Significant seismic anisotropy beneath southern Tibet inferred from splitting of direct S-waves

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Overview

- Significant anisotropy in regions of southern Tibet inferred from direct S-waves where null or negligible anisotropy has been hitherto reported from SK(K)S measurements.
- The fast polarization directions (FPDs) are oriented (a) NE–SW to E–W to the south of the Indus–Tsangpo Suture Zone (b) NE–SW to ENE–SSW between Bangong–Nujiang Suture Zone and the Indus–Tsangpo Suture Zone (ITSZ) and (c) E–W to the extreme north of the profile.
- The splitting time delays (dt) vary between 0.45 and 1.3 s south of the ITSZ (<30N latitude), while they range from 0.9 to 1.4 s north of it.
- The overall trends are similar to SKS/SKKS results. However, the differences may be due to the not so near vertical paths of direct S waves which may sample the anisotropy in a different way in comparison to SKS waves, or insufficient number of SKS observations.
- The significant anisotropy (~ 0.8 s) observed beneath Himalaya reveals a complex deformation pattern in the region and can be best explained by the combined effects of deformation related to shear at the base of the lithosphere and subduction related flows with possible contributions from the crust.

Hi-Climb Network for Direct-S Wave Splitting

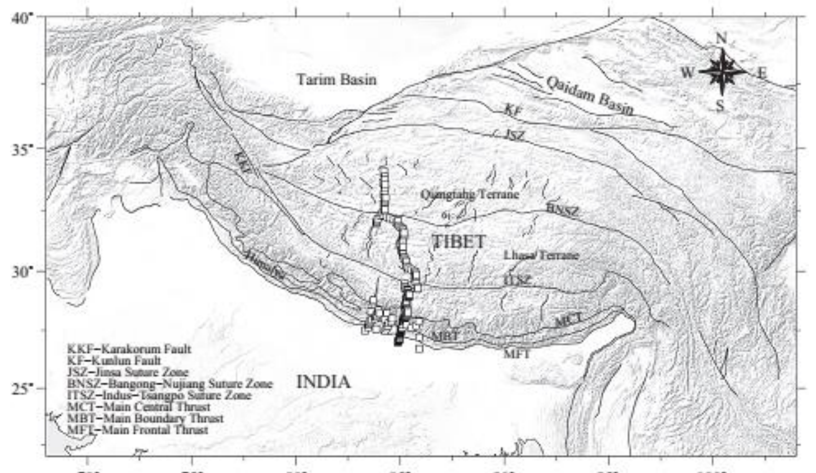

Fig. 1. Simplified tectonic map of Himalaya and Tibet. Squares represent the locations of broadband seismic stations operated by Hi-CLIMB network.

The Himalaya and the Tibetan plateau regions have been formed as a consequence of collision of the Indian and Eurasian plates nearly 50 million years ago (Royden et al., 2008). Since its separation from Gondwana land ~140 Ma ago and its flight towards north, the Indian plate has undergone extensive deformation and multi-stage subduction beneath Asia (van Hinsbergen et al., 2012), resulting in a highly heterogeneous Tibetan lithospheric-mantle

Although the deformation is extensive throughout the lithosphere, whether the crust and lithosphere are deformed coherently and are mechanically coupled or they are responding in a coherent manner to plate motion and not necessarily coupled is a matter of debate.

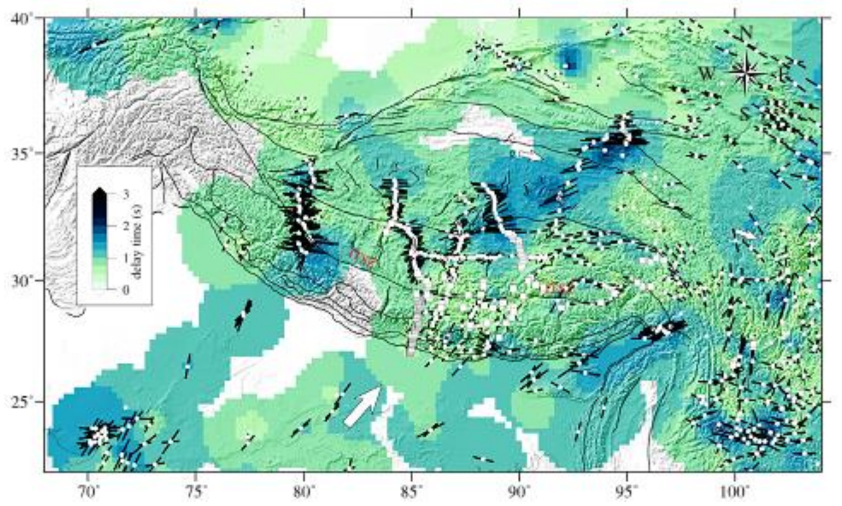

Fig. 2: Available SKS splitting measurements (bars) from the Tibet–Himalaya collision zone (Wüstefeld et al., 2008). ITSZ: Indus Tsangpo Suture Zone

