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From orogeny to rifting: when and how does rifting begin? Insights from the Norwegian 'reactivation phase'.

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Following the Wilson Cycle theory, most rifts and rifted margins around the world developed on former orogenic suture zones (Wilson, 1966). This implies that the pre-rift lithospheric configuration is heterogeneous in most cases. However, for convenience and lack of robust information, most models envisage the onset of rifting based on a homogeneously layered lithosphere (e.g. Lavier and Manatschal, 2006). In the last decade this has seen a change, thanks to the increased academic access to high-resolution, deeply imaging seismic datasets, and numerous studies have focused on the impact of inheritance on the architecture of rifts and rifted margins. The pre-rift tectonic history has often been shown as strongly influencing the subsequent rift phases (e.g. the North Sea case - Phillips et al., 2016).

In the case of rifts developing on former orogens, one important question relates to the distinction between extensional structures formed during the orogenic collapse and the ones related to the proper onset of rifting. The collapse deformation is generally associated with polarity reversal along orogenic thrusts, ductile to brittle deformation and important crustal thinning with exhumation of deeply buried rocks (Andersen et al., 1994; Fossen, 2000). The resulting structural template commonly involves metamorphic core complexes, extensional shear zones and detachment faults superposed on inherited thrust assemblages (Fossen, 2000). On the other hand, the proximal domains of rifted margins often show only moderately reduced crustal thicknesses (Whitmarsh et al., 2001). The top basement geometries are typically summarized as series of tilted blocks, bordered by 'Andersonian-type' normal faults rooted in the brittle-ductile transition at mid-crustal levels, accounting for minor amounts of extension (the 'stretching phase' of Lavier and Manatschal, 2006). Thus, orogenic collapse and early rifting are considered to represent very different deformation modes with distinct structural geometries. We used the post-Caledonian Norwegian rift system to study the relationship between these two end-member forms of deformation.

Based on onshore and offshore observations from the Mid-Norwegian and North Sea extensional systems, and on numerical modelling experiments, we show that the near-coastal onshore and proximal offshore Norwegian area is floored by a unit of intensively sheared basement, mylonitic shear zones, core complexes and detachment faults that attest to significant crustal thinning. We describe how, when and where the post-Caledonian continental crust evolved from a context of orogenic collapse to one of continental rifting. We highlight the importance of a deformation stage that occurred between the collapse mode and the high-angle faulting mode often associated with early rifting of continental crust. This transitional stage - termed the reactivation phase - which we interpret as the earliest stage of rifting, includes unexpected large magnitudes of crustal thinning facilitated through the reactivation and further development of inherited collapse structures, including detachment faults, shear zones and metamorphic core complexes. The reduction of the already re-equilibrated post-orogenic crust to only ~50% of normal thickness over large areas, and considerably less locally, during this stage shows that the common assumption of very moderate extension in the proximal margin domain may not conform to margins that developed on collapsed orogens.