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Petrophysical constraints on the seismic properties of the Kaapvaal craton mantle root

Baptiste Virginie and Tommasi Andrea
Geosciences Montpellier, CNRS & Univ. Montpellier, France

We calculated the seismic properties of 47 mantle xenoliths from 9 kimberlitic pipes in the Kaapvaal craton based on their modal composition, the crystal preferred orientations (CPO) of olivine, ortho- and clinopyroxene, and garnet, the Fe content of olivine, and the pressures and temperatures at which the rocks were equilibrated. These data allow constraining the variation of seismic anisotropy and velocities within the cratonic mantle. The fastest P and S2 waves propagation direction and the polarization of fast split shear wave (S1) are always subparallel to olivine [100] axes maximum concentration, which marks the lineation (fossil flow direction). Seismic anisotropy is higher for high olivine contents and stronger CPO. Maximum P-wave azimuthal anisotropy (AVp) ranges between 2.5 and 10.2% and the maximum S-wave polarization anisotropy (AVs), between 2.7 and 8%. Changes in olivine CPO symmetry result in minor variations in the seismic anisotropy patterns, mainly in the apparent isotropy directions for shear wave splitting. Seismic properties averaged over 20 km thick depth sections are, therefore, very homogeneous. Based on these data, we predict the anisotropy that would be measured by SKS, Rayleigh (SV) and Love (SH) waves for 5 end-member orientations of the foliation and lineation. Comparison to seismic anisotropy data in the Kaapvaal shows that the coherent fast directions, but low delay times imaged by SKS studies and the low azimuthal anisotropy with SH faster than SV measured using surface waves are best explained by a homogeneously dipping (45°) foliation and lineation in the cratonic mantle lithosphere. Laterally or vertically varying foliation and lineation orientations with a dominantly NW-SE trend might also explain the low measured anisotropies, but this model should also result in backazimuthal variability of the SKS splitting data, not reported in the seismological data. The strong compositional heterogeneity of the Kaapvaal peridotite xenoliths results in up to 3% variation in density and in up to 2.3% variation of Vp, Vs, and Vp/Vs ratio. Fe depletion by melt extraction increases Vp and Vs, but decreases the Vp/Vs ratio and density. Orthopyroxene enrichment due to metasomatism decreases the density and Vp, strongly reducing the Vp/Vs ratio. Garnet enrichment, which was also attributed to metasomatism, increases the density, and in a lesser extent Vp and the Vp/Vs ratio. Comparison of density and seismic velocity profiles calculated using the xenoliths' compositions and equilibration conditions to seismological data in the Kaapvaal highlights that: (i) the thickness of the craton is underestimated in some seismic studies and reaches at least 180 km, (ii) the deep sheared peridotites represent very local modifications caused and oversampled by kimberlites, and (iii) seismological models probably underestimate the compositional heterogeneity in the Kaapvaal mantle root, which occurs at a scale much smaller than the one that may be sampled seismologically.