CHEMICAL DIFFERENTIATION OF A CONVECTING PLANETARY INTERIOR: CONSEQUENCES FOR ONE-PLATE PLANETS SUCH AS VENUS; E.M. Parmentier and P.C. Hess, Department of Geological Sciences, Brown University, Providence, RI 02912

In a large planet, crust is generated by partial melting of the convecting planetary interior. Melt extraction lowers the density of residual mantle by reducing its Fe/Mg and by removing dense Al-rich phases such as garnet. The melting temperature of this depleted residual mantle is also increased. In the presence of plate tectonics, depleted mantle is almost certainly mixed back into the mantle by the deep circulation driven cold, strong, sinking lithosphere. In the absence of plate tectonics, mixing will be much less complete. Formation of the crust thus gives rise to the possibility of a buoyant, refractory depleted layer at the top of the mantle (1). This layer, once present, could inhibit the development of plate tectonics.

Such a buoyant, depleted mantle layer can help explain a number of important characteristics of Venus (2). 1) The apparent depth of compensation of many large-scale surface topographic features is much larger than on the Earth. If these features are created by density variations in a viscous mantle, a low viscosity zone cannot be present in the Veniran upper mantle (cf. 3). The absence of a low viscosity layer, which would occur where the mantle approaches its melting temperature, can be explained by a mantle layer that is colder and has a higher melting temperature than normal mantle. The most deeply compensated features on Venus are swell-like highland regions that are thought to be the surface expression of mantle plumes (3). If plumes rise only to the bottom of a depleted mantle layer, the melting that creates the surface volcanism will locally thicken the buoyant layer. This greater thickness of low density mantle may support the swell-like surface topography. If so, the apparent depth of compensation may reflect the thickness of the depleted mantle layer. Melting beneath a thick depleted mantle layer will also generate MgO-rich melts (4) that are more fluid than melts generated at shallower depth. This may explain the long lava flows observed on Venus (4,5). 3) The presence of a depleted mantle layer will also affect surface volcanism. Small-scale surface extension that causes only shallow upwelling, will not produce melt. Rift zones should thus be relatively free of intra-rift volcanism as appears to be the case on Venus (cf. 6,7). Upwelling beneath large-scale zones of extension will penetrate to greater depth and so be less affected by a shallow depleted mantle layer. 4) Impact craters on Venus give an apparent surface age of about 500 Myr. These craters are only infrequently modified by the volcanism which otherwise appears to be so abundant (5). One explanation is that volcanism and the generation of crust is highly episodic. Evolution models described below illustrate that a chemically depleted layer can become gravitationally unstable as a planet cools. A pulse of crustal generation results as this layer sinks into the interior. It is interesting to speculate that such a gravitational instability could release the potential energy needed to form a large compressional highland such as Ishtar Terra (8). 5) Finally the formation of a buoyant, depleted mantle layer might explain why plate tectonics has apparently not developed on Venus.

We have formulated models to explore the formation and dynamics of a buoyant, depleted mantle layer. To conserve energy, the secular change in internal thermal energy must balance the difference in radioactive heat produced and heat transfer to the planetary surface. Heat transfer is controlled by the Rayleigh number of convection in the interior (cf. 9). Heat is only conducted through the depleted layer which turns out to be at most a few hundred km thick and highly depleted in heat producing elements. Since hot mantle must be cooled in the thermal boundary layer, this material rises into the boundary layer and undergoes decompression melting. We assume the all the melt generated is extracted and use a melting temperature that varies linearly with pressure, increasing from 1100°C at the surface to 1800°C at 400 km depth, and a heat fusion of 420 J/g. A 25% maximum degree of melting corresponds to reasonable amounts of garnet and clinopyroxene in the mantle. The density of depleted mantle is linearly related to the amount of melt extracted, with 25% melt extraction reducing density by the same amount as increasing the temperature by 500°C. The depleted layer is assumed to float as long as its bulk density is less than that of the underlying mantle. As the planet cools the density of the depleted layer increases. The portion of the planet with a temperature below a prescribed value, 900°C in the following
CHEMICAL DIFFERENTIATION OF A CONVECTING PLANET
E.M. Parmentier and P.C. Hess

examples, does not flow. The remaining, hotter portion of the depleted layer is assumed to mix with the convecting mantle if its bulk density exceeds that of the underlying mantle. In the following examples, the viscosity of the convecting mantle is $10^{21}$ Pa-s. The radioactive heating and the initial temperature are varied over reasonable ranges. Radioactive heating in model (a) is small, while that in models (b) and (c) is 1/4 of that required to generate the earth’s heatflow. In model (c), depleted mantle accumulates until further cooling makes the layer unstable. Residual mantle is then continually mixed back into the convecting mantle while the crust thickens. In contrast, the depleted layer in the hotter models (a) and (b) increases initially, undergoes a period of no growth, and finally thickens again as it is stabilized by strengthening due to cooling. During this part of the evolution, the crust thickens continuously. Later in the evolution, a substantial fraction of depleted layer becomes unstable resulting in an episode of rapid crustal generation that would resurface the planet. Such an episode of resurfacing may explain why volcanically modified impact craters are rarely observed on Venus (5).

![Figure 1. Thermal evolution (upper left) of three models examined. Crustal and depleted layer thicknesses as a function of time in each of the models.](image)

References:  
(8) D.L. Bindschadler and E.M. Parmentier, JGR 95, 21329, 1990.  