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Asymmetric 3D rift evolution over active mantle upwellings and plumes in presence of uni- and bi-directional far-field force boundary conditions. Insights from ultra-high resolution numerical models

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Identification of mantle contribution to rift topography and structure is difficult, especially in the continents. At the same time, the volcanic activity, which is commonly considered a prime signature of mantle upwellings, is not systematically detected in the areas of presumed active rifting. It can be argued therefore that complex brittle-ductile rheology and stratification of the continental lithosphere result in screening and deviation of mantle upwellings as well as in short-wavelength modulation and localization of surface deformation induced by mantle flow. This deformation is also affected by far-field stresses and hence interplays with the "tectonic" topography. Testing these ideas requires fully-coupled high-resolution "tectonic grade" 3D numerical modelling of mantle- lithosphere interactions, which is so far has not been possible due to the conceptual and technical limitations of earlier approaches. We present here new ultra-high resolution (> 100 million grid elements) 3-D experiments on rift topography and structure over mantle plumes, incorporating a weakly pre-stressed (ultra-slow spreading) rheologically realistic lithosphere. The results show complex surface evolution and strain localization patterns, which are very different from the symmetric patterns usually assumed as the canonical surface signature of mantle upwellings. In particular, the topography exhibits strongly asymmetric small-scale 3D features, which include narrow and wide rifts, flexural flank uplifts and fault structures. In presence of a craton embedded in normal lithosphere, a double rift system forms with coeval development of a magma-rich rift branch above the plume head and a magma-poor one along the opposite side of the craton. Of the particular interest are the experiments with bi-directional far-field boundary conditions (trans-extensional or trans-compressional) that show the possibility of formation of strongly asymmetric oblique rift features and conjugated fault patterns with strike-slip components. Our results thus suggest a dominant role for rheology structure and intra-plate stresses in controlling dynamic topography, mantle-lithosphere interactions, and continental break-up processes above mantle plumes while reconciling the passive (plume- activated) versus active (far-field tectonic stresses) rift concepts as these experiments show both processes in action and demonstrate the possibility of developing both magmatic and amagmatic sub-parallel or oblique rifts in identical geotectonic environments.