If the characteristic size of the resurfacing areas falls between these limits the restriction of the randomness of the craters is violated.

Proportion of modified craters: The above estimates were made without considering the size distribution of the craters. When the craters are not treated as dimensionless points, however, the problem of embayed and/or tectonized craters becomes an important issue of the equilibrium model. The proportion of modified craters in the framework of this model can be estimated by the functions that describe the probabilities that a resurfacing event completely erases a crater, deforms it, or leaves it unaffected [2, Appendix C]. These are decreasing functions of the size of the resurfacing event: The smaller events are more effective in the partial embayment/deformation of the craters and the larger events more effectively erase the craters completely. Thus, when the events are smaller the larger fraction of embayed/tectonized craters appears. Figure 1 shows these functions that were constructed based on the size distribution of observable volcanic features on Venus taken from the global geologic map of Venus [5]. The upper branch takes into account the assumption that multiple resurfacing events never completely erase a crater and overestimates the proportion of affected craters [2]. For the lower branch the assumption is that that two resurfacing events completely erase a crater. It underestimates the proportion of the modified craters [2]. The expected fraction of the modified craters is between these branches.

The proportion of all volcanically embayed craters from exterior is ~0.066 (Fig. 1).

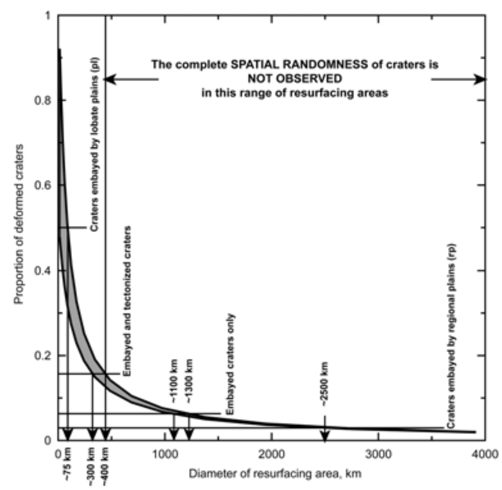

Figure 1. Proportion of deformed craters as a function of the size of the resurfacing events

This implies that the characteristic diameter of the resurfacing events should be about 1200 km (~11^o). This value is too large to satisfy the restriction of the completely spatially random distribution of craters. When the embayed and tectonized craters are combined, the proportion of these modified craters is 0.158 (regardless of the nature of modification) and corresponds to the lower limit of the range of diameters the resurfacing events, ~3-4^o (Fig. 1). This appears to suggest that the smaller sizes of the resurfacing events are more likely if the equilibrium model is correct [2]. The characteristic diameters of the events, however, should not be significantly smaller because it would cause too high a proportion of deformed craters (Fig. 1). This puts another limit on the equilibrium resurfacing model.

The size distribution of volcanic events: About 75% of the surface of Venus is covered by mildly tectonized volcanic units. Thus, volcanism is the major factor of resurfacing. In this study we tested if the equilibrium model is able to adequately describe the observable proportions of volcanically embayed craters. What are the size distributions of the volcanic features

