Constraints on the composition of LLSVPs from seismic properties of lower mantle minerals

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Seismic observations have suggested the presence of two LLSVPs in the lowermost mantle. These two reservoirs are likely to be chemically distinct from the ambient mantle and to influence the dynamics of the whole Earth. Several studies have tried to constrain the compositions explaining their seismic properties with the hope that it may help to identify their formation mechanism. In particular, compositions enriched in iron (10 wt%) and bridgmanite (Bm, 90 vol%) are good candidates. These compositions are somewhat consistent with the reservoirs produced by the solidification of a primitive magma ocean, except that the iron enrichment (>20 wt%) is much larger. Here, we provide a reappraisal of the potential compositions for LLSVPs based on an improved mineralogical model including, for instance, the effect of alumina and spin state transition. We have also investigated systematically the effects of six parameters: FeO and Al_2O_3 content, proportion of $CaSiO_3$ and Bm, oxidation state and temperature contrast between ambient mantle and LLSVPs. From the 81 millions cases studied, only 166 thousands cases may explain the seismic observations. Nevertheless, these successful cases involve a large range of parameters with, for instance, FeO and Al_2O_3 content between 12–28 wt% and 5–19 wt%, respectively. A principal component analysis (PCA) is then applied to our results. The PCA has highlighted two robust results:
(i) the proportion of ferropericlase (Fp) should be low (<6 vol%);
(ii) the formation of Fe^{3+}-bearing Bm is much more favorable than other iron-bearing phases.
Following these results, we have identified two end-member compositions: one Bm-rich and one CaPv-rich. Each end-member can then be associated with various temperature contrasts, although a low temperature contrast (<500 K) is more favorable, and various FeO contents, provided a certain proportion between oxidation state, FeO and Al_2O_3 content is maintained. As a last step, we discussed different scenarios for the formation of LLSVPs. In particular, the solidification of a magma ocean may produce reservoirs with FeO and Al_2O_3 content similar to the ones we found but their proportion of Fp is too large. From a broader perspective, constraints on the mineral proportion of LLSVPs are probably the best to discriminate between different formation mechanisms.

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