



## Lateral Moho variations and the geometry of Main Himalayan Thrust beneath Nepal Himalayan orogen revealed by teleseismic receiver functions

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### Abstract

The lateral Moho variations and the geometry of the Main Himalayan Thrust under the Nepal Himalayan orogen are investigated to determine a new crustal model using a large number of high-quality receiver functions recorded by the HIMNT and HiCLIMB portable seismic networks. Our new model shows an evident and complicated lateral Moho depth variation of 8–16 km in the east–west direction, which is related to the surface tectonic features. These results suggest a non-uniformed crustal deformation, resulted from the splitting and/or tearing of the Indian plate during the northward subduction. Our migrated receiver function images illustrate a discernible ramp structure of the Main Himalayan Thrust with an abrupt downward bending close to the hypocenter of the 2015 Gorkha Mw 7.8 earthquake. The distribution of the aftershocks coincides with the present decollement structure. Integrating previous magnetotelluric soundings and tomographic results, our results suggest that the ramp-shaped structure within the Main Himalayan Thrust could be directly linked to the generation of the Gorkha earthquake. Our crustal model provides new insights into the formation of the Himalayan orogen and large earthquakes in the Nepal region.

**Key words:** Receiver function, Moho variation, Main Himalayan Thrust, Nepal Himalayan Orogen, the 2015 Gorkha earthquake

### Introduction

Since the mid-Miocene, a series of south-vergent thrust faults have accommodated the shortening across the Himalayan range owing to the northward extrusion of the Indian plate and several distinguishable tectonostratigraphic units have been gradually formed (Fig 1). These major thrust faults are interpreted to sole into the Main Himalayan Thrust (MHT) at depth, which serve as a decollement as well as a boundary that separates the Indian crust below from the Himalayan crust above. So far, disparity exists between how geologists and geophysicists perceive of the MHT geometry. Even though a deeper ramp along the MHT is well accepted in the geological community, geophysical evidences, especially tomographic and other seismological evidences, seem to vary in this regard. In addition, although it is widely accepted that the Indian crust has been subducted beneath the Himalayan orogen, resulting in a gradual deepening Moho discontinuity to ~70 km depth in the latitude direction, the longitudinal variation of the Moho discontinuity beneath the Himalayan orogen has yet to be investigated more thoroughly.

In this paper, we employ several receiver function imaging techniques to comprehensively investigate the Moho and MHT structures in the Nepal region. Special emphasis has been placed on the observation and interpretation of a complicated Moho variation in the longitude direction and a sharp MHT variation in the latitude direction in the region.

