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Volcanically embayed craters on Venus: testing the catastrophic and equilibrium resurfacing models

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ABSTRACT

Two major types of volcanic units, older regional plains and younger lobate plains, make up ~50% of the surface of Venus and represent different epochs of volcanism. The abundance of impact craters partially embayed from the exterior by each of these two types of units permits the testing of the key points of the model of equilibrium resurfacing. The proportion of craters embayed by the older regional plains is ~3%, which requires the typical size of a volcanic resurfacing event to be ~2700 km (~25° of angular diameter) in the framework of the equilibrium model. These event dimensions are inconsistent with the quasi-random spatial distribution of the craters. The proportion of craters embayed by younger lobate plains is 33%, which can be achieved if the characteristic size of the resurfacing event is less than ~160 km (~1.5° of angular diameter). Events of this size do not disturb the character of the spatial distribution of craters. We conclude that the style of volcanic resurfacing on Venus has changed significantly during its observable portion of the geologic history. During the global volcanic regime when regional plains were emplaced, volcanism acted in large regions and the process of formation of regional plains was more intensive than accumulation of impact craters. This led to the very small proportion of embayed craters (~3%). Later, during the network-rifting and volcanism regime (emplacement of lobate plains), volcanic sources were localized at distinctive centers, the net volcanic intensity decreased and became comparable to the rate of accumulation of craters, which resulted in much larger percentage (33%) of craters embayed by lobate plains.

1. Introduction

The style of resurfacing on Venus is among the key problems in the geologic history of this planet (Schaber et al., 1992; Phillips et al., 1992; Strom et al., 1994; Phillips and Izenberg, 1995; Price and Suppe, 1995; Hauck et al., 1998; Romeo and Turcotte, 2010; Bjonnes et al., 2012; Romeo, 2013). There are two alternative end-member models of this process, catastrophic (Schaber et al., 1992) and equilibrium (Phillips et al., 1992) resurfacing. Both models are based on the fundamental properties of the crater population on Venus: (1) the spatial distribution of craters may be indistinguishable from complete spatial randomness and (2) only a small proportion of craters are modified by volcanic flows and/or tectonic structures. The spatial randomness of the distribution of craters has been tested in different ways and by different groups of researchers (Phillips et al., 1992; Strom et al., 1994; Hauck et al., 1998; Turcotte et al., 1999) with essentially the same result.

A careful geologic analysis of the morphology of craters revealed that only ~6.2% of all craters on Venus are obviously embayed by volcanic materials from outside and 9.6% of the craters are tectonized (Schaber et al., 1992). These characteristics of the spatial distribution and morphology of the craters put important constraints on the model of equilibrium resurfacing and are the starting points for the catastrophic resurfacing model. This model states that at some specific time (say, ~500 Ma ago) the entire surface of Venus was rapidly renewed by a major volcanic event and the population of craters that is seen on the surface began to accumulate since that time. An important feature of the model is the significant drop of endogenous activity after the resurfacing event, which is suggested by the small number of embayed/tectonized craters. The model of equilibrium resurfacing states that both the endogenous processes (volcanism and tectonics) and the exogenous impact cratering acted in a balanced way and that the resurfacing events occurred either relatively frequently ($\sim 0.15 \times 10^6$ years) within small ($\leq 4^\circ$ angular diameter) patches or relatively seldom ($\sim 50 \times 10^6$ years) in large ($\geq 74^\circ$) regions.

Both models did not take into account the possible differences in the time of formation of volcanic and tectonic units simply

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because the stratigraphy of Venus was not developed at the time when the models were proposed. One of the key predictions of the model of catastrophic resurfacing is the small total number of impact craters. The equilibrium model predicts important parameters of resurfacing, such as the characteristic sizes of the resurfacing events and their relationships to the number of modified craters.

The purpose of this article is to test from a stratigraphic point of view the key predictions of both the catastrophic and equilibrium resurfacing models about the number of volcanically embayed craters. The recently published global geological map of Venus (Ivanov and Head, 2011) provides the necessary basis for this testing. The map documents the spatial distribution of the most important units related to different epochs of the assessable part of the geologic history of Venus. Specifically, the map shows two units that constitute the volcanic components of two successive regimes of endogenous activity on the planet (Ivanov and Head 2013a, 2014; Head, 2014, Fig. 1): regional plains (represent the earlier global volcanic regime) and lobate plains (represent the younger network-rifting and volcanism regime). The different relative ages of regional and lobate plains were documented in many places on Venus both at local (e.g., Mcgill, 2000; Stofan and Guest, 2003; Brian et al., 2005) and global scales (Ivanov and Head, 2011, 2013b). Besides the spatial and temporal distribution of the units, the map also provides the key parameters that are required for the assessment of applicability of various resurfacing models: mode of interaction of the major volcanic units with craters and the size-frequency distribution of occurrences of volcanic plains.

