Abstract

Southeastern Tibet is a highly deformed region, formed due to multistage subduction and continued collision of Indian and Asian plates. The region is characterized by a clockwise material flow around the indenting corner of the Indian plate, which manifests itself on the surface as strike-slip faults parallel to the Himalayan Arc. Earlier geodetic and mantle-core refracted SK(K)S phase splitting observations reported the coupling of the crust and mantle material beneath the study region. However, GPS data do not necessarily reflect the strain of the entire crust. Instead, it indicates shallow crust deformation. As a result, the crust and upper mantle coupling cannot be accurately measured by comparing the surface deformation pattern provided by GPS data and upper mantle deformation shown by core refracted SK(K)S phases. Several numerical and geodynamic models have been developed emphasizing the east-west extension and tectonic history of southeastern Tibet. However, various scientific concerns such as the northern extension of the Indian plate and its spatial distribution, uppermost mantle rheology and deformation, multi-layered lithospheric deformation, and coupling/decoupling of the crust-lithospheric mantle beneath southeastern Tibet remained unanswered. My Ph.D. goal is to gain insight into these unanswered scientific problems by measuring layered lithospheric seismic anisotropy and lithospheric mantle shear wave attenuation beneath the study region using 70 seismic stations of the Eastern Syntaxis Experiment (XE network, 2003−2004).

The first part of the study deals with the formulation of a 2D-Q_{Sn} tomographic model to investigate the uppermost mantle shear wave Q and its tectonic implications beneath southeastern Tibet near Namche Barwa. To achieve this objective, I find the interstation Q values by implementing the Two Station Method (TSM) on 618 station pairs. The station pairs are obtained from 26 regional earthquakes (M $\geq$5.5) using an epicentral distance range of 5° to 15° recorded at 47 broadband seismic stations. Furthermore, the Q_{Sn} tomographic model is generated by utilizing these interstation Q values. Q_{Sn} values are varying from 101 to 490 in the region. The tomography image reveals high attenuation ($\leq$200 Q values) in the central region. Regions of low attenuation (>200 Q values) are observed in the southern part and some small areas beneath the northern side of the study region. Consecutive high-low-high Q_{Sn} values have been observed in the southern part of the Lhasa block. The obtained Q_{Sn} values, along with the prior isotropic Pn velocity model of the study area, indicate that the scattering effect is causing significant Sn wave energy dissipation on account of the structural heterogeneity

present in the uppermost mantle beneath the region. This may be the result of the break-up of the subducting Indian plate beneath the region. The Q_{Sn} analysis adds new constraints in understanding the rheology and deformation of the uppermost mantle essential to comprehend the crust and upper mantle coupling.

The second part of the study deals with detecting upper mantle seismic anisotropy parameters beneath the region using direct-S waves splitting. Direct-S wave based station averaged splitting measurements with increased back-azimuthal coverage tend to fill the coverage gaps left in SKS measurements. I have employed the reference station technique to remove the effects of source-side anisotropy. Seismic anisotropy parameters, splitting time delays and fast polarization directions, are estimated through analyses on a total of 501 splitting measurements. Direct-S waves from 25 earthquakes (M $\geq$5.5) recorded at 42 broadband stations within an epicentral distance of 30° to 90° are used to acquire the splitting measurements. I have observed a large variation in time delays ranging from 0.64 to 1.68 s, but in most cases, it is more than 1 s, which suggests a highly anisotropic lithospheric mantle in the region. A comparison between direct-S and SK(K)S derived splitting parameters show a close similarity, although some discrepancies exist where null or negligible anisotropy was reported earlier using SK(K)S waveforms. The seismic stations with hitherto null or negligible anisotropy are now supplemented with new measurements with clear anisotropic signatures. My analyses indicate a sharp change in lateral variations of fast polarization directions (FPDs) from SSW−ENE or W−E to NW−SE direction at the southeastern edge of Tibet. The observed anisotropy and hence inferred deformation patterns are not only due to asthenospheric dynamics but are a combination of lithospheric deformation and sub-lithospheric (asthenospheric) mantle dynamics. However, SK(K)S or direct-S derived splitting measurements suffer from the depth localization of anisotropic layers. Although splitting measurements are dominated by upper mantle deformation, crust anisotropy played a considerable role, particularly in the study region, which has a thicker crust (55−75 km). As a result, the third and final objective of my Ph.D. work is to estimate depth-dependent crustal anisotropic parameters in order to fully comprehend the lithospheric deformation and geodynamic processes active beneath the study region.

The last part of the study deals with detecting the depth-dependent crustal anisotropic trends based on the directional dependence of radial and tangential receiver functions (RFs). To achieve my objective, I have computed 3683 good-quality P-RFs from 174 teleseismic earthquakes (M $\geq$5.5) recorded within epicentral distance ranges of 30° to 90° at 70 seismic stations of the Eastern Syntaxis experiment. After that, I have employed the harmonic decomposition technique at each seismic station to retrieve the first ($k = 0$), second ($k = 1$), and third ($k = 2$) degree harmonics from the RF dataset. The anisotropic axes of the upper crust (0−20 km) appear to vary from approximately N−S to NE−SW. They are usually orthogonal to the trends of the major faults and suture zones in the region, implying the effect of the structure-induced anisotropy. It can be explained by regularly oriented cracks or macroscopic structure alignment along the major faults. The anisotropic orientations of the middle crust (20-40 km) are NE−SW to E−W direction, reflecting a different pattern than those estimated in the upper crust. The lower crustal (40−70 km) anisotropic pattern (E−W or ESE−WNW direction) exhibits distinct orientations than the upper and middle crust. The crystal preferred orientation (CPO) of the mica and amphibole minerals is the likely cause of anisotropy observed at mid-to-lower crustal depth ranges. It emphasizes the role of ductile deformation due to material movement towards the east underneath southeastern Tibet.

The thesis work provides insight into the details of lithospheric deformation patterns and their causes in southeastern Tibet. The obtained Q_{Sn} tomography model indicates that the Indian plate extends up to the middle of the Lhasa block in the mantle lithosphere. However, the observed Q_{Sn} variations indicate the breakage of the Indian plate in the central part of the study region. Significant anisotropy is observed using direct-S derived splitting measurements at the stations where previously null or no measurement was reported based on SK(K)S study. This could be due to the multi-layered anisotropic patterns that exist beneath the study region. The first depth-dependent crustal anisotropy model is also obtained for southeastern Tibet. The obtained upper crustal anisotropic orientations stem from the structure-induced phenomenon, whereas the mid-to-lower crustal anisotropy could indicate ductile deformation due to crustal flow beneath the study region. The discrepancies in the layered crustal anisotropic directions and direct-S splitting signatures are indicative of the partial coupling between the crust and upper mantle material beneath the region.