CONSTRAINTS ON THE BASALT TO ECLOGITE TRANSITION AND CRUSTAL RECYCLING ON VENUS  S. G. Herzog, P. C. Hess, and E. M. Parmentier.
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The transition of basaltic crust to eclogite is critical to the behavior of Venus' crust and mantle. The transition of basalt to eclogite is induced by compression (positive P-T slope), and is dependent on the thermal structure of the planet. If the basaltic crust is thickened sufficiently the base of the crust may enter the pressure regime of eclogite stability, and conversion to eclogite will make the crustal base negatively buoyant. This may result in subsidence or delamination, either of which will limit the elevation of mountain belts [1], and may promote instability of the entire crust, leading to catastrophic resurfacing of the planet [2]. We have approached the problem of delineating P and T conditions of the basalt - eclogite transition from three points: analysis of published data on natural eclogites; analysis of published data on residual phases in melting experiments; and laboratory experiments (preliminary). Eclogite will be stable at pressures greater than approximately 1.2 GPa at 800°C, or at a crustal depth greater than about 50 km. The gradual transition to eclogite will increase the density of the crust so that negative buoyancy may be achieved at smaller thicknesses. The presence of water in the crust will increase the rate of reaction and favor the transition.

On a planet with plate tectonics, like the present day Earth, the oceanic lithosphere including the basaltic crust is recycled into the mantle at convergent plate boundaries. On a volcanically active planet without plate tectonics, such as Venus, it is important to understand how crust that thickens with time can be recycled. Rayleigh-Taylor (R-T) instability due to the basalt-eclogite transition at the base of a thickening or cooling crust is an obvious mechanism. But what is the rate and scale of this process and what would its surface manifestation be? Does crustal instability occur as a fine eclogite rain or as mantle downwelling at the scale of compressional highlands? Equating the growthrate of R-T instability Δg/4πμ with the rate of layer thickening h/h gives an estimate of the layer thickness h=(4πμΔg)/μ at which the formation and sinking of eclogite diapirs balances the rate of eclogite creation. Here Δg is basalt-eclogite density difference, μ is the eclogite viscosity, and g is the gravitational acceleration. The wavelength of instability, assuming that the viscosity of underlying mantle, μm, is less than the eclogite layer, is λ=4πh(μμm)1/5. Since the basalt-eclogite transition is exothermic, the creation rate of eclogite could be controlled by heat loss by conduction to the surface so that h=kΔT/Hd where k is the thermal conductivity, ΔT is the temperature difference between the base of the crust and the surface, H is the heat of reaction, and d is the crustal thickness. For a crustal thickness of a few tens of kilometers and reasonable values of other parameters, this gives a horizontal scale of about 20 km and an eclogite diapir diameter (4λ^2h/π)^1/3 of about 10 km. However, this order of magnitude estimate depends strongly on the thermodynamic properties and kinetics of the basalt-eclogite phase transformation at the temperature present near the bottom of the Vensian crust.

Eclogite sensu stricto consists of garnet and jadeitic clinopyroxene. The transition to eclogite occurs gradually through the production of garnet and disappearance of plagioclase, with granulite the intermediate assemblage. Eclogite is denser than basalt (approximately 3.5 g cm^-3 cf. basalt: approximately 2.9 g cm^-3), and is likely to be more dense even than the upper mantle because partial melting of the mantle generates both a basaltic crust and a positively buoyant residual mantle. The P-T conditions at which the basalt - eclogite transition would be expected to occur on Venus are not well understood because of the difficulty of experimental investigation, but we have been investigated at higher temperatures [3]. If the surface temperature is held to be 475°C, and the maximum temperature difference across the crust, regardless of thickness, is about 400°C [1], the base of the crust will be less than about 900°C.

Mineral equilibrium thermometry and barometry has been applied to constrain the temperature and pressure of equilibration of terrestrial eclogites and coexisting rocks. Fifty-three published values of derived pressure and temperature for terrestrial eclogites of broadly basaltic composition have been plotted (Fig. 1). Some of these compositions include hydrous accessory phases, which indicate sufficient water content to kinetically favor the transition, but do not appear to affect the
stability field of eclogite. The data points form an array with values centered approximately from 500 C and 1.3 GPa to 800 C and 1.8 GPa. No eclogites are found below a temperature of 400 C, and the eclogite occurrences appear to reach a plateau at a minimum of 1.2 GPa. Maximum temperature and pressure conditions of equilibration of the intermediate granulite assemblage are 700 to 1000 C and 0.4 to 1.2 GPa [4]. The P and T of the transition vary with bulk composition, but are constrained by these data to lie between approximately 0.8 and 1.4 GPa at 800 C.

Residual phases produced during partial melting experiments can provide pressure-temperature-mineral stability information because rates of reaction are enhanced by the presence of melt. Partial melting of various compositions may produce a broadly basaltic (chemically) residue whose stable phases are either in equilibrium with the liquid, or last equilibrated below the peak P and T conditions imposed on the sample. We have gathered data on residues of (chemically) basaltic composition [5,6,7,8,9]. Water-saturated melting experiments at 550 C and above yield garnet, pyroxenes, and hydrous phases at pressures of 1.0 up to 2.6 GPa. Excess water in experimental charges does not prevent eclogite formation, but requires accompanying hydrous phases. Dehydration melting experiments yielding basaltic residues did not generate eclogite at pressures up to 1.0 GPa and temperatures from 850 to 1000 C. At pressures of 1.6 GPa and above at temperatures as low as 950 C the granulite mineralogy was stable. Eclogite was produced in dehydration melting experiments at pressures of 2.2 GPa at temperatures of 1050 C and above.

A crustal thickness of 50 km would place the base in the eclogite stability field. The presence of water in the crust will kinetically favor the transition to eclogite. Although the crust of Venus is dry, the atmospheric pressure is about 100 bar, and thus exsolution of water (bubbles) requires approximately 1 weight percent water in the magma, so a crust with hydrous phases is not excluded by a dry atmosphere. Eclogite formed at the base of the crust will depress or delaminate from the crust. If this is the case, the high topography on Venus is a dynamic feature permitted by the rate of elevation increase exceeding that of the transformation of basalt to eclogite.

Fig 1. Eclogite vs. Granulite Stability