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Mantle exhumation and OCT architecture dependency on lithosphere deformation modes during continental breakup: Numerical experiments

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The initiation of sea-floor spreading, during the continental breakup process, requires both the rupture of the continental crust and the initiation of decompression melting. This process results in mantle upwelling and at some point decompressional melting which creates new oceanic crust. Using numerical experiments, we investigate how the deformation mode of continental lithosphere thinning and stretching controls the rupture of continental crust and lithospheric mantle, the onset of decompression melting, their relative timing, and the circumstances under which mantle exhumation may occur. We assume that the topmost continental and ocean lithosphere, corresponding to the cooler brittle seismogenic layer, deforms by extensional faulting (pure-shear deformation) and magmatic intrusion, consistent with the observations of deformation processes occurring at slow spreading ocean ridges (Cannat, 1996). We assume that deformation beneath this topmost lithosphere layer (approximately 15-20 km thick) occurs in response to passive upwelling and thermal and melt buoyancy driven small-scale convection.

We use a 2D finite element viscous flow model (FeMargin) to describe lithosphere and asthenosphere deformation. This flow field is used to advect lithosphere and asthenosphere temperature and material. The finite element model is kinematically driven by Vx for the topmost upper crust inducing passive upwelling beneath that layer. A vertical velocity Vz is defined for buoyancy enhanced upwelling as predicted by Braun et al. (2000). Melt generation is predicted by decompression melting using the parameterization and methodology of Katz et al. (2003).

Numerical experiments have been used to investigate the dependency of continental crust and lithosphere rupture, decompression melt initiation, rifted margin ocean-continent transition architecture and subsidence history on the half-spreading rate Vx, buoyancy driven upwelling rate Vz, the relative contribution of these deformation components parameterised by the ratio Vz/Vx and the upper crustal pure-shear width W. Using numerical experiments, we explore temperature and material advection, decompression melt generation and subsidence for a sequence of 3 polyphase lithosphere deformation modes leading to continental breakup.

Pure-shear widths exert a strong control on the timing of crustal rupture and melt initiation. Buoyant upwelling, while not changing the timing of crustal rupture, speeds up continental lithosphere thinning and melt initiation. The lateral migration of the deformation flow axis also has an important control on the rupture of continental crust and lithosphere, and melt initiation; rapid migration generates a broad region of thinned continental crust, with no melt initiation or rupture of the continental lithosphere. We believe lithosphere deformation leading to breakup is polyphase. The new FeMargin model, described above, is applied and tested to the Iberia-Newfoundland conjugate margin profiles as shown by Sutra et al. (2013).