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Percolation of lithospheric mantle by asthenospheric melt and its influence on continental breakup

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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. In this work we present integration of field and modelling data on the Western Alpine – Northern Apennine ophiolitic peridotites that provide insights into the opening of the Ligurian Tethys, separating the Europe and Adria plates during Late Jurassic – Cretaceous times. These peridotites represent portions of subcontinental lithospheric mantle, which underwent progressive exhumation related to lithospheric extension and thinning of the Europe-Adria lithosphere, and were exposed at the seafloor of the Mesozoic Ligurian Tethys.

Field work evidences that, when residing in the mantle lithosphere, these peridotites were diffusely percolated by melts generated by decompressional melting of the asthenosphere which was adiabatically upwelling in response to lithospheric extension and thinning. Melt percolation was active in the mantle lithosphere from the top of the molten asthenosphere, under spinel- (or garnet-) facies conditions, to shallow levels, at plagioclase-facies conditions, where conductive heat loss caused incipient interstitial crystallization of melts. Peridotites experienced significant structural-compositional modifications by melt interaction, whereas temperatures in the whole percolated mantle lithosphere were higher than liquidus temperatures of anhydrous basaltic melts, to

allow porous flow melt migration, and significantly higher than typical lithospheric temperatures.

Accordingly, melt 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.

As a consequence, heating and weakening of the mantle lithosphere may have represented a controlling factor in the transition from passive lithosphere extension to active oceanic spreading.

This hypothesis has been tested through thermal and rheological modelling coupled with analogue modelling. The thermal and rheological modelling shows that if fast asthenospherisation of the continental mantle lithosphere occurs, the rheological consequences are relevant to the problem of initiation of oceanic spreading in an extending continental lithosphere. Nothing much happens if the thickness of the asthenospherised lithospheric mantle is only a minor part of the thickness of the lithospheric mantle. If however, the affected thickness is large and the melt fraction approaches the Moho, the total lithospheric strength can be reduced to 50-20% of the initial strength (of the extended lithosphere). Moreover, the maximum reduction in total lithospheric strength is achieved within a short time span ($\sim$ 1 Ma) of asthenospherisation.

The effect of the reduction in lithospheric strength on the extension process has been analysed through analogue models. Results suggest that mantle percolation by asthenospheric melts is able to promote strong localised thinning of the continental lithosphere, provided that a significant thickness of the lithospheric mantle is asthenospherised within a narrow region. If the total lithospheric strength is strongly reduced (asthenospherisation up to the Moho), the thickness of the lithosphere may be reduced up to more than 80% of the initial thickness in $\sim$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 represent a controlling factor in the rapid continental break-up and the transition to localised oceanic spreading in the Ligurian Tethys.