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Subduction History and the Evolution of Earth's Lower Mantle

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Understanding the complex structure, dynamics and evolution of the deep mantle is a fundamental goal in solid Earth geophysics. Close to the core-mantle boundary, seismic images reveal a mantle characterised by (1) higher than average shear wave speeds beneath Asia and encircling the Pacific, consistent with sub ducting lithosphere beneath regions of ancient subduction, and (2) large regions of anomalously low seismic wavespeeds beneath Africa and the Central Pacific. The anomalously slow areas are often referred to as Large Low Shear Velocity Provinces (LLSVPs) due to the reduced velocity of seismic waves passing through them. The origin, composition and long-term evolution of the LLSVPs remain enigmatic. Geochemical inferences of multiple chemical reservoirs at depth, strong seismic contrasts, increased density, and an anticorrelation of shear wave velocity to bulk sound velocity in the anomalous regions imply that heterogeneities in both temperature and composition may be required to explain the seismic observations. Consequently, heterogeneous mantle models place the anomalies into the context of thermochemical piles, characterised by an anomalous component whose intrinsic density is a few percent higher relative to that of the surrounding mantle. Several hypotheses have arisen to explain the LLSVPs in the context of large-scale mantle convection. One end member scenario suggests that the LLSVPs are relatively mobile features over short timescales and thus are strongly affected by supercontinent cycles and Earth's plate motion history. In this scenario, the African LLSVP formed as a result of return flow in the mantle due to circum-Pangean subduction ($\sim$240 Ma), contrasting a much older Pacific LLSVP, which may be linked to the Rodinia supercontinent and is implied to have remained largely unchanged since Rodinian breakup ($\sim$750–700 Ma). This propounds that Earth's plate motion history plays a controlling role in LLSVP development, suggesting that the location, geometry and morphology of lower mantle structures can be influenced by the movement of subducting slabs, and thus by the motions of tectonic plates at the surface. Alternatively, a long-term stability for both LLSVPs, which would suggest a first-order dissociation from the effects of surface plate motions, is hypothesised by recent studies which propose a geographic correlation between the reconstructed surface eruption sites of kimberlites and Large Igneous Provinces with the margins of the LLSVPs. If the surface volcanism was sourced from the lower mantle, such a link would suggest that the LLSVPs may have remained stationary for at least the age of the volcanic rocks (> 500 Myr) and further that the anomalies were largely insensitive to the formation and subsequent breakup of Pangea, and thus to Earth's plate motion history.

Here we discuss the evolution of lower mantle structure, LLSVPs and surface volcanics in terms of subduction dynamics. We integrate high-resolution plate tectonic histories and numerical models of mantle convection and perform a series of 3D spherical calculations with Earth-like boundary conditions to investigate the role that subduction history plays in the development and evolution of lower mantle structures. To test whether such an interaction exists, and if so, to what degree over time, we apply varying shifts to the absolute reference frame of the plate reconstruction. We incorporate global shifts in both longitude and latitude, with the correction applied over timescales of 230-50 Myrs. With this method, the location of subduction at the surface and thus the global flow field can be altered. This in turn affects the time-dependent sinking of lithospheric slabs and may affect their interaction with the lower mantle and the LLSVPs at both their margins and top surfaces. We aim to understand how the subduction history has affected mantle structure on a global scale. We show that shifts to the surface history of subduction, even for extreme and unrealistic cases, lead to minimal changes in LLSVP geometry and position, suggesting that the LLSVPs may be long-lived features (> 250 Ma).