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Deformation of Tibetan lithosphere and asthenosphere as inferred from broadband surface waves

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The numerous seismic stations deployed across Tibet and the surrounding regions in recent years have greatly increased the data coverage across the Plateau. Despite the numerous studies of its crust, however, how the convergence of northward moving India and stable Eurasia is accommodated today is still debated. Regarding the lateral distribution of deformation, end-member models invoke deformation at narrow boundaries between "rigid blocks" and, alternatively, "continuous deformation" with viscous behaviour of the lithosphere. Regarding the vertical distribution of deformation, end-member models include "vertically coherent deformation" within the entire lithospheric thickness, and "channel flow" in which mechanically weak mid-lower crust undergoes flow that is distinctly different from the motions of the (stronger) layers above and below.

Broad-band surface waves provide resolving power from the upper crust down to the asthenosphere, for both isotropic-average shear-wave speeds (proxies for composition and temperature) and the radial and azimuthal shear-wave anisotropy (indicative of the patterns of deformation and flow). We measured highly accurate Love- and Rayleigh-wave phase-velocity curves in broad period ranges (5-200 s) for a few tens of pairs and groups of stations across Tibet, combining, in each case, hundreds of inter-station measurements, made with cross-correlation and waveform-inversion methods. Robust shear-velocity profiles were then determined by series of non-linear inversions, yielding depth-dependent ranges of shear speeds and radial anisotropy consistent with the data. Azimuthal anisotropy in the crust and upper mantle was determined by surface-wave tomography and, also, by sub-array analysis targeting the anisotropy amplitude.

The Tibetan middle crust is characterised by very low shear-wave speeds, as observed previously, however with strong variations across the plateau. The mid-crustal low-velocity zone, probably indicating partial melt and low viscosity, shows particularly low wave speeds in northern Tibet (3.08−3.43 km/s). The similarity of phase-velocity curves for neighbouring station pairs across large regions within Tibet and the coherent pattern of anisotropy within them suggest that deformation is diffused across broad areas. The maximum extension directions, derived from crustal azimuthal anisotropy, show W–E and NW–SE fast directions in central and eastern Tibet, respectively. The correlation of azimuthal anisotropy with the surface strain indicates that the dominant pattern of deformation in the middle crust is the same as that in the upper crust. Furthermore, the close agreement of anisotropy and the extensional component of the current strain rate field with the traces of sutures implies that the dominant deformation mechanism within the plateau has not changed since the initiation of continental collision and is still governed by the northward push of India.

A warm Tibetan lithosphere and asthenosphere lay beneath the north-central and north-eastern plateau. SSW–NNE asthenospheric flow beneath north-eastern Tibet is evidenced by azimuthal anisotropy constrained by our data, with the fast-propagation direction parallel to that of India's plate motion. This suggests that the flow is associated with India's northward subduction beneath the Tibetan lithosphere and asthenosphere under the central and eastern plateau. The distributed, multi-layered azimuthal anisotropy beneath Tibet, with different fast-propagations directions in the crust and asthenospheric mantle, accounts for the complexity of published shear-wave splitting observations.