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Crustal decoupling and mantle dynamics on Venus: implications for Earth-like planets

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Venus is physically similar to Earth but with a hot dense atmosphere and no oceans; four-fifths of its surface is apparently volcanic in origin and likely basaltic in composition. Erosion and sedimentary processes are largely absent, preserving a near-random distribution of impact craters that led to the hypothesis of episodic global resurfacing, which proposes that the entire lithosphere was recycled in a short period ($\sim$50 Ma) about 750 Ma ago, and is currently in a stagnant-lid state, in which the crust and lithosphere are strongly coupled to a sluggishly convecting mantle.

This hypothesis is at odds with the complex and diverse range of geological features on Venus that imply a continuum of activity, at a level at least similar to Earth's continental interiors, with little evidence for a sudden change in past rates of activity. An alternative hypothesis is presented here based on geological interpretation, topographic and gravitational data, and geomechanical inferences. The elevated surface temperature results in a weak lower crust, similar to certain terrestrial continental crust strength profiles, that is effectively decoupled from the mantle. The subcrustal lithosphere is therefore able to behave in a plate-like way, with boundary conditions defined by the base of the crust. Hypsographic data are used to infer the average plate thickness (100 $\pm$ 6 km), subcrustal plate creation rate (3·8 to 4·6 km^2 a^{-1}) and mean half-spreading rate (29 to 35 mm a^{-1}). The observed 55,000 to 65,000 km long network of rift systems observed on Venus are predicted to correspond to subcrustal spreading ridges; fits to their topography demonstrate that they are consistent with the model but with a range of subcrustal spreading rates from 11 to 97 mm a^{-1}. Geoid lows correspond well with predicted sites of subcrustal subduction. Since stress transmission is restricted by the weak lower crust, the surface is tectonically modified at only a modest rate, similar to terrestrial (intraplate) continental interiors. The higher background heat flux results in a higher incidence of intraplate volcanism than on Earth, in a relatively random distribution that mirrors the near-random distribution of impact craters and results in the observed mean surface age.

While these conditions occur on Venus in basaltic crust because of its extreme surface conditions, it offers insight into mantle dynamics beneath Pangaea or an Earth-like planet entirely covered by continental crust. An ESA M-class mission, EnVision, is proposed to undertake InSAR measurements at Venus to determine rates of ground displacement in order to distinguish between these two models.