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Lithospheric deformation and mantle/crust coupling related to slab roll-back and tearing processes: the role of magma-related rheological weakening highlighted by 3D numerical modeling

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Active convergent margins are the locus of various large-scale lithospheric processes including subduction, back-arc opening, lithospheric delamination, slab tearing and break-off. Coexistence of such processes results in a complex lithospheric deformation pattern through the rheological stratification of the overriding lithosphere. In this context, another major feature is the development of an intense arc- and back-arc-related magmatism whose effects on lithospheric deformation by rheological weakening are largely unknown. Quantifying this magma-related weakening effect and integrating the three-dimensional (3D) natural complexity of subduction system is however challenging because of the large number of physico-chemical processes involved (e.g. heat advection, dehydration of subducted material, partial melting of the mantle wedge).

We present here a set of 3D high-resolution petrological and thermo-mechanical numerical experiments to assess the role of low-viscosity magmatic phases on lithospheric deformation associated with coeval oceanic and continental subduction, followed by slab retreat and tearing processes. Results in terms of crustal kinematics, patterns of lithospheric deformation and distribution and composition of magmatic phases are then compared to a natural example displaying a similar geodynamical evolution: the eastern Mediterranean subduction zone.

Our modeling results suggest that the asthenospheric flow controls the ascending trajectories of mantle-derived magmatic sources developed in the mantle wedge in response to dehydration of oceanic slab. Once stored at the base of the overriding continental crust, low-viscosity mantle- and crustal-derived magmatic phases allow to decrease the lithospheric strength. This weakening then enhances the propagation of localized extensional and strike-slip deformation in response to slab roll-back and extrusion tectonics respectively. In addition, we show that storage of large amounts of low-viscosity magmas at the base of the stretched crust (particularly true in hot regions such as in back-arc domain) induces a significant decrease of the depth-integrated lithospheric strength, thus favoring the transmission of shear stresses from the flowing mantle to the crust.

Similarities between our modeling results and the late Cenozoic tectonic and magmatic evolution across the eastern Mediterranean region confirm the role of magmatism on the distribution of lithospheric deformation via weakening effects along this subduction zone. Moreover, these results suggest an efficient control of mantle flow on the magmatic and tectonic activity in this region, then promoting lithospheric deformation by mantle drag, which is consistent with field observations.