Various efforts have been made to investigate the deformation patterns of the Himalaya–Tibet collision zone and the Indian shield using shear wave splitting data. The operation of various temporary and permanent seismic networks in the region resulted in a large number of splitting measurements from the SK(K)S phases

Fig. 3. Event distribution showing the position of earthquakes

Direct S-waves extracted from 106 earthquakes having magnitudes ⩾ 5.5 in the distance range of 30–80° (Fig. 3) and recorded by the Hi-CLIMB network operational between the years 2002–2005 are used to obtain the receiver side shear wave splitting parameters. The Hi-CLIMB profile makes two completely different data sets since the stations south of ITSZ were mostly operated during the years 2002–2003 and the northern ones during 2004–2005.

Reference Station Methodology for S-wave splitting

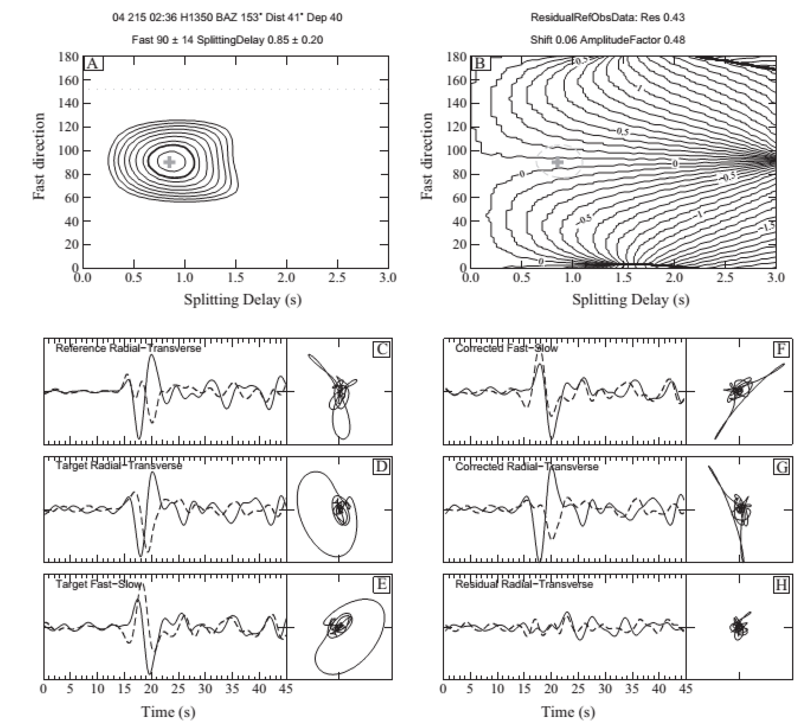

Fig.:4: An example showing direct S-wave splitting using reference station technique recorded at station pair H1220(Reference Station)-H13509target Station)

Reference station technique used to avoid source side effect when using direct S-waves.

The main assumption behind the technique is that shear wave signals recorded at both reference and target stations are subjected to the identical source -side anisotropy.

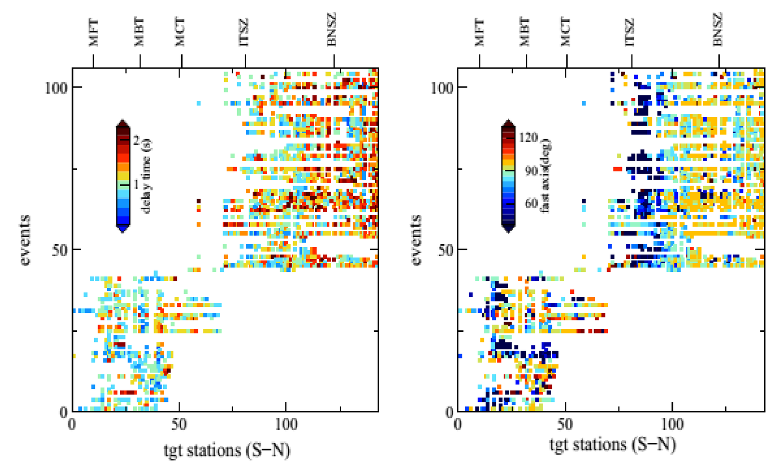

Fig. :5: All individual splitting parameters (delay time and FPD) which show consistency in measurements.

