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Beta Regio, Venus: Evidence for uplift, rifting, and volcanism due to a mantle plume

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Abstract

Geophysical data have led to the interpretation that Beta Regio, a 2000 × 25000 km wide topographic rise with associated rifting and volcanism, formed due to the rise of a hot mantle diapir interpreted to be caused by a mantle plume. We have tested this hypothesis through detailed geologic mapping of the V-17 quadrangle, which includes a significant part of the Beta Regio rise, and reconnaissance mapping of the remaining parts of this region. Our analysis documents signatures of an early stage of uplift in the formation of the Agrona Linea fracture belts before the emplacement of regional plains and their deformation by wrinkle ridging. We see evidence that the Theia rift-associated volcanism occurred during the first part of post-regional-plains time and cannot exclude that it continued into later time. We also see evidence that Devana Chasma rifting was active during the first and the second parts of post-regional-plains time. These data are consistent with uplift, rifting and volcanism associated with a mantle diapir. Geophysical modeling shows that diapiric upwelling may continue at the present time. Together these data suggest that the duration of mantle diapir activity was as long as several hundred million years. The regional plains north of Beta rise and the area east and west of it were little affected by the Beta-forming plume, but the broader area (at least 4000 km across), whose center-northern part includes Beta Regio, could have experienced earlier uplift as morphologically recorded in formation of tessera transitional terrain.
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1. Introduction

Beta Regio is a well expressed 2000 × 2500 km topographic rise in northern mid-latitudes of Venus cut by Devana Chasma, a deep tectonic valley (Figs. 1 and 2). It is one of a few highlands on Venus considered to be formed by lithosphere uplift driven by a hot plume (e.g., McGill et al., 1981; Senske et al., 1992; Phillips and Hansen, 1994; Stofan et al., 1995; Stofan and Smrekar, 2005; Smrekar et al., 1997; Rathbun et al., 1999). Several geophysical modeling studies of the plume process based on gravity and topography data generally confirmed the possibility of such a process and placed some important constraints on it (e.g., Kiefer and Hager, 1991, 1992; Moresi and Parsons, 1995; Nimmo and McKenzie, 1996; Moore and Schubert, 1997; Solomatov and Moresi, 1996; Vezolainen et al., 2003, 2004; Kiefer and Swafford, 2006). The studied area is part of the major Beta-Atla-Themis volcanic anomaly suggesting mantle upwelling in this region (e.g., Crumpler et al., 1993). Debates about the role and in some cases even the existence of mantle plumes on Earth has led some researchers to refute the general existence of plumes on Venus (e.g., Hamilton, 2005). This argument concentrates, however, mostly on the mantle diapir origin of venusian coronae and does not address domical uplifts such as Beta, Atla or Western Eistla. Recently Stofan and Smrekar (2005) considered a variety of mechanisms that have been proposed as alternatives to plumes on Earth. None of them was found to be as likely as a simple mantle plume model for the formation of topographic rises and coronae. The mantle plume origin of topographic rises and coronae of different sizes was also supported by Hansen (2002, 2003).

This paper concentrates on the results of the geologic mapping of a significant part of Beta Regio and the adjacent areas (Basilevsky, 2007). In this sense it resembles the analysis of