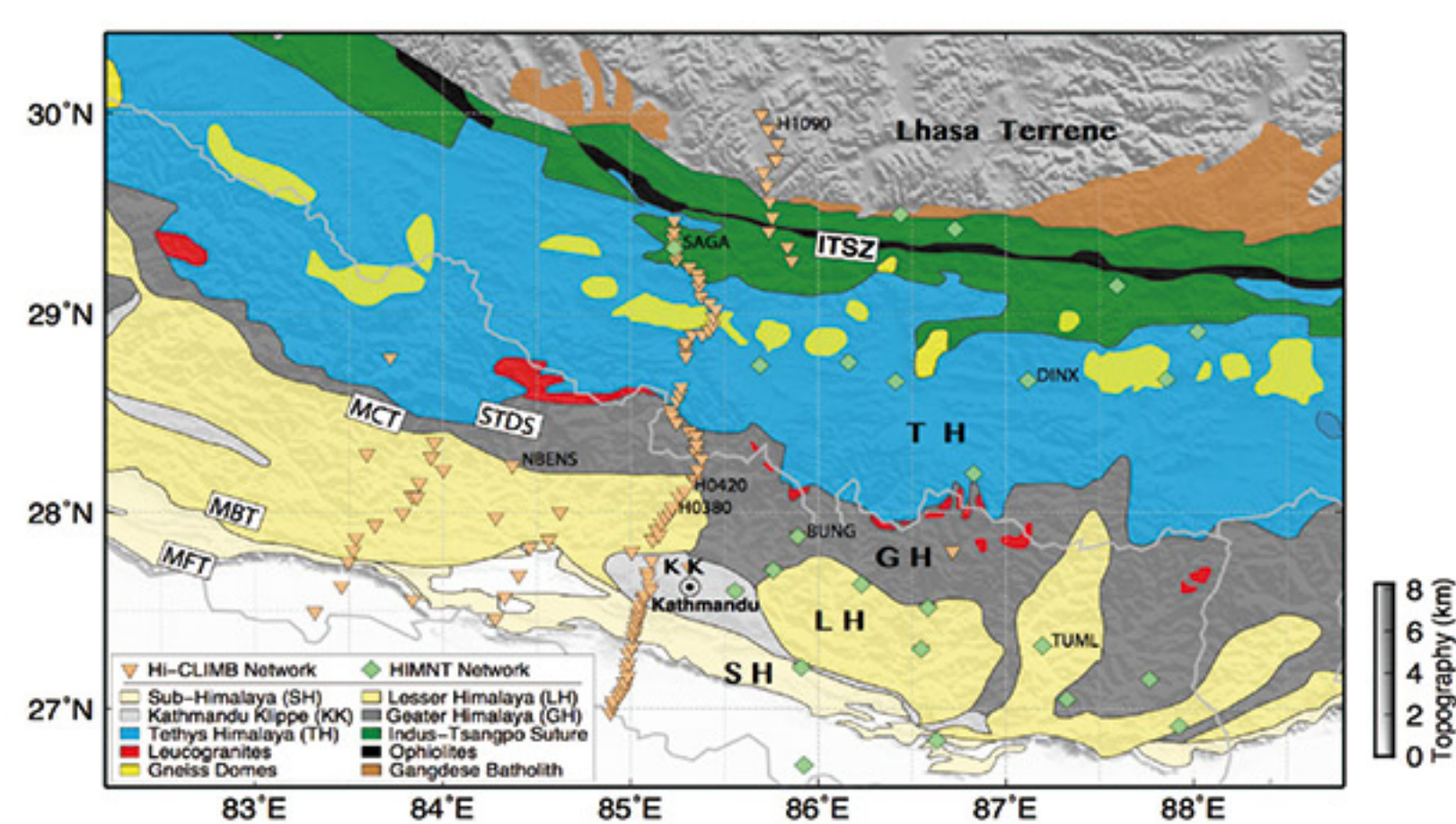


Figure 1. Tectonic map of the central and eastern Nepal Himalayan orogen and seismic stations used in the present study. Gray lines delineate the Nepal national border.

### Data & Method

The data used in our study originate from a combination of two portable seismic experiments, HIMNT (Himalayan Nepal Tibet Seismic Experiment) and HiCLIMB (Himalayan-Tibetan Continental Lithosphere During Mountain Building) (Fig 1 and 2). In this study, the seismic waves from a total number of 155 stations in the Nepal Himalayan zone are used to investigate the crustal structure beneath the study region.

Receiver functions are extracted using the standard data processing procedure, which can be summarized into data preprocessing, rotation, deconvolution, and move-out correction. With the aim to shed lights on the same subsurface structure from different angles of view and to enhance the robustness of our results and interpretation, we construct receiver function images beneath the region along different profiles using different imaging techniques including common depth points stacking, back-projection migration or common-conversion-points (CCP) and Fresnel-zone migration imaging.

