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Intraplate volcanism at the edges of the Colorado Plateau sustained by shear-driven upwelling

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While most volcanism on Earth occurs at plate boundaries, the study of intraplate basaltic volcanism provides an opportunity to examine the make-up and dynamics of the mantle. In continental settings, a range of mechanisms have been proposed to sustain mantle decompression and hence feed intraplate volcanism. These include mantle plumes, fertile melting anomalies, self-sustaining buoyant decompression melting, lithospheric dripping, and edge-driven small-scale convection. Recent studies showing that basaltic continental volcanism occurs preferentially where asthenospheric shear is most vigorous (e.g., beneath the western US) indicate that shear-driven upwelling (SDU) may induce intraplate volcanism. SDU produces decompression melting without mantle density heterogeneity: asthenospheric shear becomes concentrated within a low-viscosity pocket, and this amplified flow is accommodated by up- and down-welling close to the edges of the pocket. The induced upwelling may indeed be sufficient to sustain significant decompression melting, particularly for damp and warm pockets, as higher water contents and temperatures not only control mantle viscosity but also reduce the solidus. Seismic observations indicate that heterogeneity in mantle viscosity are indeed common beneath continents in general and the western US in particular. Here, we explore whether SDU can explain the patterns and volumes of volcanism occurring around the Colorado Plateau.

We use three-dimensional numerical models to investigate patterns of decompression melting related to the flow of low-viscosity pockets within shearing asthenosphere and around thickened lithosphere beneath the plateau. The shearing not only deforms a simulated low-viscosity pocket and translates it towards the edge of the plateau, but also gets redirected and focused into SDU near the pocket's leading edge. This upwelling can support low-degree decompression melting. Once the pocket reaches the leading edge of the plateau's thick lithosphere, the pocket's presence causes a local reduction in effective viscosity that destabilizes the thermal boundary layer at the base of the plateau. The resulting edge-driven convection is affected by the presence of asthenospheric shear. In combination with SDU, the triggered edge-driven upwelling fuels persistent decompression melting and volcanism at the leading edge of the plateau. We find that the related volcanism slowly encroaches on the Colorado Plateau, as is observed. Depending on the location of the pocket relative to the plateau, the pocket either tunnels beneath the plateau or travels around its nearest edge, with important implications for the related patterns of volcanism. In the former case, decompression melting due to SDU is choked until the pocket reascends on the far side of the plateau. In the latter case, edge-driven convection and SDU along the plateau's lateral sides can support significant volcanism. The passage of low-viscosity pockets beneath and/or around the Colorado Plateau may further remove the base of the lithosphere to promote uplift. We conclude that SDU may indeed be a relevant process for relating the physical properties of the asthenosphere to surface observables such as volcanism and dynamic topography.