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Crustal Rheology and Rifted Margin Architecture: Comparing Iberia-Newfoundland, Central South Atlantic, and South China Sea

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Crustal rheology controls the style of rifting and ultimately the architecture of rifted margins: Hot, weak, or thick continental crust is dominated by ductile deformation and extends symmetrically into a wide rift system. Extension in cold, strong, or thin crust is accommodated by brittle faults and ductile shear zones that facilitate narrow rifts with asymmetric fault geometries. This recipe provides the standard framework to understand 2D rift geometry, however, a variety of processes exert significant control on subsequent rift evolution and ultimately on the architecture of rifted margins: inherited structures, melting and volcanism, 3D effects, extension rate, and weakening mechanisms. Numerical forward modelling studies have the opportunity to evaluate the influence of these processes on rift evolution in order to understand the complex interaction between rheology and tectonic history of specific margins.

Here I compare the formation of three different magma-poor margin pairs, Iberia-Newfoundland, the Central South Atlantic Rift Segment, and the South China Sea margins within a numerical forward modelling framework. I apply a 2D version of the finite element code SLIM3D, which includes nonlinear temperature- and stress-dependent elasto-visco-plastic rheology and is able to reproduces a wide range of rift-related deformation processes such as flexure, lower crustal flow, and faulting.

The Iberia-Newfoundland rifted margins are marked by moderate crustal asymmetry, with ~70 km of hyper-extended crust (less than 10 km thick) on the Iberian side and a very narrow margin on the Newfoundland counterpart. Similar to the Iberia-Newfoundland conjugates, the Central South Atlantic margins are predominantly asymmetric, however involve a much stronger degree of asymmetry with more than 200 km of hyper-extended crust offshore Angola, but only few tens of km at the Brazilian side. Kinematic and numerical modelling suggests that the asymmetry is caused by lateral migration of the rift centre, which generates sequential fault activity within the brittle crust. Rift migration results from two processes: (i) Strain hardening takes place in the rift centre due to cooling of upwelling mantle material. (ii) The formation of a low viscosity crustal pocket adjacent to the rift centre is caused by heat transfer from the mantle and viscous strain softening of the lower crust. These mechanisms generate a lateral strength contrast that promotes rift migration in a steady-state manner forming a wide sliver of hyper-extended crust on one margins side, while the conjugate margin becomes narrow.

In contrast to these Atlantic examples where wide margins are formed diachronously, the South China Sea evolved in wide rift mode. Here, several hundred kilometres of highly attenuated continental crust are deformed simultaneously during ~40 My of extension. Numerical modelling suggests that the presence of weak, ductile crust enabled the formation of two wide and symmetric margins. Independent indicators for a weak crust come from super-deep basins on the northern margin. These basins appear to be created after the end of active extension and with a significant deficit in brittle faulting, which suggests that subsidence was controlled by sediment loading and accommodated by lower crustal flow, a style of basin formation that is only possible in the presence of low crustal viscosity.