Mechanical anisotropy of the lithospheric mantle and continental rifting: Observations and models

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Analysis of major rift systems suggests that the preexisting structure of the lithosphere is a key parameter in the rifting process. Rift propagation is not random, but tends to follow the trend of the orogenic fabric of the plates, systematically reactivating ancient lithospheric structures. Continental rifts often display a clear component of strike-slip deformation, in particular in the early rifting stage. Moreover, although the close temporal and spatial association between flood basalt eruption and continental breakup suggests that mantle plumes play an important role in the rifting process, there is a paradox between the pinpoint thermal and stress perturbation generated by an upwelling mantle plume and the planar geometry of rifts. These observations suggest that the deformation of the lithosphere, especially during rifting, is controlled by its preexisting structure. On the other hand, (1) the plasticity anisotropy of olivine single crystal and aggregates, (2) the strong crystallographic orientation of olivine observed in mantle xenoliths and lherzolite massifs, and (3) seismic anisotropy data, which require a tectonic fabric in the upper mantle coherent over large areas, suggest that the preservation within the lithospheric mantle of a lattice preferred orientation (LPO) of olivine crystals may induce a large-scale mechanical anisotropy of the lithospheric mantle.

We use multi-scale numerical models to investigate the effect of a preexisting mantle fabric on the continental breakup process. Model results show that a LPO-induced mechanical anisotropy of the lithospheric mantle may result in directional softening, leading to heterogeneous deformation. During continental rifting, this mechanical anisotropy may induce strain localization in domains where extensional stress is oblique to the preexisting mantle fabric. This directional softening associated with olivine LPO frozen in the lithospheric mantle may also guide the propagation of the initial instability that will follow the preexisting structural trend. The preexisting mantle fabric also controls the deformation regime, imposing a strong strike-slip shear component. A LPO-induced mechanical anisotropy may therefore explain the systematic reactivation of ancient collisional belts during rifting (structural inheritance), the plume-rift paradox, and the onset of transtension within continental rifts.