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Softening of the subcontinental lithospheric mantle by impregnation of asthenospheric melts: a possible factor in the transition continental extension / oceanic spreading

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Present knowledge evidences that the ophiolitic peridotites from the Alpine-Apennine system record structural, petrologic and geochemical features that indicate: i) exhumation from spinel-facies lithospheric mantle depths during passive extension of the Europe-Adria continental lithosphere, leading to the rifting and drifting stages of the Jurassic Ligurian Tethys ocean; ii) significant melt percolation and impregnation during exhumation, when the rising asthenosphere underwent partial melting during the adiabatic decompressional evolution related to the lithospheric extension and thinning. Asthenosphere/lithosphere interaction by upward percolation of asthenospheric melts caused heating and refertilization of the lithosphere, forming large areas of plagioclase peridotites (Piccardo, 2003; Piccardo et al., 2004).

In order to assess the thermorheological consequences of lithospheric extension and melt impregnation, we first estimate the temperature evolution of an initially thick lithosphere subject to various degrees of adiabatic stretching and upwards percolation of asthenospheric melts. Heat advection by diffusive porous flow brings the impregnated zone to near-asthenospheric temperatures, and heat diffusion further increases the temperature in the surrounding volume. We then assess the rheological consequences of these processes by constructing rheological profiles and deriving total lithospheric strength.

Results are presented in terms of total lithospheric strength as a function of stretching factor and of the ratio between thickness of lithospheric mantle and thickness of impregnated zone. As is well-known, lithospheric extension has a pronounced effect on lithospheric strength, which can be reduced by $\sim$ 50% for $\beta \sim 2$, depending on initial conditions and crustal thickness. The rheological effect of melt impregnation is highly non-linear. Due to the exponential decrease of creep strength with increasing temperature, the effect is more pronounced when the difference between pre-impregnation and post-impregnation temperatures is larger. Consequently, the effect becomes significant only if the impregnated zone extends to near-Moho depths. In these cases, the total strength of the lithospheric mantle can be reduced by 80% or more, with an additional decrease in crustal strength due to heat diffusion.

Whether the relative decrease in strength due to impregnation of subcontinental lithospheric mantle is sufficient to cause lithosphere failure and breakup (i.e., the initiation of oceanic spreading) depends on the initial strength of the affected lithosphere and on the balance between far-field tectonic forces and local strength. Our exploration of parameter space, however, shows that it is certainly a working hypothesis to be considered when supported by geological and petrological evidence.

Piccardo G.B. (2003) – Mantle processes during ocean formation: petrologic records in peridotites from the Alpine-Apennine ophiolites. Episodes, 26, 193-200.

Piccardo G.B., Muentener O., Zanetti A., Pettke T. (2004) – Ophiolitic peridotites of the Alpine-Apennine system: mantle processes and geodynamic relevance. International Geology Review, 46, 1119-1159.