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Layering of seismic anisotropy and deformation beneath South Africa from the upper crust to the asthenosphere

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Cratons are the parts of continents that have resisted tectonic re-working for billions of years. They are the last witnesses of the Archean age crust and mantle. Without better understanding of the physical properties and the formation of cratons, our understanding of the lithosphere as a thermo-chemical boundary layer will remain incomplete. Southern Africa contains some of the oldest crust with the ancient Kaapvaal craton neighboured to the north by the Limpopo orogenic belt. A major seismic experiment in the area (SASE) has produced shear-wave splitting measurements of surprisingly small amplitude. Shear-wave splitting data, however, lack vertical resolution. The 3-D distribution of anisotropic fabric beneath southern Africa remained unclear. We have measured thousands of seismic surface wave dispersion curves and determined the distribution of azimuthal anisotropy in the crust and upper mantle. We measured interstation phase-velocity curves of both Rayleigh and Love waves using a combination of cross-correlation and waveform inversion approaches. To obtain robust phase velocities we regrouped them into four subsets each for a sub-region with relatively homogeneous structure within it. The robust and accurate dispersion curves are obtained in the broad period range of 5-200 s. This period band resolves from the upper crust to the asthenosphere. Each subset is a combination of curves sampling the medium at different wave-propagation azimuths. The azimuthal coverage of station pairs is sufficient to determine anisotropy in the 5-130 s period range.

The largest azimuthal anisotropy is observed in the upper crust of the Limpopo Belt. It is aligned with the average stress direction, suggesting that the anisotropy is associated with cracks. Limpopo Belt is the northern-most part of the study region, and the stress-induced large anisotropy there may be related to the south-ward propagation of the East African Rift. In the lower crust and lithospheric mantle, azimuthal anisotropy across the entire region is very small, less than 0.5 percent in most places. This is much smaller than typical anisotropy in Phanerozoic lithospheres. Radial anisotropy in the lower crust and lithospheric mantle, however, is around 3-4 precent beneath the entire southern Africa. Anisotropy is greater in the lower mantle lithosphere. Beneath the Limpopo Belt, the East-West fast directions in this depth range match the fast directions given by SKS splitting studies, indicating that the splitting originates largely in the lower lithosphere. In the asthenosphere, anisotropy beneath the entire region indicates fabric trending parallel to the plate motion. The consistency of surface-wave and SKS-splitting anisotropy measurements, both in the amplitude and in the fast-propagation azimuths, confirms the accuracy of our mapping. The 3-D distribution of anisotropic fabric, with the puzzling lack of azimuthal anisotropy in the lower crust and shallow mantle and its preferential occurrence in the lower lithosphere, offers important clues on the mechanisms of formation and evolution of cratons.