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Numerical analysis on the competition between sedimentation and crustal flow: implication for rift-to-drift transition

Megan Korchinski (1), Patrice Rey (2), Christian Teyssier (1), Donna Whitney (1), and Luke Mondy (2)

(1) University of Minnesota, School of Earth Sciences, Minneapolis, United States (korch009@umn.edu), (2) The University of Sydney, School of Geosciences, Sydney, Australia

Extension of the lithosphere creates space that is accommodated by dynamic interaction between sedimentation and upward mass transport of the deep crust (exhumation). Ductile flow of the deep crust is prevalent in global rifts, and ductile layers within the lithosphere exert a first-order control on the architecture of the necking zone within the rift and the deformation mode during early rifting. Sedimentation alters the thermal structure of the rift, thereby impacting the strength profile of the lithosphere and impacting strain localisation during rifting. The dynamic interaction between syn-rift sedimentation and flow of ductile crust is investigated in a suite of 2D numerical experiments under lithospheric extension (2 cm/yr^{1}), in which two densities of rift infill (2620, 2800 kg/m^{3}) and three deep crust viscosities (weak, intermediate, strong) are used. In addition, the thickness of the crust (40-60 km) and the temperature of the Moho (600-800°C) are systematically varied between reasonable end-member values. Results demonstrate that the competition between flow of deep crust and rift sedimentation influences strain localisation in the lithosphere.

Strain localisation within the lithosphere results in crustal and lithospheric thinning in experiments with a 40 km crust, regardless of the viscosity of the deep crust or the density of the rift infill. Lithospheric thinning is coupled with basin formation and results in shearing of the deep crust early in the experiment evolution. The transition from rifting to drifting occurs at 33 to 40% extension depending primarily on the viscosity of the deep crust. However, both the viscosity of deep crust and the density of rift infill control the process by which the deep crust is thinned in experiments with a 40 km crust. In experiments with an intermediate or strong deep crust, crustal scale conjugate shear zones drive the formation of a shallow crust graben beneath a triangular shaped basin. By comparison, experiments with a weak deep crust and a high-density rift infill exhibit rift basin depths of 25 km at 33% extension, concurrent with uplift of the asthenosphere to 30 km and lateral transport of the deep crust.

Experiments with a 60 km crust do not exhibit rift-to-drift transition prior to 55% extension. Experiments with a weak and intermediate deep crust do not reach drift stage within the experiment time span (66% extension). Instead thin basins form and expand laterally above a mobile deep crust that flows into space created by localised boudinage of the shallow crust (i.e. structural domes). Experiments with a strong deep crust exhibit graben formation similar to that present in the experiment suite with a 40 km crust. In the latter case localised thinning of the mantle lithosphere is not present in the first 6 Ma of experiment evolution (33% extension), with drifting occurring at 50-66% extension. These results demonstrate that the mechanical behaviour of the deep crust has a major influence on rifting processes and on the transition from rifting to drifting.