Models of mantle plumes and their interaction with spreading ridges, lithosphere thickness variations and global mantle flow.

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Since originally proposed by Jason Morgan nearly 50 years ago, mantle plumes have been the preferred mechanism for explaining age-progressive chains of intraplate volcanism. However, the distribution of volcanics in age and time does not always follow such a clear pattern as in the classical example of Hawaii. In order to test to what extent more complicated distributions can still be explained with the same simple plume model, if one takes plume-ridge interactions, variations in lithosphere thickness and global mantle flow into account, we have developed a numerical model using the ASPECT mantle convection code.

We solve the equations of viscous flow in a Cartesian box of 3300 x 3300 x 660 km. At the bottom of the box, influx of the plume is prescribed at a position that may vary with time, based on models of plumes advected in global mantle flow. At the sides and elsewhere on the bottom of the box, optionally mantle flow from global models based on density anomalies inferred from seismic tomography is prescribed. At the surface, time-dependent prescribed plate motions, inferred from global plate reconstructions and converted from spherical to regional box coordinates are prescribed. Lithosphere thickness at the initial time, and the boundaries of the model at all times, is inferred from backward-rotated present-day thickness on continents, and sea floor age in the oceans. Inside the model, it evolves self-consistently. Mantle viscosity is temperature- and depth-dependent; further, dehydration rheology is considered when melting occurs. If the solidus is exceeded, melt is immediately extracted to the surface in the model. Using plate reconstructions, the melt is rotated to its present-day position. Total amounts of melt can be compared with crustal thickness, and the time of melting with volcano ages.

So far we have applied this method the Tristan, Reunion, Kerguelen, Iceland and Hawaii plumes, and we will show a couple of interesting features that have appeared in those models. While in the case of Hawaii our model yielded a classical narrow hotspot track – in fact much narrower than the size of the underlying plume spreading beneath the lithosphere – in other cases the resulting distribution of volcanics looks less straightforward: For Tristan, plume material flowing to the nearby spreading ridge yields simultaneous volcanism above the plume, at the ridge and in between – volcanism is more widely spread and sometimes arranged in several parallel chains. For Reunion, interaction with the ridge along a sublithospheric channel yields a feature that resembles the Rodriguez Ridge. In the case of Iceland, material from a plume situated beneath Greenland may flow towards either side of it, where the lithosphere is thinner, and lead to simultaneous volcanism on both sides. If the plume head impinges beneath thick lithosphere such as in Greenland, the initiation of volcanism may occur only several tens of Myr later, when plume material has reached regions beneath thinner lithosphere.

In the future, our model can be used to study other relevant regions. Possible extensions could include modeling vertical uplift and dynamic topography, and self-consistent instead of prescribed plate velocities. Remaining challenges are that our model – despite dehydration rheology which already leads to improvements – tends to give too much volcanisms in the oceans, but too little beneath continents. For example, in the case of Reunion almost no volcanics are predicted where the Deccan traps are, instead, volcanism occurs in the model in the nearby rifts with thinner lithosphere. Probably, this misfit occurs because our model is currently lacking a suitable mechanism of plume-induced lithosphere erosion.