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Seismic anisotropy in the earth's deep mantle: review and future directions

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The presence of seismic anisotropy in the crust and upper mantle is well documented, with relatively good consensus on its origins, owing to direct observations in the field and laboratory experiments on mineral crystal structure and deformation properties, in a range of pressures and temperatures that is readily accessible. The situation is much less clear for the deep mantle, due to poor sampling by seismic waves, contamination by upper mantle effects, and the difficulty for mineral physics deformation experiments to reach relevant physical conditions. However, in the last decade, there has been significant progress in both fields, and a new and promising approach has emerged, aiming at combining seismic observations of anisotropy in the deep Earth with knowledge from geodynamics modelling and constraints from mineral physics, towards understanding deformation patterns related to global mantle circulation.
Here we review the present state of knowledge on deep mantle anisotropy in seismology and mineral physics, describe current efforts at linking the two through mantle circulation modelling, and discuss future directions and challenges.

Most of the lower mantle appears largely isotropic, except in the last 200–300 km (D" region). Recently, a picture has emerged, where strong anisotropy is associated with high shear velocities at the edges of the large low shear velocity provinces (LLSVPs) under the central Pacific and Africa. These observations are consistent with relatively isotropic $MgSiO_3$ perovskite (Pv) In the upper part of the lower mantle and highly anisotropic $MgSiO_3$ post-perovskite (pPv) crystals, aligned during the deformation of slabs impinging on the core-mantle boundary, and upwelling flow within the LLSVPs.

We review these observations and present the latest results in our efforts to combine recent mineral physics information on the deformation of dominant phases in the lower mantle, 2D and 3D geodynamic modelling of a slab impinging on the core-mantle boundary, and seismological observations, in order to better understand the origin of seismic anisotropy in the vicinity of the LLSVPs. In this approach, we consider a subducting slab sinking through the lower mantle to the core mantle boundary. The 3D geodynamic calculations solve non-dimensional equations for the conservation of mass, momentum and energy, using the Boussinesq approximation (McNamara et al., 2003). The strain evolution is evaluated by inserting tracers into the isotropic convective medium. This strain is then used to calculate development of preferred orientation using the viscoplastic self-consistent method (Lebensohn and Tomé, 1993). Plasticity calculations are performed assuming different combinations of dominant slip systems for pPv, and we assume only a portion of the strain is accommodated by dislocation glide. Following this procedure for many streamlines, we can map anisotropic velocity patterns over the whole region of the geodynamic model. We then calculate predictions of radial and azimuthal anisotropy, and confront them with seismic observations at the earth's surface (e.g. Wenk et al., 2011; Cottaar et al., 2014). Adding progressively more complexity to this modelling, we recently implemented a pressure and temperature dependent Pv-pPv transition and are focusing on the deformation observed at the roots of upwellings.