PARAMETERIZED CONVECTION MODELS OF THE DEGASSING HISTORY OF THE EARTH AND VENUS. David R. Williams and Vivian Pan, Department of Geology, Arizona State University, Tempe, AZ 85287

The degassing history of the interior of a terrestrial planet has important implications to the evolution of the planet's mantle as well as its atmosphere (and hydrosphere). Parameterized convection models can provide us with broad pictures of the thermal evolution of a planet through time, at the expense of representing mantle parameters in terms of simplified bulk values. We have developed a parameterized mantle convection model for the Earth and applied it to various degassng/ regassing scenarios. We are now looking at the evolution of Venus, and are using our Earth model to draw some preliminary conclusions.

We assume whole mantle convection with an aspect ratio of one. The mantle is internally heated and heat flow from the core is neglected. The concentration of radiogenic elements is constrained to give a present day terrestrial mantle heat flow of 70 mW/m^2 (1). A heat flow/ Rayleigh number relationship appropriate for an internally heated case (2) is used. The viscosity is temperature, volatile content, and stress dependent, and is determined by the flow law equations (3) with a stress exponent of 3.6 (4). The value of the pre-exponential constant in the flow law is calculated to be 0.91 $MPa^{-3.6}s^{-1}$ by assuming a viscosity of 5×10^{17} m^2/s and a temperature of 1700 K at a depth of 400 km. The melting temperature at this depth for the Earth is taken as 2190 K (5). The dependence of the melting temperature on volatile content is assumed to be a linear function of the weight fraction of water in the mantle.

For the Earth, we take the approach that the degassing and regassing rates are functions of the spreading velocity (1). Given the concentration of water released at a spreading center versus the concentration subducted, an equilibrium value of mantle water content can be determined, independent of the spreading rate.

The parameterized convection calculation was run for 4.6 billion years assuming an initial mantle homologous temperature (actual temperature divided by melting temperature), and the effects of various parameters were examined. Figure 1 shows that degassing of the mantle takes place rapidly for most cases, reaching an equilibrium value in less than 200 My. The solid line shows the nominal case (1), to which the other cases are compared. The dotted line shows a "cold-start" case, with an initial homologous temperature of 0.8 in contrast to 1.2 for the nominal case. For this example, the loss of water from the mantle is considerably slower. The dashed/dotted line shows the case in which the efficiency of melting is assumed to decrease with time as the Earth cools. For this case, the rapid early degassing leads to a net regassing of the mantle through time, and concurent loss of water from the Earth's hydrosphere to the present day.

Venus exhibits a number of obvious differences from the Earth, including little or no evidence of active plate tectonics, a higher surface temperature (740 K compared to 273 K for Earth), lower atmospheric abundance of ^{40}Ar, and a low resurfacing rate. The low ^{40}Ar and resurfacing rates could be the result of a high degree of intrusion versus extrusion, coupled with inhibited surface erosion and transport, which would have the effect of leaving the intrusive rocks unexposed, and hence keep ^{40}Ar (and water) from reaching the atmosphere. Alternatively, these factors could be indicative of fundamentally different processes occuring in the interior of Venus. It is possible that the Moon-forming collision left the Earth depleted in water relative to Venus, but that most of Venus' water now resides deep in the interior due to the higher density of melts at depth (6). We have suggested that a water-rich mantle will evolve a "cold-trap" at about 100 km depth due to hydrous phases resolidifying as eclogite at this depth, and that water and crust-forming melts will be prevented from reaching the surface (7). Initiation of this process depends on the mantle cooling sufficiently before losing so much water that the hydrous mineral phases cannot form. As we have shown for the Earth, the loss of water occurs quite early due to the rapid degassing. We have modified the Earth model to attempt to gain a preliminary understanding of the degassing history of Venus.

