Crustal Thickening Above a Convecting Mantle with Application to Venus and Mars

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Abstract: Understanding the response of a near surface chemical layer to the deforming nature of a convecting mantle is useful for addressing several problems of planetary tectonics. It has been suggested that highlands on Venus (Ishtar, in particular) have formed via crustal thickening, be it viscous thickening or thrust stacking, over regions of mantle downwelling. It has also been suggested that the Martian highlands may have formed via crustal thickening above a mantle downwelling. To help in evaluating the physical plausibility of these hypotheses, we explore a simplified system of chemical layer thickening above a convecting mantle. The simple system allows us to develop insight into the physical condition that does or does not allow for crustal thickening above a convecting mantle.

Chemical layers can be stabilized from deformation by possessing a higher viscosity and/or a higher plastic yield strength than the convecting mantle. Numerical simulations were conducted to determine the transitions between viscous and localized plastic deformation of a chemical layer within a convecting mantle. Several deformation responses were mapped, as were the parameter conditions required for lithosphere stability.

As the Rayleigh number increases, the buoyancy ratios and chemical boundary layer (CBL) thicknesses required for stability decrease. The viscosity contrast that leads to stability decreases with the CBL thickness and extent and is independent of the Rayleigh number. As the Rayleigh number increases, the friction coefficients and CBL thicknesses required for stability decrease. These results are consistent with simple physical scaling laws. Outside of the stability parameter windows, both localized and distributed deformation modes were observed. It is in these parameter windows that crustal thickening above mantle downflows becomes viable. Further scaling laws are being developed to help physically explain the parameter space transitions from localized to distributed deformation regimes.

A preliminary conclusion is that crustal thickening on Mars and Venus can be achieved via localized deformation even in presence of high viscosity (i.e., dry and/or cold) crust that would inhibit viscous deformation.

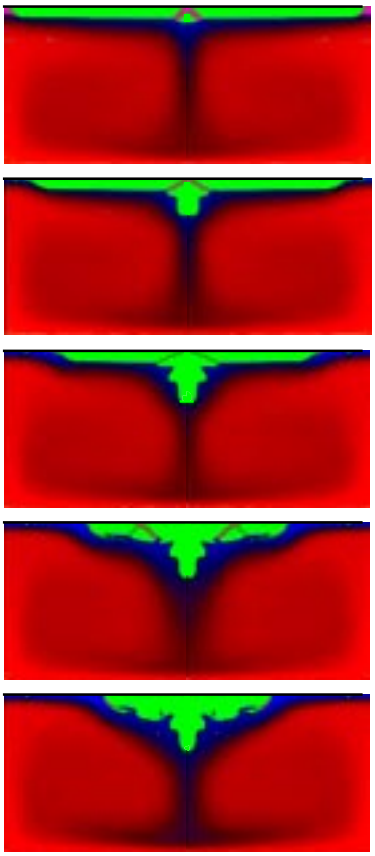

Figure 1: *Crustal Thickening via localized deformation* – Chemical layer (in green) is thickened by thrust stacking of material. Yielding occurred along localized zones of failure highlighted in bring pink.