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Radially and azimuthally anisotropic shear-wave velocity model of the Earth's upper mantle

François Lavoué[1,2,3], Sergei Lebedev[1,2], Nicolas Celli[2], and Andrew Schaeffer[4]
[1]Irish Centre for Research in Applied Geosciences (iCRAG), Ireland
[2]Dublin Institute for Advanced Studies (DIAS), Geophysics Section, 5 Merrion square, Dublin, Ireland
[3]now at Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre, 38000 Grenoble, France
[4]Geological Survey of Canada, Pacific Division, Natural Resources Canada

We present new models of shear-wave velocity and of its radial and azimuthal anisotropy in the crust and upper mantle at global scale. Seismic anisotropy is the consequence of the preferential orientation of minerals due to deformation. The reconstruction of both its radial and azimuthal components provides insights into past and present deformation and flow in the lithosphere and asthenosphere. The full consideration of anisotropy also makes possible to accurately determine the isotropic shear-velocity average, and therefore to isolate the effects of thermal or compositional variations from those of anisotropic fabric.

Our model is constrained by a large compilation of waveform fits for more than 750,000 vertical-component and 250,000 transverse-component seismograms. We follow a two-step procedure that comprises the Automated Multimode Inversion of surface, S, and multiple-S waveforms in a period range from 10 to 450 s, followed by a 3D tomographic inversion that reconstructs dV_{SH} and dV_{SV} velocity perturbations and their 4-ψ and 2-ψ azimuthal dependencies. The joint inversion of vertical and transverse components is regularised in terms of linear isotropic average perturbations $dV_{S0} = (dV_{SH} + dV_{SV})/2$ and of radial anisotropy $\delta = dV_{SH} - dV_{SV}$.

We compare our model with other published anisotropic models. The different models show good agreement on major isotropic structures but relatively poor agreement on anisotropic features. We identify different patterns of anisotropy for different tectonic regions. At shallow depths (< 60 km), there is a clear difference between oceanic and continental regions of different ages. While radial anisotropy is consistently negative ($V_{SH} < V_{SV}$) in the top 50 km of oceanic lithosphere, it is positive ($V_{SH} > V_{SH}$) under continents, with a thick layer of slightly positive anisotropy under cratons and a shallower layer of stronger anisotropy under phanerozoic crust, subject to more recent deformation. The largest anisotropy —positive and exceeding 2% in our and most other models— occurs between 70 and 150 km depth. This pattern is observed in both continents and oceans, and depends on their age and lithospheric thickness, which is indicative of the anisotropic fabric developed in the asthenosphere and frozen in the lithosphere. Finally, we observe a remarkable reversal from positive to negative anisotropy between 200 and 330 km depth over the entire globe. Again, the depth at which this reversal occurs depends on the tectonic settings: it is deeper

under cratons and old oceans than under young continents and oceans. Synthetic tests demonstrate the robustness of this observation. While it could be interpreted as a transition from dominantly horizontal to dominantly vertical deformation in the mantle, this anisotropy reversal is also consistent with mineralogic experiments that suggest a transition in olivine slip mechanism which causes horizontal shear to induce negative seismic anisotropy below a certain depth. In lack of a satisfying scenario that could explain a global trend to vertical mantle flow between 260 and 410 km depth, we favour the second interpretation. If this interpretation is correct, our anisotropic model provides global-scale evidence for the transition in the olivine slip mechanism documented in the mineralogic literature.