TECTONICS AND COMPOSITION OF VENUS

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Abstract. The uncompressed density of Venus is a few percent less than the Earth. The high upper mantle temperature of Venus deepens the eclogite stability field and inserts a partial melt field. A thick basaltic crust is therefore likely. The anomalous density of Venus relative to the progression from Mercury to Mars may therefore have a tectonic rather than a cosmochemical explanation. There may be no need to invoke differences in composition or oxidation state.

The density of Venus is 1.2 to 1.9% less than that of the Earth after correcting for the difference in pressure [Ringwood and Anderson, 1977; Smith, 1979]. This has been attributed to differences in iron content [e.g., Kovach and Anderson, 1965], sulfur content [Lewis, 1972] or oxidation state of the mantle [Ringwood and Anderson, 1977]. Except for Venus there is apparently a decrease in iron content or an increase in oxidation state as one progresses away from the sun to Mercury to Mars. This trend is presumably related to the pressure and temperature gradient in the early solar nebulae.

I have recently argued [Anderson, 1979] that most of the original basaltic crust of the Earth subducted when the upper mantle temperatures cooled into the eclogite stability field. The density difference between basalt and eclogite is about 15%. Because of the high surface temperature on Venus the upper mantle temperatures are 200-400 K hotter in the outer 300 km or so than at equivalent depths on the Earth [Ringwood and Anderson, 1977; Toksöz et al., 1978].

Since the deep interior temperatures of the two planets are likely to be similar the near surface thermal gradient is controlled by the thickness, $\delta$, of the conductive thermal boundary layer. This is related to the Rayleigh number, $Ra$, and the thickness, $D$, of the underlying convecting layer by

$$\delta \propto Ra^{-1/3} D$$

where

$$Ra = \frac{ag\Delta T D^3}{K\nu}$$

The Rayleigh number depends on the coefficient of thermal expansion, $\alpha$, gravitational acceleration, $g$, temperature rise across the layer, $\Delta T$, thermal diffusivity, $\kappa$, and kinematic viscosity, $\nu$. The largest difference between Earth and Venus is the viscosity since this depends exponentially on temperature and pressure. The higher temperatures in the outer layer of Venus and the lower pressures throughout serve to decrease the average viscosity of the Venus mantle by at least several orders of magnitude. The other parameters in the Rayleigh number are only weakly dependent on temperature or on the size of the planet. Because of the thinner boundary layer the near surface thermal gradient is steeper in Venus than the Earth. The net result is that the deep mantle adiabat is brought closer to the surface. This has interesting implications for the phase relations in the upper mantle and the evolution of the planet.

Schematic geotherms are shown in Figure 1 for surface temperatures appropriate for Earth and Venus. With the phase diagram shown, simplified from Wyllie [1971], the high temperature geotherm crosses the solidus at about 85 km. With Yoder's [1976] phase relations the eclogite field is entered at a depth of about 138 km. For Venus, the lower gravity and outer layer densities increase these depths by about 20%. Thus, we expect a surface layer of 100 to 170 km thickness on Venus composed of basalt and partial melt. This is in dramatic contrast to...
the Earth where the oceanic basalt layer is only 6 km thick and the average crustal thickness is 20 km. The tectonics on Venus is likely to be quite different from the thin plate-deep subduction style that we see on Earth.

A large amount of basalt has been produced by the Earth's mantle, but only a thin veneer is at the surface at any given time. There must therefore be a substantial amount of eclogite in the mantle which I have estimated to be the equivalent of about 450 km in thickness. If this were still at the surface as basalt the Earth would be 3% less dense. Correcting for the differences in temperature, surface gravity and mass and assuming that Venus is as well differentiated as the Earth but with a different basalt/eclogite ratio, the uncompressed density of Venus is calculated to be about 0.8 to 1.5% less than the Earth. We have assumed that the outer 100 to 170 km of Venus, which includes both basalt and partial melt, is 18% less dense than eclogite. Thus, depending on the composition of the basalt and the phase diagram chosen, most or all of the difference in density between Earth and Venus may be accounted for without invoking differences in composition or oxidation state. Venus may be closer to the Earth in composition than previously thought.

It is possible that the present tectonic style on Venus is similar to that of the Earth in the Archean when temperatures and temperature gradients were higher.

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References


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