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Non-hotspot volcano chains from small-scale sublithospheric convection (a 3D-numerical study)

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Although most of the intraplate volcanism in ocean basins is expressed in linear chains, not all of these can be attributed to a stationary hotspot. Many ridges do not show a linear age-distance relationship predicted by the hotspot hypothesis - such as the Cook-Austal, Magellan or Line Islands, and Pukapuka ridges. Small-scale sublithospheric convection (SSC) has been proposed to account for the volcanism at Pukapuka [Buck and Parmentier, 1986] and may also explain enigmatic geochronology at other intraplate ridges.
In the Earth's uppermost mantle SSC is likely to develop due to instabilities of the thickened thermal boundary layer below mature oceanic lithosphere. It is characterized by convective rolls aligning plate motion. Their onset is earlier (i.e. beneath younger and thinner lithosphere) for lower mantle viscosities (e.g. for hot or wet mantle) or adjacent to lateral thermal or compositional heterogeneity. In these cases, partial melt potentially emerges in the upwelling limbs of SSC. Partial melting changes the compositional buoyancy owing to melt retention and additional depletion of the residue. Therefore, it promotes upwelling and allows for further melting. This self-energizing mechanism is able to sustain melt production in a once partially molten layer for a couple of million years [Raddick et al., 2002].
In this study [Ballmer et al., 2007], we take the step towards fully thermo-chemical 3D-numerical models of SSC (using the FEM-Code CITCOM) with a realistic, temperature- and depth-dependent rheology in order to quantitatively test the SSC-hypothesis on intraplate volcanism. We explore the 3D-patterns of melting associated with SSC, the age of seafloor over which it occurs, and the rates of melt generation by

varying the key parameters mantle viscosity, temperature T_m, and water content. We also investigate the effect of lateral heterogeneity that locally reduces the onset age of SSC, and of a rheology dependent on composition (water and melt content).

Melting due to SSC is predicted to emerge in elongated features ($\sim$1000 km) parallel to plate motion and not just at a fixed spot. Thus, irregular age-distance relationships of the associated volcanism are predicted - contrary to the hotspot model. The seafloor age over which volcanism occurs is sensitive to T_m. For moderate T_m (1350 $^\circ$C), volcanism develops beneath a relatively young lithosphere ($\sim$30 Myr), and higher T_m retards the onset of SSC and volcanism because of the stabilizing influence of a thicker residue from previous mid-ocean ridge melting (e. g., $\sim$50 Myr for T_m=1410 $^\circ$C). Higher water contents have a similar effect as higher T_m. Mantle viscosity controls the rate of melt production with decreasing viscosities leading to more vigorous convection and volcanism. Effective viscosity required to obtain km-high seamounts is smaller than $\sim 2{\cdot}10^{19}$ Pa·, or significantly lower if stiffening due to exhaustion of water is considered. Our calculations predict many of the key observations of the Pukapuka ridges, and the volcano groups associated with the Cook-Austral, Line and Marshall Islands.

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