2. Limits of the equilibrium model

The observable random (quasi-random; Hauck et al., 1998) spatial distribution of impact craters places the most important constraints on the model of equilibrium resurfacing. In this model (Phillips et al., 1992), craters were considered as dimensionless points and the successive and randomly distributed resurfacing events were modeled as two-dimensional circular areas. They could either completely cover (erase) the craters or did not affect them. The model predicts that the craters remain randomly distributed if the diameter of the resurfacing areas is either smaller than about 4° (~420 km) or larger than about 74° (~7700 km). If the characteristic size of the resurfacing areas falls between these limits the interaction of resurfacing events with the crater population leads to the craters with spatial distribution statistically indistinguishable from random. One of the major goals of our study was to determine how the dimensions of actual occurrences of lava plains on Venus correspond to the limits of the equilibrium model.

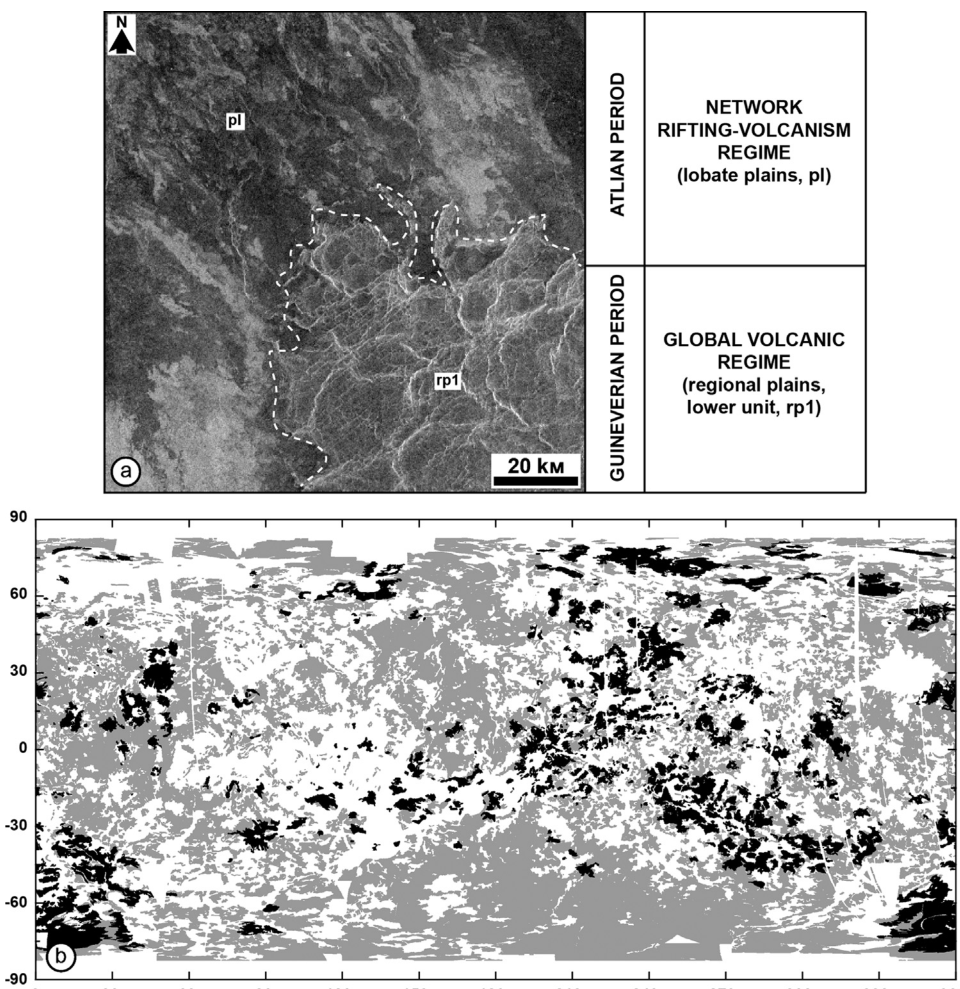

Fig. 1. a) Typical stratigraphic relationships between regional plains (rp1) and lobate plains (pl) define two major regimes of endogenous activity on Venus. Regional plains represent the older, Global volcanic regime (Guineverian Period) and lobate plains characterize the younger, Network rifting-volcanism regime (Atlian Period). b) The spatial distribution of regional (gray) and lobate (black) plains on Venus.