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Dynamical modelling of lithospheric extension and small-scale convection: implications for magmatism during the formation of volcanic rifted margins

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Enhanced melt productivity as a consequence of buoyant upwelling and small-scale convection of the mantle during rifting may play an important role in determining the fundamental structure of igneous crust produced during and following continental breakup. We investigate the relationship between rift-related decompression melting and the influence of small-scale mantle convection and rift geometry on the subsequent production and distribution of melt-related crust. Extension of the lithosphere is modelled numerically using a two dimensional plane-strain finite element method for viscous-plastic creeping flows. The evolving temperature and pressure fields within the model are coupled to an algorithm that predicts the amount and timing of decompression melting of upwelling mantle. Predicted melt fractions are converted to equivalent thicknesses of igneous crust, and the predicted crustal thicknesses for a series of models are compared to the observed crustal structure of rifted margins inferred from seismic data. Models characterized by small-scale mantle convection can to first order reproduce the general architecture of most volcanic rifted margins, that is, a relatively narrow band of thick (12-13 km) igneous crust (inferred to occur along strike of the margin), juxtaposed with thinner oceanic crust farther offshore. The variability in thickness (4-7 km) predicted for the later-stage thinner igneous crust is however difficult to reconcile with global observations of oceanic crustal thickness (7$\pm$1 km). Also, the peak 13 km thickness of igneous crust predicted for models with convectively enhanced upwelling fails to match the great thicknesses (> 20 km) of igneous crust observed at many volcanic margins. Composite models that include both small-scale convection and a small increase to mantle potential temperature predict large pulses in initial magmatism and generation of 17-21 km thick crust, followed by unstable production of thinner igneous crust. The results indicate that models with small-scale convection and no temperature anomaly may play a role in explaining the formation of volcanic margins with only moderately thick (11-15 km) igneous crust. Further, convection coupled with small increases to mantle temperature may be important during the initial phase of very thick igneous crust generation at some volcanic margins. Predicted distributions of igneous crust are moderately sensitive to asymmetric rifting of the lithosphere. Prior to breakup, igneous crust accretion is asymmetric; subsequent to breakup, symmetry in the thermal structure of the upwelling sub-lithospheric mantle is the dominant control on the final distribution of igneous crust.