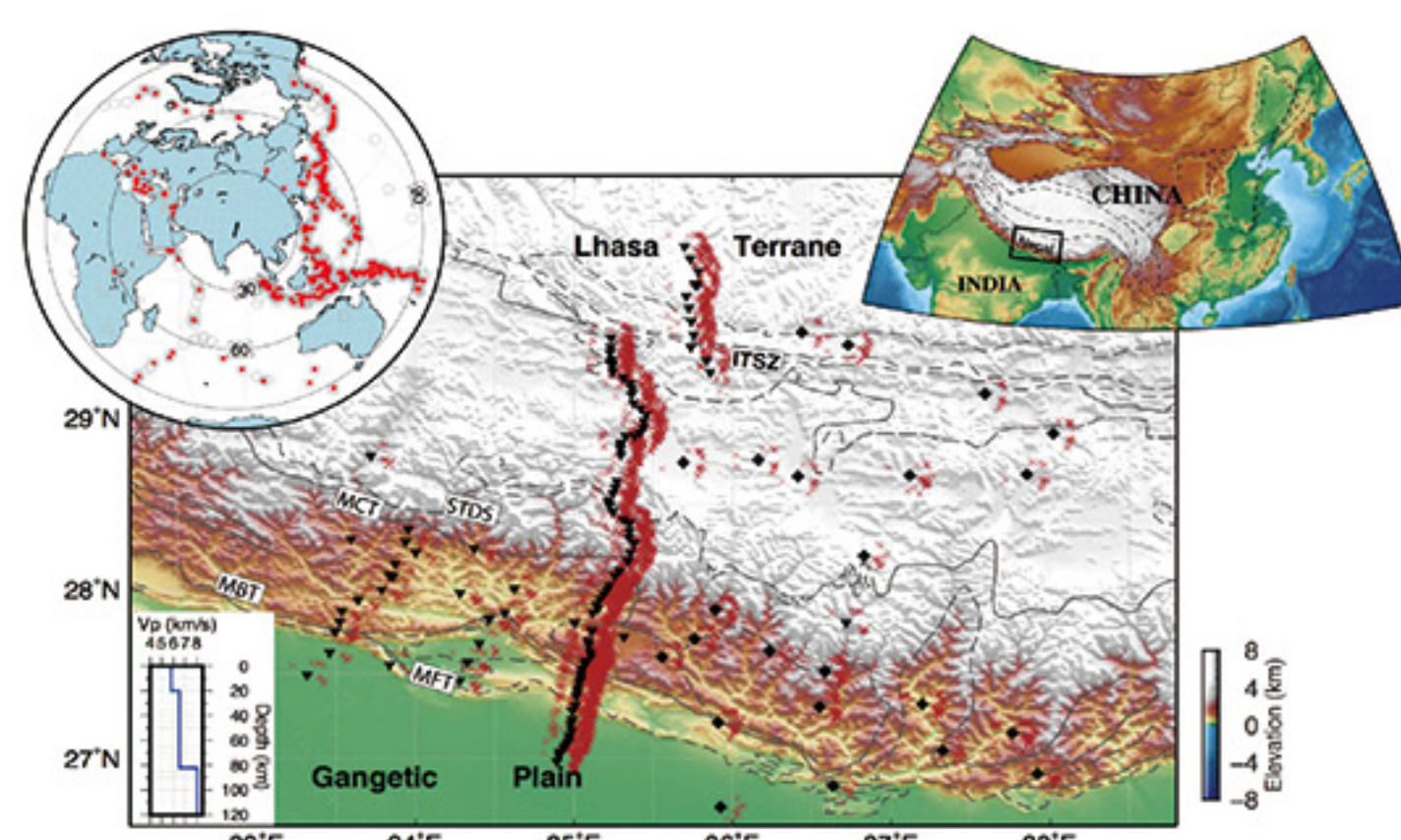


Figure 2. The distribution of stations and the piercing points of seismic rays used. The adopted velocity model, teleseismic events, and the location of study area are shown in the left bottom, left top, right top corners respectively.

### Results

The Moho phase generally appears later in the north than that in the south (Figs 3 & 4). Although the shallower crustal structures above the Moho depth along the ITSZ appear to be less complicated than those along the MHT (Figs 3a and 3c), both the depth and pulse shape of Moho conversions along the ITSZ vary significantly.

