Intraplate volcanism due to small-scale convection

M. Ballmer[1], J. van Hunen[2], G. Ito[3], P. Tackley[1] and T. Bianco[3].
[1] Insitute of Geophysics, ETH Zurich
[2] Department of Earth Sciences, University of Durham
[3] SOEST, University of Hawaii at Manoa

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 linear age-progressions predicted by this model (e. g., Pukapuka ridges, Magellan and Line Islands). The well-studied Pukapuka ridges reside among other short-lived seamount-chains in the eastern part of the South Pacific Superswell. They are aligned by plate motion and by topography and gravity lineations with a wavelength of ∼200 km.

In order to account for the gravity lineations and the volcanism, three types of models have been put forward yet. Firstly, cracks in the lithosphere due to diffuse extension of the Pacific Plate or due to thermal cracking might sample pre-existing melt. Secondly, melt generated at the South Pacific Superswell might undergo fingering and channelling by flowing towards the East Pacific Rise. Thirdly, small-scale convection (SSC) might dynamically produce melting and the associated gravity lineations. Gravity and tomography studies have rejected the lithospheric cracking model [*Harmon et al.*, 2007], which furthermore presumes a reservoir of pre-existing partial melt in the asthenosphere. Channelized return flow might be a good explanation for the volcanism and the associated density anomalies. But it remains unexplained, why most of the ridges do not extend as far west as Pukapuka and why many of the gravity lineations are not associated with volcanism at all. The SSC-hypothesis is instead able to explain the lineaments and the volcanism altogether.

In the Earth's uppermost mantle SSC is likely to develop due to instabilities of the thickened thermal boundary layer below mature oceanic lithosphere (usually ∼70 Ma). 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.

In this study, 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 and temperature, T_m. We also investigate the effect of lateral heterogeneity that locally reduces the onset age of SSC.

Melting due to SSC is predicted to emerge in elongated features (∼700 km) parallel to plate motion and not just at a fixed spot, which does not imply linear age progressions of the associated volcanism contrary to the hotspot model. The seafloor age at which volcanism occurs is sensitive to T_m. For moderate T_m (1350 °C), volcanism develops beneath relatively young lithosphere (∼30 Myr) for viscosities nat higher than $1.5 \cdot 10^{19}$ Pa·s. Increasing T_m retards the onset of SSC because of the presence of a thicker buoyant residue from previous mid-ocean ridge melting. Mantle viscosity controls the rate of melt production with decreasing viscosities leading to more vigorous convection and volcanism. The geochronology and volumes of volcanism of the Pukapuka ridges, Line and Marshall Islands are consistent with our predictions.