Continental rifting and upper mantle strength

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The uppermost mantle has traditionally been considered to be relatively strong compared to the crust. However, this view has recently been contested based on improved assessments of earthquake focal depths and considerations regarding effective elastic thickness, and caused much subsequent debate.

Here we employ a high resolution, numerical model of continental rifting to constrain the strength of the uppermost mantle. Our model shows that a rift developing in the presence of a relatively strong uppermost mantle leads to lithospheric necking well beneath the Moho. This is consistent with previous models of lithospheric extension, but here we identify two important inconsistencies with observations from both recent and ancient continental rifts: 1): Necking beneath the Moho leads to downwards dislocation of the Moho beneath the rift. However, seismological studies always indicate that the Moho tends to shallow beneath rifts. 2): Deep necking additionally causes the development of regionally supported and unrealistically high flank uplifts together with associated extreme gravity anomalies. By modelling the thermo mechanical development of continental rift flanks at a range of lithosphere thicknesses and mantle strengths and comparing with topographic profiles from a global set of recent rift systems, we show that the strength of the uppermost mantle should be no more than 200 MPa.

Our numerical model employs a self consistent representation of the lithosphere by including equilibrium small-scale convection which contributes with a relatively constant sub-crustal heat flux. Since the lithospheric mantle is colder and thus denser than the asthenosphere below, continental rifting requires a certain level of strength of the mantle in order to avoid unstable lithospheric delamination. We find this strength to be less than 20 MPa.

Uppermost mantle strength in the range of 20-200 MPa is typically less than that of the crust and previous estimates. Previous numerical studies require a strong uppermost mantle in order to obtain localized deformation as evident from narrow continental rifts. However, our model shows that rifts developing in weak mantle lithosphere, relative to the crust, indeed tend to become narrow. Additionally, explicit load experiments of our lithosphere model indicate that uppermost mantle strengths of 20-200 MPa are associated with high values of equivalent elastic thickness (up to 100 km) which are often assumed to proxy high strength of the mantle. Instead, our results indicate that the equivalent elastic thickness is strongly dependent on the amplitude and wavelength of the applied load and cannot be directly applied to assess uppermost mantle strength.