THE TIMING OF FORMATION OF BETA REGIO AND ITS GEODYNAMICAL IMPLICATIONS. A. V. Vezolainen, V. S. Solomatov, Department of Physics, New Mexico State University, Las Cruces NM 88003, USA, J. W. Head, Department of Geological Sciences, Brown University, Providence, Rhode Island 02912, USA, A. T. Basilevsky, V. I. Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Moscow, Russia, L.-N. Moresi, Australian Geodynamics Cooperative Research Centre, CSIRO Exploration & Mining, 39 Fairway, Nedlands 6009, Western Australia.

Introduction. Beta Regio is one of several broad rises on the surface of Venus characterized by relatively recent rift zones and associated volcanism [1,2]. It is a broad topographic rise several thousand km across, rising several km above the surrounding plains, and distinguished from steep-sided tessera plateaus which are of more ancient age [2,3]. Beta Regio is characterized by a major gravity anomaly [4], and the associated rift zone forms a three-pronged junction near the summit, the site of extensive late-stage volcanic extrusion (Theia Mons). Detailed geologic mapping [5] of the region shows that the background geologic units (tessera, early plains, and regional plains) seem to have formed prior to the development of major topography presently associated with Beta. In these earlier units, the geologic structure and unit distribution is similar to that of many other areas of Venus [3,5]. Subsequent to this, extensive rifting clearly associated with Beta occurred, and associated volcanic deposits show the influence of slopes tilting away from the focus of rifts in central Beta [5]. The absolute age of the change in transition from background to Beta-related activity is not known. Recent evidence suggests, however, that the early units were emplaced over a relatively short period of time in earliest observed Venus history (less than 150 m.y.) [6], and that the regional plains were emplaced geologically rapidly (within less than a few tens of millions of years) soon thereafter [7]. Thus, the initiation of Beta Regio could date back as old as the first one-third to one-half of the presently observed geological history of Venus.

The most likely explanation for the origin of Beta Regio is mantle upwelling [8]. Gravity and topography anomalies predicted by steady-state models suggest that the present-day lithosphere in this region is thick, perhaps around 400 to 500 km [9]. The time factor, however, is important and can be partially responsible for various unresolved issues. In particular, it has not been shown that a thick lithosphere can be uplifted on a sufficiently short time scale consistent with geological constraints. Also, the models showed that the lithosphere and the mantle should be different in Beta Regio compared to other areas: the rest of the planet seems to be covered by a lithosphere which is apparently thinner by a factor of two or so. The plume which produced Beta Regio seems to have arrived from a larger depth. These issues are critical in distinguishing between various models of global evolution of Venus. For example, in the model of cessation of plate tectonics [9] it is possible that plumes originated at the core-mantle boundary as a result of intensive core cooling. On the other hand, if Venus evolved in the stagnant lid regime during the entire evolution [10] formation of plumes at the core-mantle boundary is unlikely because the mantle was heated up during a substantial period of time. In this case, plumes are likely to originate at the bottom of the depleted upper layer. In the scenario described in [10] such a layer would be formed as a result of convection and melting and would be heated from below by the undepleted layer. To get some insight into these problems, it seems necessary to consider the time-dependent model of Beta Regio.

Figure 1: Uplift of Beta Regio with 1600 km depth layer and a low Rayleigh number. The temperature field and topography are shown as a function of time. The depth is chosen to fit both gravity and topography so that the present-day gravity is correct too. Convection gradually approaches the steady-state solution described in [9].

Time-dependent models of Beta Regio. We start with a reference model which gave a good agreement with gravity and topography of Beta Regio [9] and also satisfied experimental constraints on the viscosity law (square box heated from below, viscosity contrast of $10^6$ and bottom Rayleigh number of $3 \times 10^7$). Both the average interior temperature and the bottom temperature are taken from the reference model. The only
difference is that the lid is initially flat. The plume starts at the bottom, heats the lid and eventually reaches the equilibrium thermal state which corresponds exactly to the reference model (Fig. 1). An important result is that it takes about 4 billion years for the topography to reach the present-day topography of Beta Regio (note that the depth of the layer is 1600 km which is required to fit simultaneously both topography and gravity, [9]). This large time scale is inconsistent with the geological constraints. It is also difficult to reconcile this time scale with any of the suggested models of Venusian evolution. Any reasonable variations in the initial interior temperature, the initial lid thickness and the viscosity contrast do not seem to affect the result much.

One of the factors which does have a big effect on the uplift rate is intensity of convection. It has been noted that more intense convection (higher Rayleigh numbers) might also satisfy topography and gravity [9]. To satisfy the observed gravity and topography of Beta Regio, the thickness of the mantle should also increase according to the general trend of temperature-dependent viscosity convection. Investigation of higher Rayleigh number convection models shows that a reasonable time scale of the formation of Beta Regio can only be obtained for the maximum possible thickness of the convective layer (2900 km, the entire mantle thickness, Fig. 2).

**Conclusion.** Our results suggest that to satisfy not only the gravity, topography and rheological constraints but also the timing of the formation of Beta Regio, convection must be substantially more vigorous than previously thought and the plumes must come all the way from the core-mantle boundary. It is interesting to note that the lithospheric thickness remains almost the same and is about 400 km. It is important to note, however, that interpretation of gravity and topography strongly depends on the rheological models. Therefore future studies should consider more realistic rheologies (as constrained by experimental data and theory, e.g. [11]) and with a reasonable range of governing parameters. Among the most significant factors is, perhaps, pressure-dependent viscosity which was shown to be extremely important for mantle dynamics [10].