Some particular portions are completely blank due to different operating periods of southern and northern stations. Larger delay times and consistency in the FPDs are clearly evident for stations north of the ITSZ. Stations located to the south of the MCT show smaller delay times

Observations emerged from this type of statistics:

- The consistency of splitting parameters is quite good for stations located north of the ITSZ, while they are not so coherent to the south (mainly southern Tibet and Himalaya)
- The number of splitting measurements is quite small in Himalayan region compared to stations north of the ITSZ (c) The δt is small (<1 s) for stations south of the MBT, while it is higher north of the ITSZ (>1.2 s)
- No specific event (earthquake) dominance is seen, except in the case of a FPDs at a few stations corresponding to event numbers 20–25.

Observed differences in Direct S and SKS Splitting

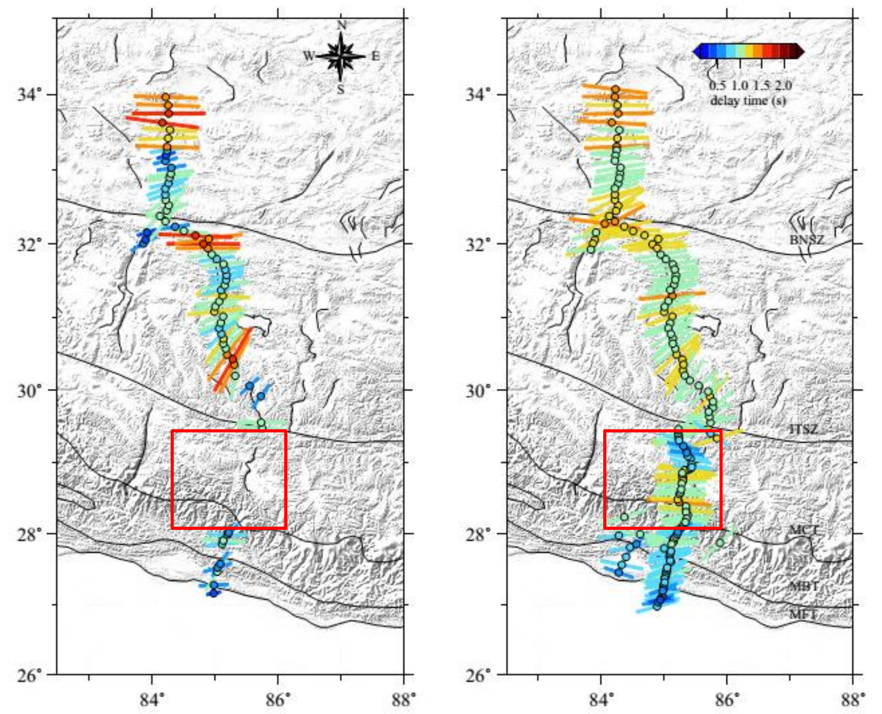

Fig. 6: Lateral variation of station-averaged direct-S waves derived splitting parameters; φ and δt are obtained by reference station technique (right hand side). Station averaged SKS splitting parameters are also shown for comparison (left hand side) (Chen et al., 2010).

The differences can be attributed to:

- the complex and multi-layered anisotropy and
- the inability of SKS phases to trace the sub-vertical shear strain of the downwelling Indian lithosphere.

Comparison of direct-S and SKS Measurements

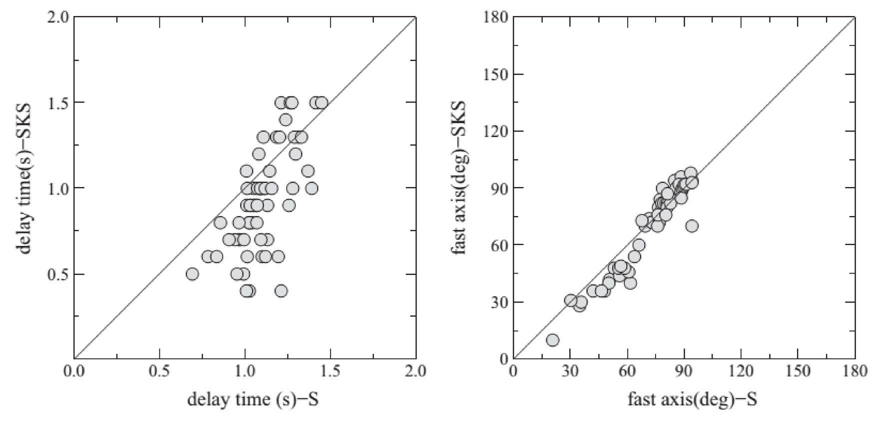

Fig.7: Scatter plot of SKS-and S-derived splitting parameters

The final results and FPDs obtained through direct-S and close similarity to SKS on a larger scale does suggest that the reliability of the method and any systematic bias which may remain in delay times due to reliability of SKS will be minimal. While the FPDs estimated from SKS and direct S are similar at most of the stations, the delay times show a definite positive correlation, although the delay times for direct-S fall in a narrower range compared to SKS delays times