Two prominent positive converters along the latitudinal profiles beneath the Tethys Himalaya (TH) are easily identifiable in Figs 3b and 4b.

There also exist apparent differences of the steepening extents between the Moho depth along the profiles across the central Nepal Himalayan orogen and that across eastern Nepal Himalaya. (Figs 3f, g & 4f, g)

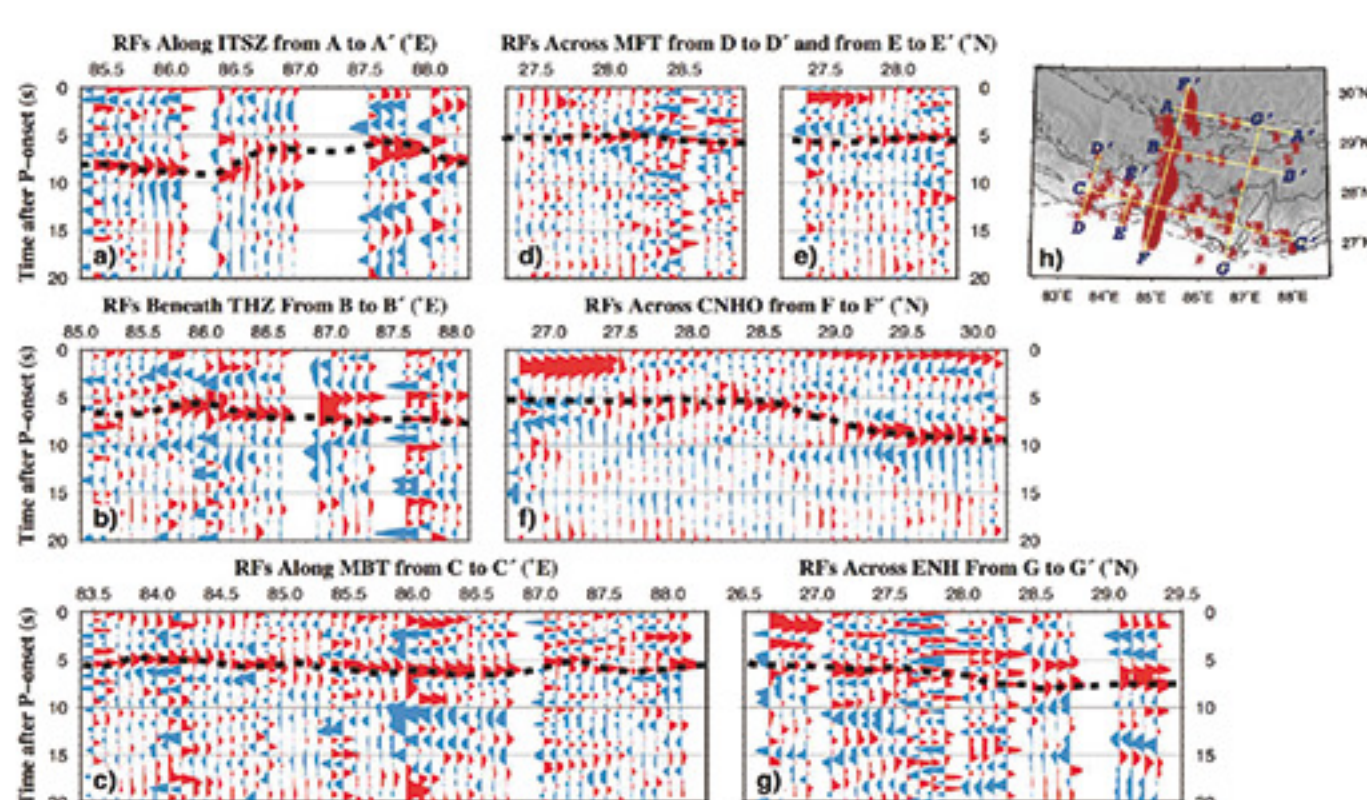


Figure 3. (a-g) Common depth point (CDP) stacking of P receiver functions along the seven profiles as shown in (h). (h) Locations of profiles. Piercing points of teleseismic rays are shown as crosses. Black dotted lines are the inferred tracks of the Moho discontinuity.

