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Rotation, narrowing and preferential reactivation of brittle structures during oblique rifting

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Occurrence of multiple faults populations with contrasting orientations in oblique continental rifts and passive margins has long sparked debate about relative timing of deformation events and tectonic interpretations. Here, we use high-resolution three-dimensional thermo-mechanical numerical modeling to characterize the evolution of the structural style associated with varying geometries of oblique rifting in a layered continental lithosphere. Automatic analysis of the distribution of active extensional shears at the surface of the model demonstrates a characteristic sequence of deformation. Phase 1 with initial localization of deformation and development of wide oblique en-échelon grabens limited by extensional shears oriented close to orthogonal to $\sigma 3$. Subsequent widening of the grabens is accompanied by progressive rotation of the Phase 1 extensional shears to an orientation sub-orthogonal to the plate motion direction. Phase 2 is characterized by narrowing of active deformation resulting from thinning of the continental mantle lithosphere and development of a second-generation of extensional shears. During Phase 2 deformation localizes both on plate motion direction-orthogonal structures that reactivate rotated Phase 1 shears, and on new moderately oblique structures orthogonal to $\sigma 3$. Finally, Phase 3 consists in the oblique rupture of the continental lithosphere and produces an oceanic domain where oblique ridge segments are linked with highly oblique accommodation zones. We conclude that while new structures form normal to $\sigma 3$ in an oblique rift, progressive rotation and long-term reactivation of Phase 1 structures promotes orthorhombic fault systems, which accommodate upper crustal extension and control oblique passive margin architecture. The distribution, orientation, and evolution of frictional-plastic structures observed in our models consistent with documented fault populations in the Main Ethiopian Rift and the Gulf of Aden conjugate passive margins, both of which developed in moderately oblique extensional settings.