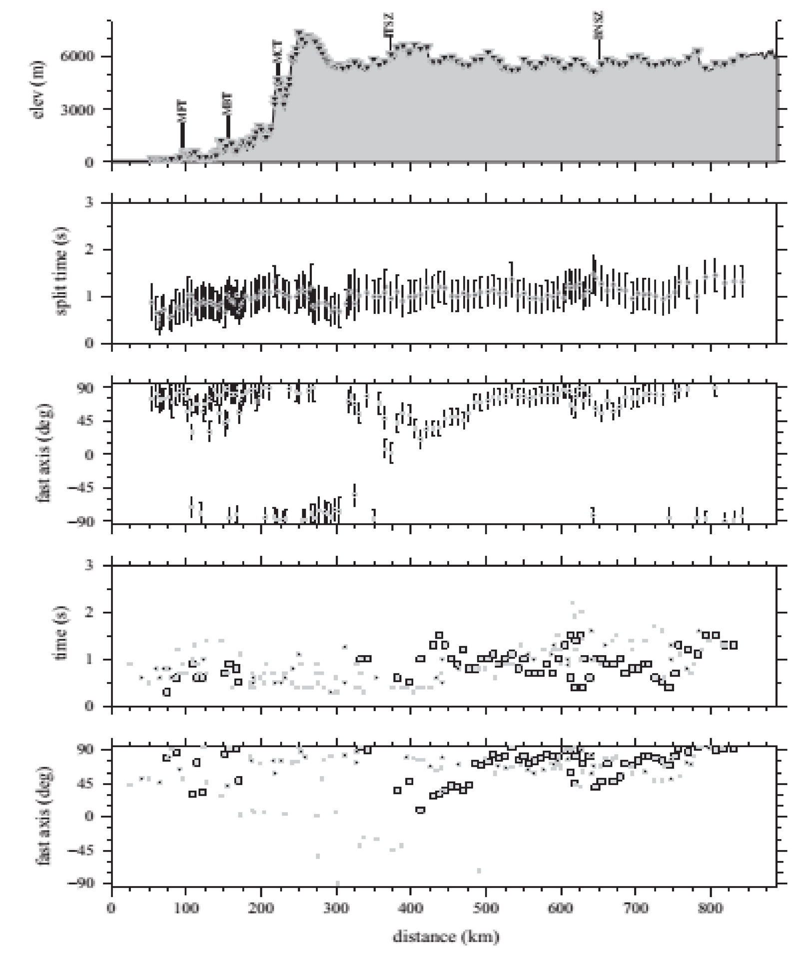

Fig.8: Station-averaged splitting parameters shown with average of their individual error estimates, (a) station locations along with elevation (b) delay times (average simple mean) along with error bars from the present study (c) FPD (circular mean) along with error bars from the present study (d) split time delays inferred from SKS splitting measurements from Chen et al. (2010), grey filled squares; black filled squares are from other studies (Wüstefeld et al., 2008) from the region projected along the profile (e) same as d, for FPD.

The change in splitting time delays and fast polarization directions between the north and south of the ITSZ reveals a sharp change in the deformation fabric.

The changes in the fabric may be related to either sudden slab steepening or change in the ductile flow patterns across the ITSZ, between Lhasa terrane and the Himalayan belt.

The possibilities of corner flow induced by the sub-vertical subduction of Indian lithosphere can not be ruled out (Fu et al., 2008; Heintz et al., 2009), where asthenospheric flow is playing adominant role.

Conclusions

- Our study clearly brings out significant anisotropy south of the ITSZ, a region hitherto considered to possess null or negligible anisotropy.
- Large anisotropic delays (~0.8 s) observed south of the ITSZ suggests contributions from multiple layers of anisotropy in the lithospheric and sublithospheric mantle as well as the crust and rules out consideration of an isotropic Indian lithosphere.
- In the present study, we do observe a change across the ITSZ in terms of smaller delay times towards south (0.8s) and larger (>1 s) delay times north of it. If the contact between the Indian and the Eurasian lithospheric mantle (Chen et al., 2010) is defined based on time delays, the northern limit of the Indian lithospheric mantle could well be terminated at the ITSZ.

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