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Fault Orientations at Obliquely Rifted Margins: Where? When? Why?

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Present-day knowledge of rifted margin formation is largely based on 2D seismic lines, 2D conceptual models, and corroborated by 2D numerical experiments. However, the 2D assumption that the extension direction is perpendicular to the rift trend is often invalid. In fact, worldwide more than 75% of all rifted margin segments have been formed under significant obliquity exceeding 20° (angle measured between extension direction and rift trend normal): During formation of the Atlantic Ocean, oblique rifting dominated at the sheared margins of South Africa and Patagonia, the Equatorial Atlantic margins, separation of Greenland and North America, and it played a major role in the protracted rift history of the North East Atlantic. Outside the Atlantic Ocean, oblique rifting occurred during the split between East and West Gondwana, the separation of India and Australia, India and Madagascar, Australia and Antarctica, as well as Arabia and Africa. It is presently observed in the Gulf of California, the Aegean and in the East African Rift.

Despite its significance, the degree to which oblique lithospheric extension affects first-order rift and passive margin properties like surface stress pattern, fault azimuths, and basin geometry, is still not entirely clear. This contribution provides insight in crustal stress patterns and fault orientations by applying a 3D numerical rift model to oblique extensional settings. The presented forward experiments cover the whole spectrum of oblique extension (i.e. rift-orthogonal extension, low obliquity, high obliquity, strike-slip deformation) from initial deformation to breakup. They are conducted using an elasto-visco-plastic finite element model and involve crustal and mantle layers accounting for self-consistent necking of the lithosphere. Results are thoroughly compared to previous analogue experiments, which yields many similarities but also distinct differences for late rift stages and for high obliquity.

Even though the model setup is very simple (horizontally layered, no inherited faults, constant extension velocity and direction), its evolution exhibits a variety of fault orientations that are solely caused by the three-dimensionality of oblique rift systems. Allowing new insights on fault patterns of the proximal and distal margins, the model shows that individual fault populations are activated in a characteristic multi-phase evolution driven by lateral density variations of the evolving rift system. Moreover, the model depicts strain partitioning between rift-parallel and rift-perpendicular far-field velocity components that are accommodated by strike-slip faults in the rift centre and normal faults at the rift sides, respectively.

Oblique extensional systems worldwide differ in many aspects and clearly one suit of models cannot explain all rifted margin structures at the same time. However, the distinct pattern of fault populations discussed in this study and their sequence of activity compares very well to previous studies of the Gulf of Aden and holds implications for many other rifted margins worldwide. Note that in nature, the resulting stress and fault pattern will also be affected by inherited heterogeneities, surface processes, as well as melting and dyke dynamics.