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Unraveling crustal thinning processes at magma-poor rifted margins: Evidence from the Alpine Tethys margins

Geoffroy Mohn (1), Gianreto Manatschal (1), Emmanuel Masini (1), Marco Beltrando (2), Othmar Müntener (3), and Nick Kusznir (4)

(1) IPGS-EOST, University of Strasbourg CNRS, Strasbourg, France (geoffroy.mohn@illite.u-strasbg.fr), (2) Dipartimento di scienze Mineralogiche e Petrologiche, Università di Torino, Torino 10125, Italy, (3) Institute of Mineralogy and Geochemistry, University of Lausanne, CH 1015 Lausanne, Switzerland, (4) Department of Earth and Ocean Sciences, University of Liverpool, Liverpool, L69, UK

Many of the questions that currently frame ongoing research about rifted margins are related to the mechanisms of extreme lithospheric extension. The discovery of exhumed subcontinental mantle at magma-poor rifted margins is at present generally accepted. However, mantle exhumation along detachment faults seems to occur after the crust is thinned to less then 10 km, i.e. when the complete crust is within the brittle field. This lead to the question “where”, “when” and “how” the continental crust can thin from its initial thickness to less than 10 km. Many refraction seismic surveys conducted in present-day magma-poor rifted margins reveal that the transition from continental crust that underwent minor thinning in the proximal margins to hyper extended crust ($\leq$10 km) in distal margins occurs within a well-defined domain that we refer to as the “necking zone”. However a discrepancy exists between the amount of extension deduced from visible normal faulting and the amount of crustal thinning in hyper-extended margins. This observation calls for crustal deformation processes that have to be localized within the necking zone. However, the low resolution of seismic data and the lack of drilling at present-day rifted margins make it difficult to image these structures and therefore to investigate these processes in present-day rifted margins.

A more direct access to the crustal architecture and associated structures of hyper-extended rifted margins is exposed in the Alps in Western Europe. We focused our study on the Austroalpine Bernina-Campo-Grosina units. These units preserve respectively the relics of the former distal margin and necking zone of the SE-Alpine Tethys rifted margin. The Campo-Grosina necking zone is made of pre-rift upper and mid crustal levels that were juxtaposed and exhumed during the rifting as indicated by new thermochronological data. Relics of distal margin are made by upper and lower crust directly juxtaposed with omission of the mid crustal level. Within the Campo-Grosina necking zone, different high-strain shear zones responsible for lithospheric thinning can be defined including: 1) a system of detachment faults active in the brittle upper crust (Grosina detachment) and lower crust (Pogallo type shear zone); 2) mid-crustal decollements decoupling the deformation in the upper and lower crust (e.g. Eita shear zone, Margna shear zone) whose activity resulted in the total excision of the middle crust. These high-strain zones are interpreted to accommodate crustal thinning to less than 10 km during Pliensbachian to Toarcian time (190-180Ma) and to predate mantle exhumation. Final rifting postdates this extreme crustal thinning, and associated with low-angle detachment faults (e.g. Err and Bernina detachment fault). These structures are responsible for the exhumation of upper and eventually lower crust and finally subcontinental mantle to the seafloor.

Our results suggest that major crustal thinning occurs in the necking zones, pre-dates mantle exhumation and is the result of an interplay of conjugate, symmetric detachment faults that are decoupled and sole out in mid-crustal decollements. This model, based on observations from the Alpine Tethys margins, can explain the first-order crustal architecture observed at many present-day magma-poor rifted margins. Future work will be necessary to understand how the proposed tectonic evolution is linked with the thermal, rheological and isostatic evolution of the extending lithosphere during rifting.