THE GABBRO - ECOLOGITE PHASE TRANSITION AND THE ELEVATION OF MOUNTAIN BELTS ON VENUS; Noriyuki Namiki and Sean C. Solomon,
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Introduction. The linear mountain belts of Ishtar Terra on Venus are notable for their topographic relief and slope and for the intensity of surface deformation [1,2]. The mountains surround the highland plain Lakshmi Planum, the site of two major paterae and numerous other volcanic features and deposits [3,4], and evidence is widespread for volcanism within the mountains and in terrain immediately outward of the mountain belt units [2,4]. Whether western Ishtar Terra is a site of mantle upwelling and consequent hot spot volcanism [5-7] or of mantle downwelling and consequent convergence of lithospheric blocks [8,9] is currently a matter of debate. However, the mountains are generally regarded as products of large-scale compression of the crust and lithosphere [2,10].

Among the four mountain belts surrounding Lakshmi Planum, Maxwell Montes is the highest and stands up to 11 km above the mean planetary radius and 7 km above Lakshmi Planum. The bulk composition and radioactive heat production of the crust on Venus, where measured, are similar to those of terrestrial tholeiitic basalt [11]. Because the thickness of the low-density crust may be limited by the gabbro - garnet granulite - eclogite phase transitions (Fig. 1), the 7-11 km maximum elevation of Maxwell Montes is difficult to understand except in the unlikely situation that the crust contains a large volume of magma [12]. A possible explanation is that the base of the crust is not in phase equilibrium. It has been suggested that under completely dry conditions, the gabbro - eclogite phase transition takes place by solid state diffusion and may require a geologically significant time to run to completion [13]. Solid state diffusion is a strongly temperature-dependent process. In this paper we solve the thermal evolution of the mountain belt to attempt to constrain the possible depth of the gabbro - eclogite transition.

Thermal Model. The one-dimensional heat equation is solved numerically by a finite difference approximation. The deformation of horizontally shortening lithosphere is assumed to occur in the manner of pure shear, and therefore the vertical velocity is given by the product of the horizontal strain rate $\dot{\gamma}$ and depth $z$. The thermal diffusivities are assumed to be $1.0 \times 10^{-6} \text{m}^2\text{s}^{-1}$ in both crust and mantle. Crustal heat production is assumed to equal $1.4 \times 10^{-13} \text{Ks}^{-1}$. Temperature at the surface and the bottom of the lithosphere are fixed at 750 and 1500 K. The initial temperature profile is determined by the assumption of steady-state conditions with zero velocity.

The phase diagram is assumed to be that of quartz tholeiite [14], and the densities of gabbro and eclogite are taken to be 2900 and 3500 kg m$^{-3}$. The density of garnet-granulite is assumed to increase linearly from that of gabbro to that of eclogite as pressure increases at a given temperature. The density of the mantle is assumed to be 3400 kg m$^{-3}$. According to [13] the characteristic reaction time of the gabbro - eclogite transformation is governed by the solid state diffusion of $\text{Al}^{3+}$ in $\text{Al}_2\text{O}_3$,

$$\tau = \frac{\delta^2}{D_0 \varepsilon \text{exp}^{\frac{A}{RT}}}$$

where $\delta$ is the grain size, $D_0$ is the diffusion frequency, $2.8 \times 10^{-5} \text{m}^2\text{s}^{-1}$, and $A$ is the activation energy divided by the gas constant, $5.7 \times 10^4 \text{K}$. The extent of reaction in each grain is calculated at each time step by simply dividing the time step by the characteristic reaction time at a given temperature. Then this extent of reaction is summed at each depth, and the density at a given depth is determined from the volume fractions of unreacted and reacted components.

Numerical Results. Temperatures in the thickening lithosphere are calculated for strain rates of $10^{-15}$ (Fig. 1a) and $10^{-16}$ s$^{-1}$ (Fig. 1b). In both cases, crustal and to
lithospheric thicknesses are assumed to be initially 20 and 40 km, respectively, and increase to values of 100 and 200 km, respectively. Temperature distributions at a given total strain do not differ significantly for the two strain rates because heat is mainly transferred by advection, and the temperature increase due to crustal heat production is minor. However, the temporal variations of elevation of the mountain belt are different (Fig. 2). For a strain rate of \(10^{-15}\) s\(^{-1}\), gabbro remains metastable for 50 My, and elevation can increase as much as 12 km above the surrounding plains. For a strain rate of \(10^{-16}\) s\(^{-1}\), the maximum elevations depend on the assumed grain size. For a larger grain diameter (\(\delta=10\) mm), the phase transition does not proceed deeply into the grains. For smaller grains (\(\delta=1\) mm), gabbro is transformed to garnet-granulite and eclogite, and because of these phase transitions there is a maximum elevation of 8 km above the undeformed plains.

Discussion. The apparent difficulty in supporting the maximum elevation of mountain belts on Venus can be explained if mountains form on a time scale comparable to or less than the characteristic time of the gabbro - eclogite phase transition. However, the estimation of this characteristic time has a large uncertainty due to a paucity of experimental data. The minimum strain rate to account for elevations as great as in Maxwell Montes is also sensitive to the initial temperature at the base of the crust.