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Subduction of the Indian lithosphere beneath Tibet and deformation of the Tibetan crust and mantle, imaged with broad-band surface waves

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Seismic deployments over the last two decades have produced dense broadband data coverage across the Tibetan Plateau. Yet, the lithospheric dynamics of Tibet remains enigmatic, with even its basic features debated and with very different end-member models still advocated today. Most body-wave tomographic models do not resolve any high-velocity anomalies in the upper mantle beneath central and northern Tibet, which motivated the inference that the Indian lithosphere may sink into deep mantle beneath the Himalayas in the south, with parts of it possibly extruded laterally eastward. In contrast, surface-wave tomographic models all show pronounced high-velocity anomalies beneath much of Tibet at depths around 200 km. Uncertainties over the shapes and amplitudes of the anomalies, however, contribute to the uncertainty of their interpretations, ranging from the subduction of India or Asia to the extreme viscous thickening of the Tibetan lithosphere. Within the lithosphere itself, a low-viscosity layer in the mid-lower crust is evidenced by many observations. It is still unclear, however, whether this layer accommodates a large-scale channel flow (which may have uplifted eastern Tibet, according to one model) or if, instead, deformation within it is similar to that observed at the surface.

Broad-band surface waves provide resolving power from the upper crust down to the asthenosphere, for both the isotropic-average shear-wave speeds (characterising the composition and thermal state of the lithosphere) and the radial and azimuthal shear-wave anisotropy (indicative, in an actively deforming region, of the current and recent flow). We measured highly accurate Love- and Rayleigh-wave phase-velocity curves in broad period ranges (up to 5-200 s) for a few tens of pairs and groups of stations across Tibet, combining, in each case, hundreds to thousands of inter-station measurements made with cross-correlation and waveform-inversion methods. Robust shear-velocity profiles were then determined by extensive series of non-linear inversions, designed to constrain the depth-dependent ranges of isotropic-average shear speeds and radial anisotropy consistent with the data. Temperature anomalies in the upper mantle were estimated from shear-velocity using pre-computed petro-physical relationships. Azimuthal anisotropy in the crust and upper mantle was determined by surface-wave tomography and, also, by sub-array analysis targeting the anisotropy amplitude.

Our results show that the prominent high-velocity anomalies in the upper mantle are most consistent with the presence of subducted Indian lithosphere beneath much of Tibet. The large estimated thermal anomalies within the high-velocity features match those to be expected within subducted India. The morphology of India's subduction beneath Tibet is complex and shows pronounced west-east variations. Beneath eastern and northeastern Tibet, in particular, the subducted Indian lithosphere appears to have subducted, at a shallow angle, hundreds of km NNE-wards.

Azimuthal anisotropy beneath Tibet is distributed in multiple layers with different fast-propagations directions, which accounts for the complexity of published shear-wave splitting observations. The fast directions within the mid-lower crust are parallel to the extensional components of the current strain rate field at the surface, consistent with similar deformation through the entire crust, rather than channel flow. Anisotropy within the asthenosphere beneath northeastern Tibet (sandwiched between the Tibetan lithosphere above and the subducted Indian lithosphere below) indicates SSW-NNE flow, parallel to the direction of motion of the Indian Plate, including its subducted leading edge.