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Hydrous secondary plumes: towards understanding the enigmatic «finger» structures in the intraplate lithospheric mantle

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Many vertical seismic velocity anomalies originate in the transition zone between the upper and lower mantle (410–660 km) and form so-called secondary plumes. These anomalies are interpreted as the result of thermal effects of large-scale thermal upwelling (primary plume) in the lower mantle and/or deep dehydration of fluid-rich subducting oceanic plates. We present the results of thermo-mechanical modelling to investigate the dynamics of such small-scale thermal and chemical (hydrous) anomalies rising from the lower part of the Earth's upper mantle. Our goal is to determine the conditions that allow thermo-chemical secondary plumes of moderate size (initial radius of 50 km) to penetrate the overlying lithosphere, as detected in seismo-tomographic studies in such intra-continental areas as the Tengchong volcano in south-western China and the Eifel volcanic fields in north-western Germany. To this end, we investigate the effect of the compositional deficit of the plume density due to the presence of water and hydrous silicate melts. In our models, secondary plumes of purely thermal origin do not penetrate the overlying plate, but flatten at its base, forming "mushroom"-shaped structures at the level of the lithosphere-asthenosphere boundary. On the contrary, plumes with enhanced density contrast due to a chemical (hydrous) component are shown to be able to penetrate upward through the lithospheric mantle to shallow depths near the Moho. Our findings can explain the enigmatic observations of columnar ("finger"-shaped) anomalies in the intraplate lithospheric mantle discovered in Europe and China. We argue that a chemical component is a characteristic feature not only of conventional hydrous plumes developed in the big mantle wedge over presently descending oceanic slabs, but also of upper mantle plumes in other tectonic settings.