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Linking Lithospheric Structure, Mantle Flow and Intra-Plate Volcanism

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Several of Earth's intra-plate volcanic provinces cannot be explained solely through the classical mantle plume hypothesis. Instead, they are believed to be generated by shallower processes that involve the interplay between uppermost mantle flow and the base of Earth's heterogeneous lithosphere. The mechanisms most commonly invoked are edge-driven convection (EDC) and shear-driven upwelling (SDU), both of which act to focus upwelling flow, and the associated decompression melting, adjacent to steps in lithospheric thickness.

In this study, we first undertake a systematic numerical investigation, in both 2-D and 3-D, to quantify the sensitivity of EDC, SDU and their associated melting to several key controlling parameters, in the absence of mantle plumes. Our simulations demonstrate that the spatial and temporal characteristics of EDC are sensitive to the geometry and material properties of the lithospheric step, in addition to the depth-dependence of upper mantle viscosity. These simulations also indicate that asthenospheric shear can either enhance or reduce upwelling velocities and predicted melt volumes, depending upon the magnitude and orientation of flow relative to the lithospheric step. When combined, such sensitivities explain why step changes in lithospheric thickness, which are common along cratonic edges and passive margins, only produce volcanism at isolated points in space and time. Our predicted trends of melt production suggest that, in the absence of potential interactions with mantle plumes, EDC and SDU are viable mechanisms only for Earth's shorter-lived, low-volume intra-plate volcanic provinces.

To complement the results from our first numerical investigation, we subsequently explore how the upwelling of a mantle plume within our 3-D domain modifies the occurrence of melting, both in terms of spatio-temporal distribution and intensity. Preliminary results indicate that edges close to the location of plume impingement have their melting shut off as a result of the intense flow generated through sub-lithospheric spreading. Additionally, the heterogeneous distribution of continental lithosphere thickness constrains plume material spreading and results in melting patterns that do not directly reflect the path of the plume relative to the lithosphere, as described by classical mantle plume theory.