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Influence of rheological layering on the formation of offset basins at inherited weak zones during continental rifting: effects of stiff and pliable layers

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We use numerical modelling to investigate the influence of lithosphere rheological layering on the reactivation of inherited crust and mantle weak zones during continental rifting. Such reactivation often leads to the formation of offset basins, ie. basins whose development is concomitant with the rifting event, but whose location is offset/set off the main rift/locus of the breakup. Offset rift basins are ubiquitous features of rifted continental margins and are often located at inherited sutures and their fold-and-thrust belts.
We use the software Sopale nested to test the effects of different lithospheres comprising Stiff and/or Pliable crust and mantle layers. Here Stiff (S) implies a nonlinear flow law with a high stress exponent (n $\sim>$ 10,000), a plastic material, and Pliable (P) means a low stress exponent (n$\sim$ 2 - 5) as in ductile, power-law creep of rocks. To achieve this rheological change without modifying the thermal structure of the model, we introduce a scaling factor f in the power-law creep parametrization of the viscosity, such that large values of f result in Coulomb frictional-plastic failure of a layer and small values result in power-law creep. One weak (ie. with reduced internal angle of friction, $\varphi = 2^\circ$) zone is embedded in the central part of the uppermost mantle lithosphere and two weak zones are embedded in the upper crust, offset on either side of the mantle weak zone by 150 km in most models.
During extension of the model lithosphere weak zones embedded in a stiff layer are preferentially and rapidly reactivated, whereas the same zones are either ignored or slowly reactivated when embedded in pliable layers. This is because necking instabilities grow much more rapidly in stiff layers than in pliable ones. Moreover, the intensity of coupling between the crust and the mantle determines which layer controls the morphology of the model continental margin. When the crust is strongly coupled to the underlying mantle, offset basins only form at the crustal weak zones when the mantle is pliable. Conversely, when the crust is decoupled from the underlying mantle, offset basins only form when the crust is pliable.
Whether offset rift basins form during rifting of a composite lithosphere therefore depends on the competition between necking instabilities that develop at the weak zones in the stiff layers, and the coupling between the stiff and pliable layers. The results show that Stiff/cratonic lithosphere results in early localization of the deformation at the mantle weak zone, rapid necking and breakup without developing offset rift basins. In contrast, warm Pliable lithosphere develops significant offset basins and has protracted rifting because the mantle weak zone is now embedded in a pliable layer.
We use a tectonic rifting styles diagram to show that the model results agree with natural examples.