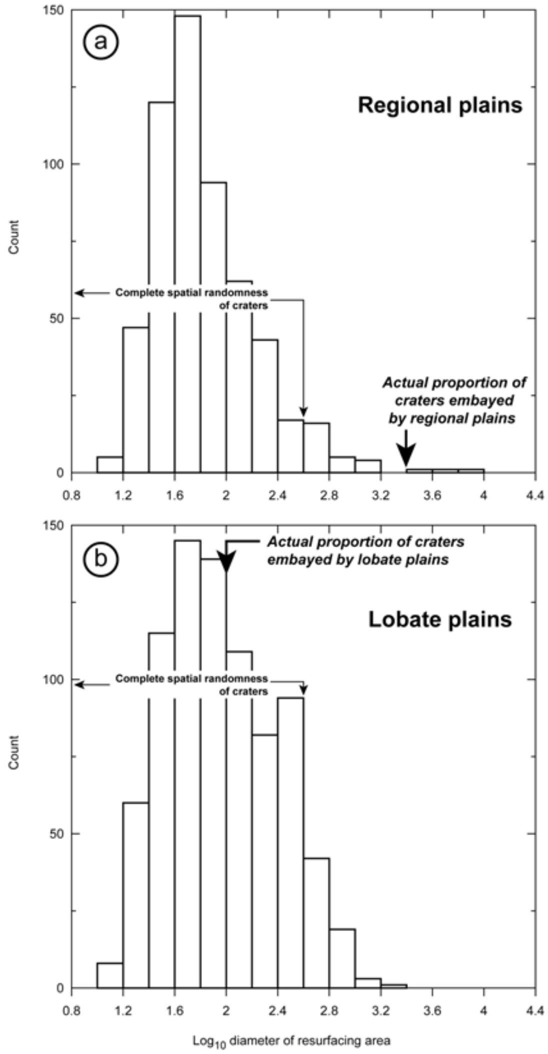

Figure 2. The size distributions of individual occurrences of volcanic plains: (a) regional plains, (b) lobate plains.

seen on the surface? How do they correspond to the actual proportions of the volcanically embayed craters? In order to address these questions we measured areas of individual fields of the two major types of volcanic plains on Venus (regional plains, rp and lobate plains, pl). Regional and lobate plains cover ~52% of the surface and represent two distinctly different episodes of volcanism on Venus. The densities of craters superposed on these two units are ~1.96 ± 0.30 (3 σ) for regional plains and ~1.06 ± 0.51 (3 σ) for lobate plains. These values mean that the plains emplaced during widely separated periods. The third regionally important volcanic unit (shield plains, psh, ~19% of the surface) was not considered because it is heavily embayed and, therefore, the size distribution of the fields of shield plains should be strongly biased toward the smaller sizes. Regional plains are also embayed by younger materials but for this study the only occurrences of this unit that are as far as possible from the covering plains were taken into account. Figure 2 shows the size distribution of the occurrences of the plains and the proportions of craters embayed by them.

The number of craters embayed by regional plains is 17 and the total number of craters that occur within the areas of rp is 582. This gives the proportion of embayed craters as ~3%. In the framework of the equilibrium model, this percentage of embayed craters requires that the characteristic diameter of the resurfacing event should be ~2500 km (Fig. 1). This diameter is well in the forbidden zone where the random distribution of craters is not observed (Fig. 1) and is much larger than the majority of sizes of individual fields of regional plains (Fig. 2a). The actual size distribution of occurrences of this unit suggests that the proportion of the embayed craters must be much larger if the equilibrium resurfacing operated during emplacement of regional plains. The observable characteristics of the plains (the size of occurrences and the number of embayed craters) strongly contradict the predictions of the equilibrium resurfacing model. Thus, the model falls to describe adequately the process of formation of the plains.

The total number of craters on lobate plains is 54 and the plains embay 27 of them. The proportion of the embayed craters in this case is, thus, ~50%. The characteristic size of the resurfacing events in the case of lobate plains is about 75 km, which is inside the zone where the spatially random distribution of craters is warranted (Fig. 1). This diameter corresponds also to the middle of the size distribution of occurrences of the plains (Fig. 2b). Thus, the model of equilibrium resurfacing can be adopted for the explanation of the process of emplacement of lobate plains.

Conclusions: The model of equilibrium resurfacing falls to explain the characteristic features (the size distribution of occurrences and the proportion of embayed craters) of the older regional plains. The same characteristics of the younger lobate plains, however, correspond well to the predictions of the model. This suggests that the style of resurfacing on Venus changed significantly during the observable portion of the geologic history of this planet. Emplacement of regional plains probably can be explained by the catastrophic resurfacing [1], whereas the equilibrium resurfacing [2] dominated at later stages of the geologic history of Venus.

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