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From continental rifting to conjugate passive margins: Insights from analogue and numerical modelling

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Conjugate passive margins of the southern segment of the South Atlantic are characterized not only by various deformation patterns and unequal width of the continent-ocean transition zones but also by different structure of adjacent continents (for example, the crustal thickness of South America is 30 km whereas that of Africa is 40 km). Lithosphere-scale analogue models and 2D thermo-mechanical numerical experiments handling complex rheological behaviour and structure are used to investigate the rift evolution in the context of laterally heterogeneous continental lithosphere consisting of two equally sized segments with different rheological properties.

The results of the analogue lithosphere-scale models show that extensional deformation always localizes in the relatively weak section of the lithosphere and not at the contact between the different segments where the strength contrast is highest. When a strong sub-Moho mantle is present, the system develops in two phases when under extension. For such a model, the lithosphere strength profile of the weak segment consists of 4-layer model that alternate brittle and ductile layers (brittle crust, ductile crust, brittle mantle and ductile mantle). The brittle crust and brittle mantle are decoupled by the ductile lower crust. During the initial stage a wide-rift develops. The transition to the second phase is related to a significant drop in strength of the strong, brittle upper mantle. The resulting mechanical coupling between the weak layers of the ductile lower crust and the ductile lower mantle favors a fast localization that concentrates deformation along a symmetrical narrow rift zone within the weak segment of the lithosphere.

If extension would continue, the lithosphere would break at the localized point in the weak segment. This evolution occurs in a ‘pure-shear’ fashion within the weak segment. The conjugate margin with the initially stronger lithosphere segment now has a narrow segment of weak lithosphere attached to it due to the localization leading to break-up within the weak lithosphere. Overall, the system has developed highly asymmetric margin geometries within a ‘pure-shear’ setting.

The 2D thermo-mechanical models with similar setups as the analogue models include the thermal complexity of the system, which is characterized by several different thermal gradients and the presence of thermal anomalies. The model results show an increase in the variety of break-up modes. Plume-induced continental break-up can occur in a classical ‘central’ fashion with the break-up center directly above the plume-impingement point. Other possibilities are ‘shifted’, ‘distant’ and ‘two-branch’ break-up modes.

Our study shows that it is possible to reproduce the formation of a-symmetric passive margins with ‘pure-shear’ continental break-up, without the need of pre-imposed thermal anomalies. However, when complex initial and boundary thermal conditions are added, continental break-up can occur in a variety of ways, thereby better explaining a combination of observed features including high density/high velocity bodies and the asymmetry of conjugate margins.