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We follow previous work (8), and adapt our model to a surface temperature of 740 K, a decreased degassing rate, and eliminate regassing. For a Venus mantle enriched in water by a factor of three, and a net degassing one-third the nominal Earth value, we find close agreement with the previous study (8, case d). That is, the present day mantle temperature is lowered by hundreds of degrees K from the minimal case. This is a necessary condition for the "cold trap" to operate on Venus (7). The other condition is that enough water (~0.2 wt.%) is left in the mantle when the temperature reaches a point where the "cold trap" process can start, i.e., when the homologous temperature is less than 1.

To study this condition, we have used the nominal Earth case, with a surface temperature of 740 K and again assumed an initial mantle water content three times the Earth's. This is equivalent to assuming that plate tectonics was operating on the early Venus, which may not be the case. The point is to maximize the efficiency of water loss from the Venus mantle and therefore get the most conservative estimate of the amount of water remaining in the mantle. As the line in figure 1 shows, the water is lost rapidly. However, at time t = 9 My (arrow) the temperature has dropped below the melting temperature and the mantle still contains 0.26 wt.% water, enough for the "cold trap" to work.

If crust forming melts can no longer reach the surface at this stage, less efficient mechanisms of heat transport will take place. This could lead to net heating of the mantle, and eventually cause the bulk temperature to exceed the melting temperature, shutting off the "cold trap". The more efficient heat loss resulting from this process would then cool the interior, the "cold trap" would be reactivated, and the cycle would repeat itself. Each cycle would result in loss of water from the mantle, but the net loss of volatiles over time would be inhibited. Episodic volcanism on Venus, both temporally and spatially, could be the result of this process, and this in fact may be what is seen in the Magellan images. These are only preliminary results, however, and many of the parameters, particularly for Venus, are poorly constrained. A more complete analysis of these processes will require further detailed calculations.

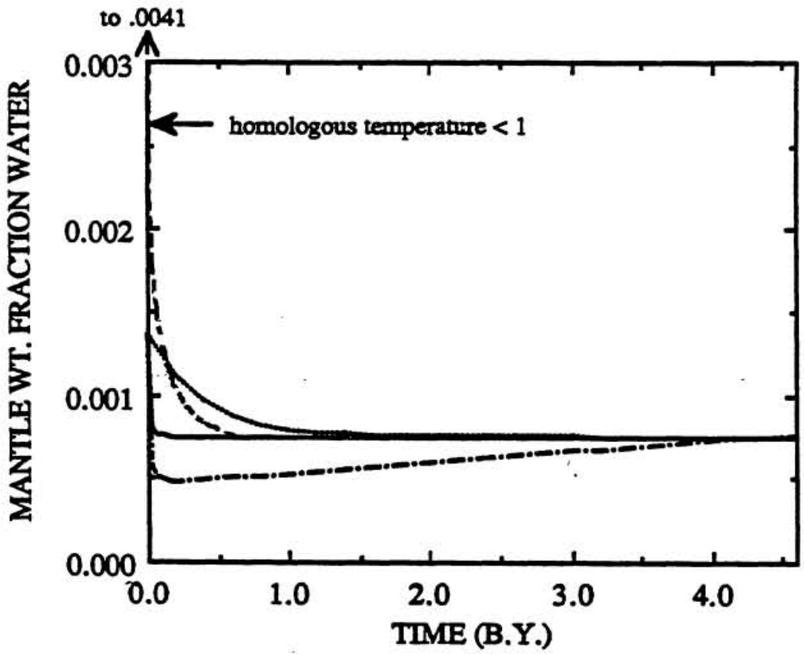

Figure 1 - Mass fraction of water in the mantle vs. time for various parameterized convection cases. Case 1 (solid line) - Earth: nominal case; Case 2 (dotted line) - Earth: initially cool mantle; Case 3 (dashed/dotted line - Earth: change in outgassing efficiency with time; Case 4 (dashed line)- Venus: high initial water content. Cases are explained in the text.

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