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The problems of the kinematic restoration of hyper-extended rifted margins: the example of the southern North-Atlantic

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The development in space and time of hyper-extended lithosphere is fundamental to our understanding of the 3D development and propagation of rifting and lithospheric breakup. Hyper-extended domains, consisting of extremely thinned continental crust and exhumed mantle with possible minor magmatic addition, often extend over wide areas, sometimes up to 400 km, continentward of the first unequivocal oceanic crust. Although considerable work has been done in the last decades to describe the evolution of hyper-extended domains, there is yet no generally accepted approach to kinematically restore them. Indeed, in contrast to oceanic crust, where the kinematics can be defined by isochronal magnetic anomalies, in hyper-extended well-defined consistent magnetic anomalies are lacking. Therefore in order to restore these domains, we need to define alternative approaches. The main questions to be addressed to solve this problem are: 1) how can hyper-extended domains be restored, 2) which kinematic markers could be used 3) what are the implications for the 3D propagation of hyper-extended systems.

We use the example of the southern North-Atlantic to develop and apply an approach to kinematically analyse the evolution of hyper-extended domains. We combine seismic dataset and drill hole data available with crustal thickness maps determined from gravity inversion to define and map rift domains and rift domain boundaries. We distinguish between the proximal domain (weakly thinned continental crust), thinned continental crust, exhumed mantle, and oceanic crust. From this mapping, we observe that the width of each domain is variable along the margins and that domain boundaries are not always straight lines. It implies that these boundaries, in particular the edge of the continental crust cannot be easily superimposed at a specific time. Therefore, rift domain boundaries cannot be considered as isochrones and do not represent kinematical markers. The restoration of hyper-extended margins needs to distinguish: 1) "new real-estate" material (oceanic crust and exhumed mantle) that can be discarded in a palinspatic restoration, from 2) thinned continental crust whose volume must be included (e.g. using areal balancing). By combining these two approaches, a full-fit restoration is proposed, however, such a restoration does not include time constraints. As further constraints, we use geological datasets, such as structural orientation (e.g. strike of the necking and related transfer faults, inherited sutures), stratigraphical observations (necking and breakup age), and geochronological data (e.g. magmatism and exhumation) to guide our kinematical modelling.

Our results suggest that linear magnetic anomalies located at or near the transition between oceanic crust and exhumed mantle (such as the J anomaly) may be not isochronous over its whole length, and possibly does not record a geomagnetic reversal. There are no indisputable isochronal kinematic markers in hyper-extended domains. The kinematical restoration of hyper-extended domains presented in this work opens new questions on the propagation and localisation of extensional deformation. Eventually, our model shows that continental thinning is characterized by a distributed and segmented deformation whereas the exhumation and oceanic stages can be described as V-shaped propagators.