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Dynamics of slab-plume interaction in Central America

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Subducting slabs and mantle plumes are two end-member mechanisms for driving vertical flow inside the Earth. However, their mutual interactions remain underexplored. One example is the potential interaction between the Galápagos plume and the Cocos slab in Central America. This region hosts many abnormal tectonic features, such as dramatic along-trench variations in heat flow and surface topography, which may represent surface responses to the interacting Cocos slab and Galápagos plume at depth. The slab is found to be torn in tomographic studies and may provide a channel for plume material to travel from the Pacific to the Caribbean mantle. We design 3D finite-element subduction models using the code CitcomS to study the plausible geodynamic processes. In our initial experiments, we find that the evolution of the subducting Cocos slab is strongly influenced by far-field forces associated with the ancient Farallon slab. As the Farallon slab below the eastern Caribbean continues to sink, the increasing lateral pressure gradient across the Cocos trench induces repeated episodes of slab tearing and renewed subduction of the Cocos slab. This process ultimately leads to the formation of an imbricate slab geometry, consistent with structures observed in seismic tomography. After incorporating the Galápagos plume into our model, hot plume material ascends through the tear in the Cocos slab and enters the Central American mantle wedge. The resulting present-day distribution of plume material shows a strong spatial correlation with regions of elevated heat flow and high topography in Central America. These results suggest that that slab–plume interaction dynamically enhances surface heat flow and contributes to regional topographic uplift. Our study provides new insights into slab–mantle dynamics in other subduction systems around the Pacific where nearby hotspots are present.