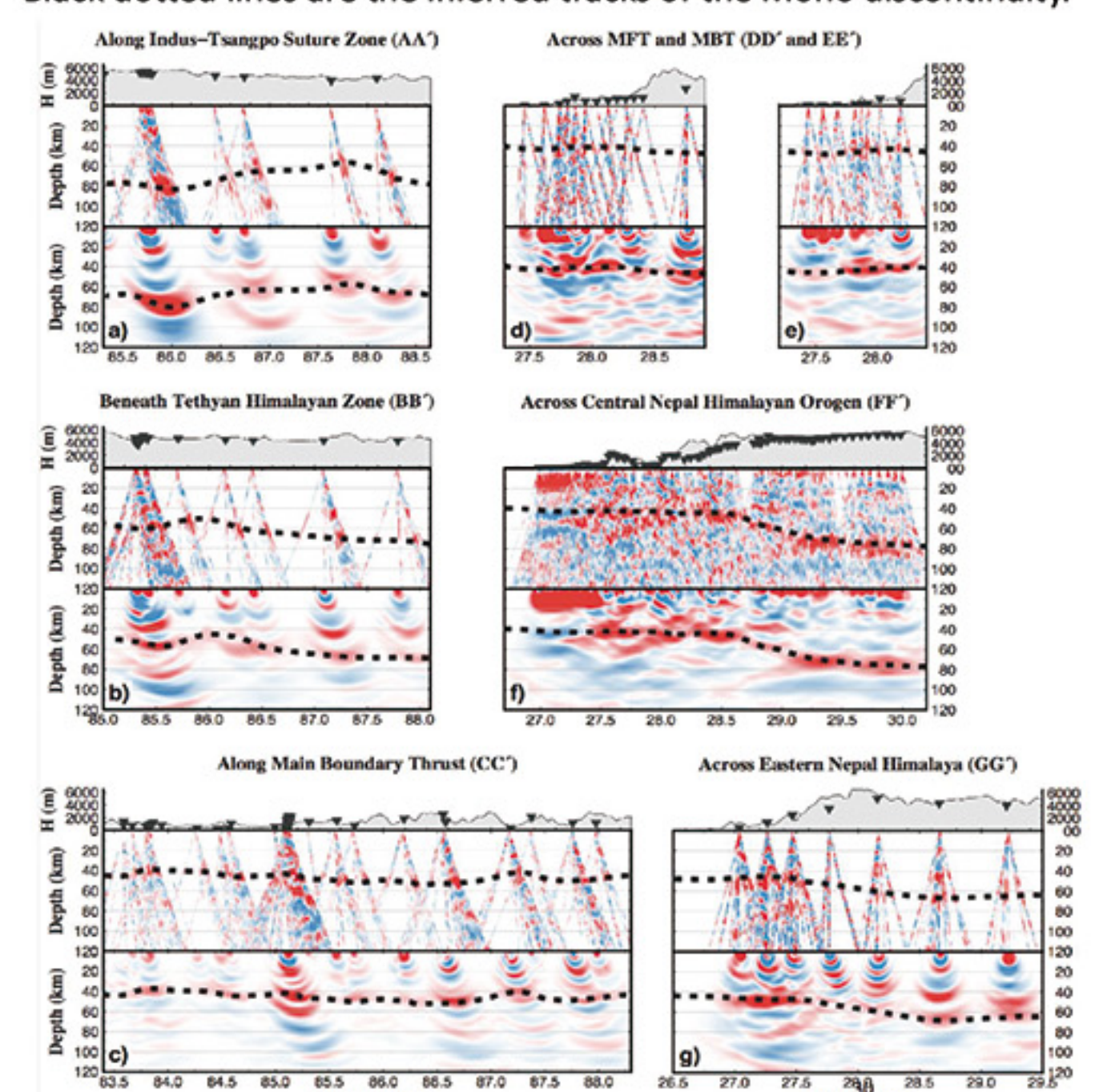


Figure 4. (a-g) Back-projected (top) and Fresnel-zone (bottom) migration image in the depth domain along the profiles as shown in Figure 3. Topography (polygons) and stations (inverted triangles) are displayed on the top. Black dotted lines delineate the Moho depth.

### Discussions

Lateral Moho depth variations are clearly identifiable from ~8 km along profile CC' to ~16 km along profile BB' to ~16 km along profile AA' (Fig 5a). The dipping angle varies from ~27 degrees along profile FF' to ~20 degrees along profile GG' (Fig 5a). These results suggest that the subducting Indian plate has experienced different extents of deformation in different parts of the Nepal Himalayan orogen along the Himalayan arc as the Indian plate makes indentations northward beneath the Tibetan plateau, suggesting a possible tearing of the subducted Indian slab for a complicated convergent mechanism of the Indo-Eurasian collision zone. (Fig 5b)

Our present study shows that the Moho depth variations are related to the geological features on the surface (Fig 6). Beneath the SH zone the Moho depth variations reaches ~4 km, from ~40 km depth in the west to ~44 km depth in the center of the study region. Beneath the LH zone, the Moho dips smoothly from 83°E to 86.5°E in the central and western parts of our study region, whereas the dipping angle of the Moho becomes complicated in the eastern part, where the Moho depth reaches ~50 km eastward to 86°E in contrast to ~44 km in the west. (Fig 6)

After analyzing the seismic impedance for the lithologic structures juxtaposed across the MHT throughout the region, we derive the possible geometry of MHT. Our CCP stacking images along profile FF' reveals a ramp structure along the MHT, the geometry of which might be suggestive of a duplexing neotectonic thrusting mode rather than the out-of-sequence thrusting or passive overthrusting mode, together with a possible linking to the occurrence and the locus for the initiation of the 2015 Gorkha major earthquake. (Fig 7)

The 2015 Gorkha mainshock seems to be generated at a greater depth compared with the majority of its aftershocks, and is located north to the lower corner of the ramp structure proposed along the central Nepal Himalayan orogen profile (Fig 7 & 8).

As illustrated in the interpretation cartoon (Fig 8), the 2015 Gorkha earthquake seems to originate not directly at the bottom of the ramp structure, which might serve as a locked structure for the bursting of major earthquakes, but several kilometers north to the lower corner of the ramp. This locale relationship between major event and ramp structure might be interpreted to be linked by some possible duplex structures in between.

