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Can seismic anisotropy in D″ be used to constrain flow patterns in the lowermost mantle?

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Observations of shear wave splitting in ScS phases reveal the signature of strong seismic anisotropy in D″ and suggest that it may be possible to use seismology to probe the dynamics of the lowermost mantle. A key step in this quest is to establish the mechanism leading to anisotropy in D″ and show how this is linked to mantle flow. In this study we test the hypothesis that the observed anisotropy under Siberia, the Caribbean and North America is caused by deformation-induced crystallographic preferred orientation by combining 3D models of current mantle flow with simulations of texture development and compare the predicted splitting with new seismic observations.

The starting point is a model of current mantle flow. For this we use a global three-dimensional flow field derived from the TX2008 model of mantle density (Simmons et al. GJI 2009). This is generated by joint inversion of data including S-wave travel times, the global gravity field, dynamic surface topography, observations of plate motion and of the excess ellipticity of the core-mantle boundary. The inversion makes use of realistic mineral physics parameters and seeks to explain as much density variation as possible in terms of thermal, rather than compositional, anomalies. Using this flow model, we trace the pathlines followed by packets of material moving through the post-perovskite stability field. During this process we account for the topography on the perovskite to post-perovskite phase transition caused by lateral variations in temperature. We calculate the velocity gradients tensor at steps along each pathline and use these as the boundary conditions for the calculation of the textural evolution of post-perovskite aggregates.

Texture development in the polycrystalline aggregates are modelled using the self-consistent visco-plastic (VPSC) approach where the interactions between grains are represented by embedding each grain in a homogeneous effective medium representing the other grains in the sample. This results in the compatibility and equilibrium conditions being fulfilled in an average way while allowing the stress and strain in each grain to differ. Parameters describing the single crystal plasticity (e.g. slip activities) are currently poorly constrained by experiment and theory. To compensate for this a range of key parameters are chosen empirically, to agree with selected experimental results, or are taken from Peierls-Nabarro models of dislocations using density functional theory and assuming deformation is rate limited by the intrinsic Peierls potential. We calculate the elastic constants tensors of each textured aggregate and use this as input for forward modelling of the propagation of seismic waves corresponding to our observations. By investigating the texture, and aggregate elastic constants tensors, generated by a wide range of different single crystal parameters we are able to examine the ability of each to explain seismic observations.

We predict the shear wave splitting parameters - the delay times and fast polarisation directions - for seismic waves propagating through our model and compare these with studies that measure shear wave splitting in two directions in the study areas. This allows us to compare the model predictions with current constraints on the anisotropy of D″. We are able to reject several feasible models of single crystal plasticity on the basis of disagreement with observation but cannot uniquely constrain the glide plane for easy-slip in post-perovskite. Furthermore, the study shows that knowledge of the easy-slip system is, by itself, insufficient to constrain the modelled texture. The activities of secondary slip systems in post-perovskite are also needed but these are currently particularly poorly constrained by experiment. Another promising avenue would be to place further constraints on the deformation parameters from seismic observations.