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Numerical simulations of complex normal fault interaction during continental extension

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Observations from regions of active continental extension and mature rifted margins suggest continental breakup occurs through multiple phases with distinct styles of deformation. These deformation phases are characterized by different localization of extension as expressed by different patterns of faulting, basin formation and crustal thinning. The transitions between the phases inherently reflect the forces driving extension, the lithosphere's rheological profile and inherited zones of weakness, such as faults, developed during prior phases of deformation. Here, we use 2D and 3D numerical experiments to examine how normal faults developed during the initial phases of continental extension influence subsequent phases of deformation, where significant lithospheric thinning or breakup occurs.

Our thermal-mechanical experiments model lithospheric extension using velocity boundary conditions and viscous-brittle material behavior. The 2D models have a high spatial resolution of 250 m grid spacing. To promote the formation of distributed normal faulting in the initial phases of extension, the lithosphere is randomly seeded with brittle strength perturbations. An initial low extension rate (1 mm/yr) leads to distributed normal faulting that persists for 10's of Myr in brittle layers of the lithosphere. An increase in the rate of extension (to 5 or 10 mm/yr) at 50 Myr leads to vertical coupling of deformation throughout the lithosphere, which proceeds through new fault development and reactivation, deactivation or incision of pre-existing faults. This complex evolution of the fault network leads to the formation of commonly observed rifted margin structures, including core-complexes and incision of low-angle structures by high-angle faults.

Our 3D simulations of continental extension reveal that such fault interaction can also lead to margin-parallel (e.g., along strike) complexity. Even at lower numerical resolutions (2.5 km) and a constant rate of extension (10 mm/yr), initially widely distributed normal faults localize onto larger faults, which are laterally offset along the length of the margin. Even though our numerical results inherently reflect a simplified view of rifted margin evolution, we hope that the evolution of the structural complexity developed from fault network interaction can potentially provide a useful template for interpreting detailed observations of rifted margins.