DIFFERENTIATION OF MAGMA OCEANS AND THE THICKNESS OF THE DEPLETED LAYER ON VENUS; V. S. Solomatov, and D. J. Stevenson (Division of Geological and Planetary Sciences, 170-25, California Institute of Technology, Pasadena, CA 91125, U.S.A.)

Various arguments suggest that Venus probably has no asthenosphere and it is likely that beneath the crust there is a highly depleted and highly viscous mantle layer which was probably formed in the early history of the planet when it was partially or completely molten [*Kaula*, 1990; *Head et al.*, 1992; *Parmentier and Hess*, 1992]. Models of crystallization of magma oceans suggest that just after crystallization of a hypothetical magma ocean the internal structure of Venus consists of a crust up to about 70 km thickness, a depleted layer up to about 500 km and an enriched lower layer which probably consists of an undepleted "lower mantle" and heavy enriched accumulates near the core-mantle boundary.

Partial or even complete melting of Venus due to large impacts during the formation period [*Kaula*, 1979; *Benz and Cameron*, 1990; *Melosh*, 1990; *Wetherill*, 1990] eventually results in differentiation [*Agee and Waker*, 1988; *Herzberg and Gasparik*, 1991; *Abe,* 1990]. However, the final result of such a differentiation can vary from a completely differentiated mantle to almost completely preserved homogeneous mantle depending on competition between convection and differentiation: between low viscosity ("liquid") convection and crystal settling at small crystal fractions or between high viscosity ("solid") convection and percolation at large crystal fractions [*Solomatov and Stevenson*, 1992a,b,c]. The model is following. After the melting event, cooling and crystallization of a magma ocean is due to convection driven by the temperature difference between the hot magma and a relatively cool surface. The surface of Venus radiates as a black body or can be covered by a dense steam atmosphere creating a greenhouse effect. The initial depth of the magma ocean is assumed to be from a few hundreds kilometers to the bottom of the mantle. The equilibrium multiphase thermodynamics of magma ocean assumes three-component ideal mixture between olivine and pyroxenes (upper mantle) or between perovskite and magnesiowüstite solid solution (lower mantle). Rheology is newtonian and coincides with the rheology of dense suspensions (or with the rheology of solids at large crystal fractions). Convection is described in terms of multiphase thermodynamics and rheology with a correction for rotation.

The structure of the magma ocean consists of a completely molten uppermost layer, a layer consisting of melt and the first solid phase, a layer consisting of melt and the first two solid phases and so on. The lowest layer is purely solid, although the complete solidification could be reached somewhere in the middle of the lower mantle. In the absence of differentiation and chemical layering, the convective flow passes through all the regions that causes crystallization and melting cycles in the moving magma. During the crystallization the number and size of the crystals is determined by kinetics. A kinetic model of this process together with calculation of subsequent Ostwald ripening estimates crystal sizes depending on the convective velocities and the kinetic parameters.

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There are three regimes of differentiation: no differentiation (sedimentation is completely compensated by re-entrainment); differentiation is controlled by a competition between crystal settling and turbulent or laminar remixing; differentiation is catastrophic in the sense that all the crystals settle down or float because the heat flux from the magma ocean is unable to remove the heat dissipating from sedimentation.

There are three pronounced critical periods for differentiation – the uncertainties in kinetics are so large that other intermediate cases occupy only a small space in the parameter range. Already in the very beginning of crystallization, the differentiation could be catastrophic that results in a complete "ideal" fractional crystallization. This happens, for example, if the crystals grow to 1 cm size. If this period is passed, the second critical period occurs when the "wet" adiabats drop below liquidus everywhere. Now, the time for ripening is several orders of magnitude larger because it is controlled not by the curculation time scale but by the time scale of the complete crystallization. The last critical moment occurs when the crystal fraction beneath the surface reaches some critical value $0.3 - 0.7$. At this point, the partially molten region extends to pressures 5-10 GPa. It differentiates via melt expulsion by compaction forming a crust and a depleted layer. Stratification occurs in any case. However, in the first case, the entire mantle is differentiated and the mantle consists of 4-5 chemically different layers. The depleted layer beneath the crust could be up to 500 km. In two other cases, the differentiation is limited mostly by the upper mantle. The minimum thickness of the depleted layer is about 100 km. However, such a thin layer implies a small degree of differentiation and a small chemical density difference, and as a result the stratification is convectively unstable. Although it is still an open question, we beleive that the difference from the crystallization of a terrestrial magma ocean (likely to result in a small degree of differentiation) could be due to the volatile content. This works in several ways: composition of the early atmosphere can change the cooling rate and convective velocities by several orders of magnitude; the crystal growth rate can be changed by 1-2 orders of magnitude and the viscosity of magmas is also very sensitive to volatiles.

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