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On the relationship between sequential faulting, margin asymmetry and highly thinned continental crust

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The architecture of magma-poor continental margins is remarkably variable. The width of highly thinned continental crust (with a thickness < 10 km) varies from 70 km off Iberia, and 200 km offshore Angola, to over 300 km in the Antarctic Enderby Basin. The respective conjugate margin, however, is restricted to few tens of kilometres resulting in large scale crustal asymmetry. Growing evidence from rifted continental margins in the North and South Atlantic, as well as from the East Australia/Lord Howe Rise margin pair supports the idea that rifts with a very wide margin and a narrow conjugate are rather the rule than the exception. In this study, we use numerical thermo-mechanical models to investigate the dynamics of rifting. Our simulations apply an elasto-visco-plastic rheology formulation that relies on laboratory-derived flow laws for crustal and mantle rock. The models are constrained by geophysical and geological observations like limited melt generation, cold initial geotherms, and mafic lower crustal rheology.

We show that small-scale lateral rift migration simultaneously explains the observed margin asymmetry and the presence of highly thinned continental crust. Rift migration results from two fundamental processes: (1) Strain hardening in the rift centre due to cooling of upwelling mantle material; (2) Formation of a low viscosity exhumation channel adjacent to the rift centre that is generated by heat transfer from the upwelling mantle and enhanced by viscous strain softening. Rift migration takes place in a steady-state manner and is accomplished by oceanward-younging sequential faults within the upper crust and balanced through lower crustal flow.

We demonstrate that the rate of extension has paramount control on margin width. Since higher velocities lead to elevated heat flow within the rift and hence to hot and weak lower crust, a larger low-viscosity exhumation channel is generated that facilitates rift migration leading to wider margins. The South Atlantic is an ideal test bed for the hypothesis of velocity-dependent margin width since rifting was fast in the south, but slow in the northern part. As predicted by our numerical models, the maximum present-day margin width increases almost linearly from the conjugate Equatorial margin segments to the Florianopolis/Walvis ridge. Even though the polarity of the magma-poor South Atlantic margins alternates, the asymmetry and the width of the wider margin are in very good agreement with our simulations.

The described rift evolution has three fundamental implications: (1) It implies sustained transfer of material across the extensional plate boundary thereby predicting that large portions of a wide margin originate from its conjugate side. (2) Migration of the deformation locus causes faulting in the distal parts of the margin to postdate that of the proximal parts by as much as 10 million years. This means that syn-rift and post-rift phase are location-dependent. (3) Lateral movement of the rift centre generates drastically different peak heat flow and subsidence histories at the proximal and the distal margin.