Factors controlling the asymmetry of lithosphere extension inferred from numerical experiments

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It has been argued that extension of the lithosphere may occur either in a pure shear mode or in a simple shear mode of deformation. The case for an asymmetric mode of extension has been made based on two types of observations. Low angle detachments, which have been active over a longer time interval, have been interpreted as whole lithosphere scale shear zones offsetting the areas of mantle lithosphere and crustal thinning. Strong asymmetry in crustal structure between the conjugates of passive continental margin systems has lead to interpretations of the conjugates in terms of an upper / lower plate geometry. We use 2D thermo-mechanical Arbitrary-Eulerian-Lagrangian finite element techniques to study factors controlling the asymmetry of lithosphere extension. In order to be able to model the interaction between lithosphere processes and the underlying asthenosphere, the models extend from the surface to 660 km depth. The upper surface of the model is free to move. Crust and mantle-lithosphere rheology are represented by a plastic failure criterion following Byerlee's law and temperature dependent non-linear creep, the asthenosphere follows a temperature dependent non-linear creep flow law. We focus on the role of plastic strain softening and on the effect of (de) coupling between crust and the mantle lithosphere, starting from a lithosphere with a "normal" crustal thickness. Our numerical model results indicate (at least) three modes of deformation, 1) symmetric extension, 2) (transient) whole lithosphere scale asymmetric extension, and 3) crustal asymmetry concomitant with a whole lithosphere scale symmetric style of deformation. Asymmetric extension with a fault zone continuing from the surface into the upper mantle lithosphere is promoted in models with a large ratio between the initial strength and the final strength of the strain softened brittle / plastic shear zone and by strong coupling between crust and mantle lithosphere. In these models asymmetry is a transient feature where the single fault zone is abandoned when viscous processes start to dominate and when the brittle shear zone is warped up into a less favourable position for further deformation. When the strength reduction upon "faulting" is lower, the coupled models show a fully symmetric style of extension, with a conjugated brittle fault system cutting the crust and upper mantle. When low viscosities in the lower crust facilitate decoupling between the brittle upper crust and the brittle upper mantle, decoupling of the "fault" zones in the lower crust results in an asymmetric crustal necking profile with strongly differing width and structure of the conjugated margins. The overall style of extensional deformation, however, is still dominated by pure shear deformation.