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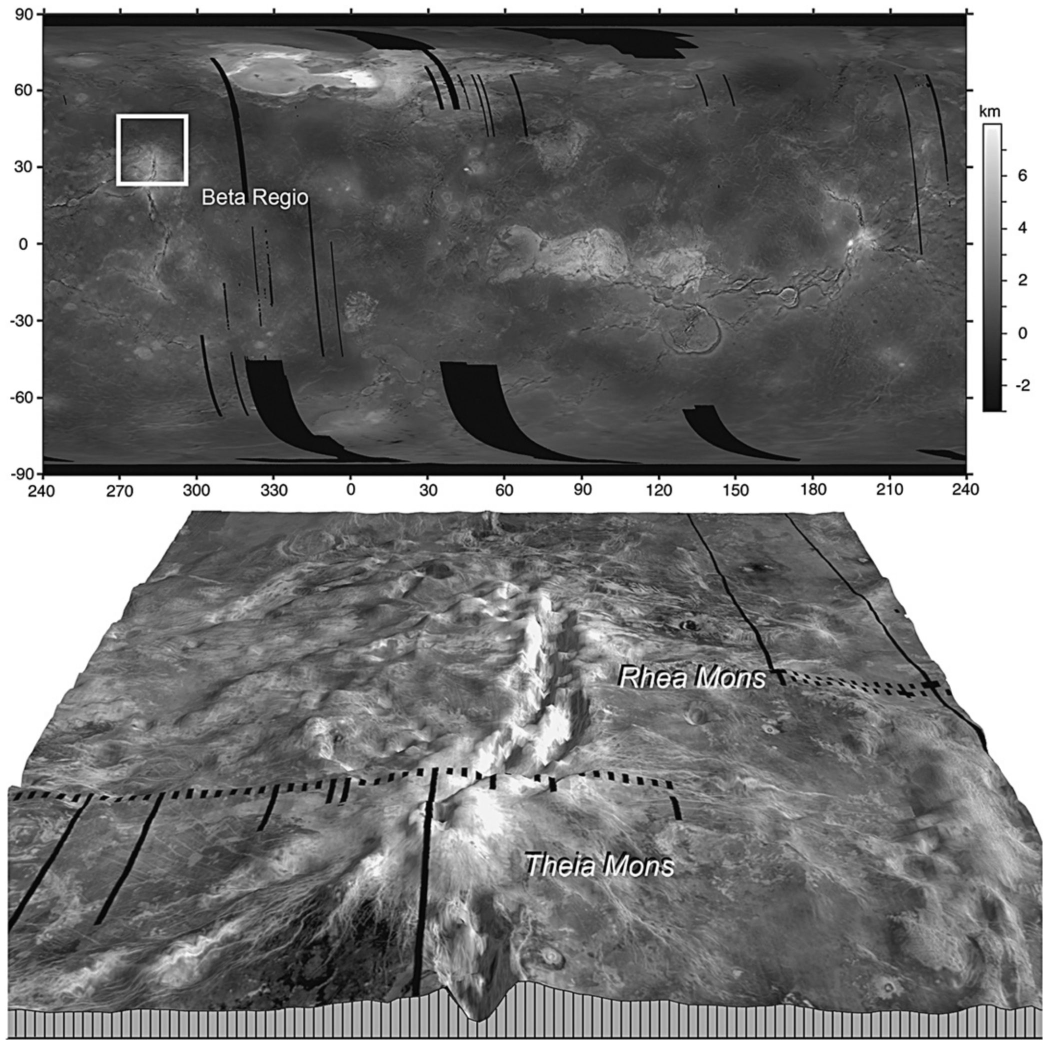

Fig. 1. Magellan-based global topography of Venus (top) and S to N perspective view of Beta Regio (bottom). White quadrangle in the top image outlines the study area.

Central Eistla Regio rise done by McGill (1998). Analysis of the mapping results has led us to documentation of observations indicating tectonic uplift of the Beta Regio structure, the establishment of a time sequence of material units and structures prior, during and possibly after formation of the uplift, and an estimation of the age of at least some of the uplift-related activities (Figs. 3 and 4). This geologic documentation and analysis is possible because of the lack of significant erosion and sedimentation on Venus, processes which seriously complicate deciphering of past episodes of the geologic history of Earth.

In our geologic mapping we used the traditional methods of geologic unit definition and characterization for the Earth (for example, American Commission on Stratigraphic Nomenclature, 1961) and planets (for example, Wilhelms, 1990) appropriately modified for radar data (Tanaka, 1994). We defined units and mapped key relations using the full resolution Magellan synthetic aperture radar (SAR) data and transferred these results to the base map compiled at a scale of 1:5 million (Figs. 2 and 3). Further discussion of these approaches and related issues can be found in Basilevsky and Head (2000a) and Hansen (2000).

2. Short history of Beta Regio studies

Beta Regio is one of the first features discovered on the surface of Venus in early Earth-based radar observations (e.g., Goldstein, 1965; Goldstein et al., 1978). In 1975 the Venera 9 probe landed on the north-eastern flank of the Beta rise (Moroz and Basilevsky, 2003). The gamma spectrometer measurements showed that in its contents of K, U, and Th, the surface material at the landing site is close to terrestrial basalts (Surkov et al., 1976). The Pioneer–Venus radar studies showed Beta Regio in global context. Together with later Earth-based radar observations they showed that Beta Regio is an area of interrelated rifting and volcanism (Masursky et al., 1980; McGill et al., 1981; Schaber, 1982; Campbell et al., 1984; Stofan et al., 1989). Devana Chasma was interpreted to be a part of a global system of rifts resembling terrestrial continental rifts (McGill et al., 1981; Schaber, 1982). It was found that Beta Regio has a prominent positive gravity anomaly, and that

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