Some Remarks on Lithospheric Extension: Insights from a Self-Consistent Asthenosphere-Lithosphere Numerical Model

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Dynamical models of rifting typically ignore the effects of sublithospheric convection, assuming an initial "steady state", conductive lithosphere geotherm and an isothermal asthenosphere. While such techniques may be valid to describe geodynamic processes which are fast (<10 m.y.) compared to the lithosphere diffusive time scale (~50 m.y.), they are not adequate to model the formation and structure of rift basins and passive continental margins, which often evolve through 10's or even 100's of m.y. In this work, we use a recently developed Lagrangian-Eulerian, self-consistent, thermo-mechanical numerical modelling code to examine how the initial lithosphere configuration and rate of lithospheric extension control the style of rifting (width, topography and structural framework), and address some long-standing issues associated with the formation of passive continental margins, such as: (1) depth dependent stretching; (2) the upper-plate paradox; and (3) the development of wide post-rift sag basins.

The modelling results suggest that the style of rifting primarily is controlled by the structure of the lithosphere. A thick mantle lithosphere and/or a thin pre-stretched crust favour mechanical coupling between the crust and mantle during stretching, leading to rapid and narrow lithospheric necking, prominent rift flanks and basin collapse. In these settings, the models also predict normal faults dipping predominantly towards the rift centre between the uplifted rift flanks and the basin centre. On the other hand, stretching a relatively thick, hot crust, mechanically decoupled from a thin (< 60 km) lithospheric mantle lid, may result in much wider rifts, depending on the stretching velocity, subdued rift flanks and low initial basin topography, where normal faults dip both towards and away from the rift centre.

Independently of the assumed lithospheric structure and stretching velocity, the models show that by accounting for small-scale convection in the asthenosphere, with ongoing mass exchange and syn-rift erosion at the base of the lithosphere, depth-dependent stretching is pervasive and an intrinsic characteristic of the rifting process. In fact, all the tested models show considerably greater thinning of the mantle lithosphere near the centre of the rift, in relation to that observed in the crust. This may also explain why pairs of conjugate margins often exhibit more subsidence than predicted from the measured/inferred crustal stretching; i.e. the "upper plate paradox". Interestingly, however, only the "decoupled" lithopsheric models show higher mantle stretching away from the rift centre, particularly when a low rifting velocity is assumed. In such cases a wide, post-rift sag basin may develop, similar to that described in a number of South Atlantic margins.