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What controls continental breakup at magma-poor rifted margins?

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Simple physical considerations show that tectonic forces are insufficient to rupture continental lithosphere, unless, the lithosphere has been weakened prior to rifting. Therefore, magmatic activity is often considered to be a prerequisite for successful rifting. This assumption, however, is in conflict with the apparent lack of magma along so-called non-volcanic rifted margins such as the Iberia-Newfoundland or Alpine Tethys margins. The discrepancy between theory and observations leads to the question about what are the processes that weaken the lithosphere and finally control continental break-up?

In order to understand what processes control the strain distribution at magma-poor rifted margins, we developed a multi-disciplinary and multi-scale approach using drill-hole and geophysical data from the Iberia-Newfoundland margins and direct observations and unlimited samples from the Alpine Tethys margins. More particularly, we investigate onset and timing as well as distribution of magmatic, serpentinization and deformation processes in drill-hole samples and outcrops and observe the strain evolution and near surface response of lithospheric extension in seismic sections and dated sedimentary formations. Based on these data we developed a numerical modelling approach that can reproduce the constrained geological evolution of rifting and enables to quantify and parameterize the bulk rheological evolution of continental rifting.

Our investigations show that rifting in the case of the Iberia-Newfoundland and Alpine Tethys margins is poly-phase and characterized by a change in the style of rifting. During early rifting deformation is distributed along symmetric normal faults that are decoupled in the middle crust (e.g. stretching mode). In contrast, final rifting is localized along asymmetric downward concave faults cutting across the crust and exhum-

ing underlying mantle rocks to the seafloor (e.g. exhumation mode). Serpentinization and emplacement of gabbros and dolerites are contemporaneous to detachment faulting and are the consequence rather than the reason for strain localization and extreme crustal thinning. In our numerical experiments we were able to reproduce and study extreme crustal thinning occurring at the transition from pure-shear dominated crustal stretching to simple-shear dominated mantle exhumation. Extreme thinning of the crust is controlled by a system of superimposed concave-downward faults that simultaneously exhume middle crust to the seafloor and deeper mantle at the base of the thinned crust. The two rolling hinges eventually merge to form one concave downward fault that explains final mantle exhumation. This mode of deformation can account for the observed extreme thinning of the crust to less than 10 km over several tens of kilometres, the lack of major fault bounded topography, and the emplacement of deep mantle rocks beneath thinned crust prior to break-up. The processes that control this mode of deformation are the initial composition and thermal structure of the crust and mantle, and the capacity to form large-scale mylonitic shear zones. The tectonic exhumation of deeper, hotter and infiltrated mantle rocks underneath thinned crust is a fundamental process to weaken and finally breakup the lithosphere.

Our observations show that in magma-poor settings, an interaction/competition between mechanical, magmatic and hydrothermal processes is responsible for weakening leading to final continental break-up. However, the role of magma in the evolution of “non-volcanic” margins is probably more important than previously anticipated. In particular the exhumation of infiltrated, hot mantle rocks underneath a thinned crust during final rifting may explain the strong ductile thinning predating final serpentinization and emplacement of mafic rocks. Thus, although magma alone cannot explain crustal thinning and continental break-up at magma-poor margins, it is a prerequisite to thin and rupture the continental lithosphere.