Modelling extension of the continental lithosphere and the development of passive margins: rheological modifications in the lithosphere and geodynamical effects

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The thermo-mechanical process of continental break-up and the transition to oceanic spreading represent some of the most important aspects of plate tectonics. Yet, the mechanics and evolution of continental rifting and the dynamics by which distributed continental deformation is progressively focused at oceanic spreading centres remain unclear.

Data on the Western Alpine – Northern Apennine ophiolitic peridotites that provide insights into these processes as they record the complex evolution of continental riftng and break-up related to the opening of the Mesozoic Ligurian Tethys, separating the European and African (Adria) plates during Late Jurassic – Cretaceous times. These ophiolites represent portions of subcontinental lithospheric mantle, which underwent progressive exhumation related to lithospheric extension between Europe and Adria, and were exposed at the sea-floor of the Ligurian Tethys. Field work evidences that, when residing in the mantle lithosphere, the periodtites were diffusely percolated by melts generated by decompressional melting of the asthenosphere which was adiabatically upwelling in response to lithospheric extension and thinning. This percolation was accompanied by significant heating of the subcontinental mantle to asthenospheric conditions, which resulted in the thermo-chemical erosion ("asthenospherisation") of the mantle lithosphere. Distribution and abundance of these "modified" peridotites within the ophiolitic peridotites from the Ligurian Tethys suggest that substantial volumes of the lithospheric mantle along the axial zone of the future basin underwent these melt-related processes and were asthenospherised. Consequently, heating and weakening of the mantle lithosphere may have represented a controlling factor in the transition from continental extension to oceanic spreading.

Thermal and rheological modelling shows that asthenospherisation of the continental mantle lithosphere is a fast process and the rheological consequences are relevant to the problem of the process of break-up of a continental plate, provided that a significant thickness of the lithospheric mantle is weakened. In these conditions, the initial strength is reduced (up to one order of magnitude) within 2-3 Ma of the time of the percolation, and recovers asymptotically its initial value within 20-30 Ma. Following this strength reduction, strong localization of the extensional strain may occur in the asthenospherised region. Small-scale analogue models support this conclusion and show strong localised thinning of the continental lithosphere when the lithosphere is characterised by significant asthenospherisation within a narrow region. If the lithospheric mantle is asthenospherised up to the Moho and total lithospheric strength is strongly reduced, the thickness of the lithosphere may be reduced up to more than 80% of the initial thickness in ~3 Ma of extension. Conversely, localised thinning is strongly reduced if the thickness of the percolated zone is only a minor part of the thickness of the lithospheric mantle and/or the lithosphere is weakened over wide regions.

These data suggest that the thermo-mechanical erosion (or asthenospherisation) of the mantle lithosphere may have represented a controlling factor in the rapid continental break-up and the transition to localised oceanic spreading in the Ligurian Tethys.