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Sub-lithospheric small scale convection – a process for continental collision magmatism

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We have studied the role of sub-lithospheric small scale convection in the generation of collision zone magmatism, using combined geodynamic-petrological models. We compare the results with the collisional magmatism of the Turkish-Iranian plateau, where a number of randomly (in both space and time) distributed volcanic centres on has been produced by the active Arabia-Eurasia collision since initial plate collision at ∼27-35 Ma. These volcanic rocks have a highly variable geochemical signature, but commonly point to a lithospheric mantle or asthenospheric source. Major and trace element characteristics span the range from OIB-like, to calc-alkali, shoshonitic and even ultrapotassic.

We suggest these spatially, temporally and chemically diverse patterns of volcanism are caused by sub-lithospheric small scale convection (SSC), manifested as small (50 to 300 km) convection cells at the lithosphere-asthenosphere boundary and dripping of the lithospheric mantle into the asthenosphere. SSC is activated by the increased amount of water in the lithospheric and asthenospheric mantle and its rheological weakening effect. The increase in water content is caused by the subduction prior to the collision and/or continental subduction during collision.

The mantle convection code CitCom, together with a parameterized melting model, is used to model the SSC process. We relate the water content to the mantle solidus and viscosity, and the amount of depletion to the viscosity and buoyancy of the mantle material. We measure the amount of magmatism taking place by assuming direct and instantaneous percolation of mantle melts to the surface. We mimic the dislocation creep mechanism with a diffusion creep mechanism using low activation energy–either one is needed for the SSC to take place under realistic conditions.

Results show that SSC is able to produce small degrees (0-2 %) of melting of the mantle through dripping lithosphere, decompression melting, erosion of the overlying lithosphere, and advection of hot material into contact with the cold lithosphere. The degree of melting might be strongly controlled by the lithosphere thickness and the extent of its hydration during the past Tethyan subduction. Mantle melting leaves behind depleted, more viscous and more buoyant layers at the lithosphere-asthenosphere boundary which may take millions of years before sinking back to deeper mantle. Average volcanic layer thicknesses of hundreds of meters can be reached via the SSC process, corresponding to observations from the Turkish-Iranian plateau.

By its random nature, SSC can explain why the continental collision magmatism on the Turkish-Iranian plateau does not seem to have clearly recognisable spatial or temporal patterns. The potential of the SSC to effectively mix the asthenosphere-lithosphere close to their boundary appears to offer an explanation for the geochemical heterogeneity of the observed volcanism. SSC may be related to whole mantle delamination (offering zones of weaknesses for its initiation) or slab break-off (SSC being enhanced by the break-off), but neither is a prerequisite for SSC magmatism.