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Long-term stability of Large Low Shear Velocity Provinces (LLSVPs) at the base of the mantle and Velocity Provinces at the base of the mantle and near the equator

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The observed long-term stability of Large Low Shear Velocity Provinces (LLSVPs) at the base of the mantle and near the equator raises two major questions: Even if gravitational stability can in principle be explained from intrinsically increased density of LLSVP material, (i) how can LLSVPs retain their shape and coherence within a vigorously convecting mantle over long geological times given their expectedly relatively low viscosities? We devised a numerical convection model to investigate this question of dynamical stability. Our results indicate that dense, low viscous LLSVPs can remain stable in the convecting mantle over long geological time. Yet, we observe in our numerical model that LLSVPs, whereas remaining dynamically stable, move laterally along the base of the model, thus leading to question (ii): How can we explain the stability of LLSVPs near the equator for at least the last 300 m.y. given their ability to move laterally? A common explanation for the fact that LLSVPs are situated near the equator is that true polar wander (TPW) arising from the geoid anomalies associated with LLSVPs would cause their rotation towards and subsequent stabilization at the equator. Indeed, if LLSVPs move along the base of the mantle and stay at antipodal position, TPW would reorient the Earth's rotation axis such that the anomalies remain at the equator. Yet, Steinberger and Torsvik (2008) show that TPW did not occur in a plane containing the LLSVPs during the last 320 m.y., meaning that TPW played no role in the near-equatorial stabilization of LLSVPs during that time. Consequently, the lack of latitudinal migration of LLSVPs over long geological time requires explanation. We suggest that centrifugal acceleration, even though providing only small driving forces, might be important in explaining migration of dense, low viscous LLSVPs to the equator, given the vast amount of time available in Earth history, and their subsequent stabilization near the equator. A first feasibility estimate based on the classical pole-flight theory shows that the presumably high viscosity of the lower mantle represents a strong impediment for equatorwards migration of LLSVPs and leads to the conclusion that, if the viscosity of the lower mantle is indeed that high, the drift velocity is too slow to explain the equatorial position of LLSVPs. We subsequently investigated the effect of centrifugal forces on soft and rigid anomalies with excess density for both symmetric and asymmetric anomaly shapes in a numerical model. In our model, we excluded the effect of thermal convection in order to purely examine the mechanical effect of centrifugal forces on LLSVPs. Our results indicate that soft anomalies collapse gravitationally on rather short geological times (on the order of 1 m.y.) if they are not dynamically supported by downwellings to their sides and thus the effect of centrifugal forces is hard to examine for soft anomalies. Yet, if the shape of the anomalies is retained throughout the simulation which we provide for in another simulation by ascribing a high viscosity to the anomalies, we observe a relatively slow trend of motion of the anomalies towards the equator which is consistent with the result from the analytical solution using classical pole-flight theory. We further found that the motion of the anomalies is strongly affected by two aspects: (i) The excess density of the anomalies has important influences on the figure of the model globe and therefore on the absolute position of the anomalies. (i) The shape of the anomalies (symmetric or asymmetric) plays a significant role for their sense of motion. Further modeling that includes the effect of thermal and possibly thermochemical convection is required for obtaining a definite answer to the question whether centrifugal forces are a candidate for explaining the observed long-term near equatorial stability of LLSVPs in the lower mantle.