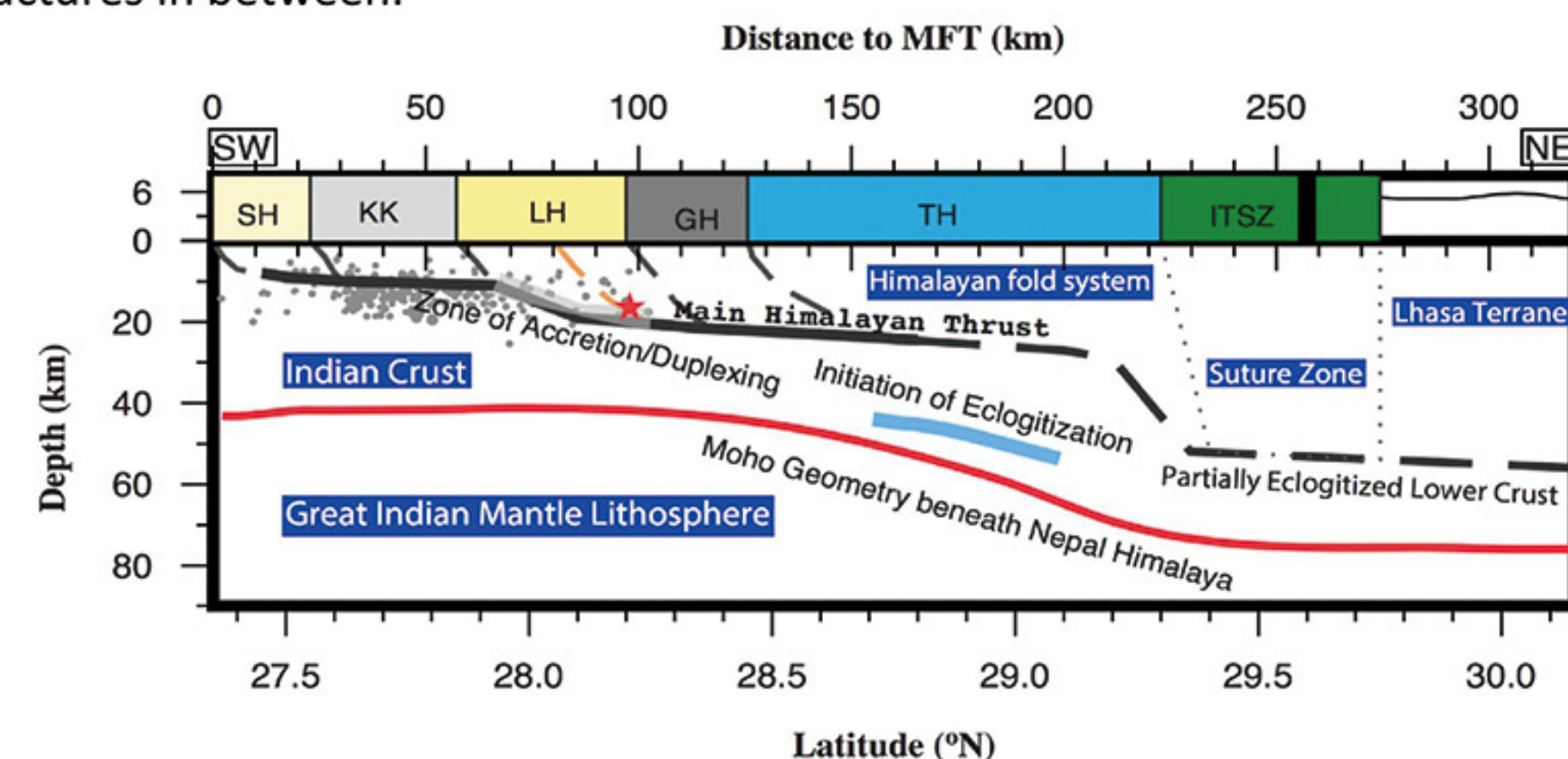


Figure 8. Possible interpretation for the underlying crustal structures beneath the Nepal Himalayan orogen along profile FF'. The star and dots show the 2015 Gorkha main shock and aftershocks. The filled colors over the topography curve are coded as shown in Figure 1.

### Conclusions

- (1) Evident lateral variations of the Moho discontinuity have been found perpendicular to the indentation of India into Eurasia, suggesting a possible tearing of the subducted Indian slab and/or a complicated convergent mechanism of the Indo-Eurasian collision zone.
- (2) Our results show that the Moho variations are related to the surface geological units. For example, along the ITSZ, such a variation appears to be the most dramatic, reaching up to ~16 km, suggestive of the hot material upwelling due to the sharp change in the subduction angle there.
- (3) Our observations clearly reveals a ramp structure along the MHT as the decollement stretching from the MFT to the south Tibet. Such a flat-ramp-flat MHT structure could be caused by duplexing mode of thrusting, which would be helpful for understanding the Nepal Himalayan orogen and the 2015 Gorkha main shock and aftershocks.