The role of intrusive magmatism in shaping Venus’ present-day crust and its age distribution

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In its bulk properties, Venus appears similar to Earth, but both planets have developed substantially different geodynamic regimes. Earth has plate tectonics with a continuously renewed surface and its crustal distribution is very dichotomous in composition, thickness, and age. Venus, on the other hand, presently displays a period of a stagnant-lid regime, which may or may not was interrupted by catastrophic events of tectonic recycling during its history. Venus’ crustal thickness is not well constrained, but likely thicker than Earth’s oceanic crust; pronounced crustal dichotomy may be possible but evidence needs yet to be found. The age of the crust appears rather uniform, which traditionally has been taken as evidence that an episodic overturn must have taken place. However, recent arguments have challenged the episodic overturn hypothesis and favor a more continuous stagnant lid on Venus.

To resolve the problem of Venus’ geodynamic regime understanding the generation of Venus’ crust in a dynamic context that also considers the underlying mantle is necessary. This can be achieved using numerical models of mantle convection tailored to Venus, which include the basic complexities of planetary mantle convection in terms of effective rheology, mineralogy and melting processes. Still, previous models have essentially failed to predict the thickness and age characteristics of Venus’ crust. One possible reason is that these models only considered extrusive volcanism, which renews the surface directly, while intrusive magmatism does not. Yet, intrusion seems the dominant mode of magmatism at least on Earth, so we investigate its influence in our model and evaluate whether this ingredient is key to predict Venus’ crustal characteristics.

Using the code StagYY, we compute a suite of mantle convection models in 2D spherical annulus geometry that run through the entire solid-state history of Venus. We vary the partitioning of intrusive and extrusive volcanism from purely extrusive to dominantly intrusive and predict the present-day distributions of crustal thickness and surface age in the stagnant lid regime. With more intrusive magmatism, average crustal thickness is reduced by 20-25%, but mean crustal thickness still exceeds other independent estimates. The surface is on average much older, which is more consistent with mean age estimates from crater counting. However, lateral age variations
also become stronger with dominantly intrusive volcanism, which indicates that volcanism keeps going on, but is more restricted spatially. Governing parameters like mantle reference viscosity and relative enrichment of heat-producing elements into the crust change the absolute values of mean crustal thickness and surface age, but do not improve surface age uniformity. This is somewhat at odds with Venus' seemingly uniform surface age, so suitable conditions for this possibility are further evaluated in models featuring episodic overturn events.