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West–east transition from underplating to steep subduction in the India–Tibet collision zone revealed by receiver-function profiles

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ABSTRACT

Closely-spaced receiver-function profiles in the east-central India–Tibet collision zone reveal drastic west–east changes of the crustal and upper mantle structure. West of ∼91.5°E, we show the Indian crust-mantle boundary (Moho) extending subhorizontally from ∼50 km depth below sea level under the High Himalaya to ∼90 km under the central Lhasa terrane. Further north, this boundary transitions to become the top of the Indian lithospheric mantle and, becoming faint but still observable, it can be tracked continuously to ∼135 km depth near ∼31.5°N. The top of the Indian lithospheric mantle is clearly beneath the Tibetan Moho that is also a conspicuous boundary, undulatory at 60–75 km depth from the central Lhasa terrane to the north end of our profile at ∼34°N. This geometry is consistent with underthrusting of Indian lower crust and underplating of the Indian plate directly beneath southern Tibet. In contrast, east of ∼91.5°E, the Indian Moho is only seen under the southernmost margin of the Tibetan plateau, and eludes imaging from ∼50 km south of the Yarlung-Zangbo suture to the north. The Indian lower crust thins greatly and in places lacks a clear Moho. This is in contrast to our observation west of ∼91.5°E, that the Indian lower crust thickens northwards. A clear depression of the top of the Indian lower crust is also observed along west-east oriented profiles, centered above the region where the Indian Moho is not imaged. Our observations suggest that roll-back of the Indian lithospheric mantle has occurred east of ∼91.5°E, likely due to delamination associated with density instabilities in eclogitized Indian lower crust, with the center of foundering beneath the southern Lhasa terrane slightly east of 91.5°E.

1. Introduction

The Tibetan Plateau is the spectacular consequence of the ongoing India–Eurasia continental collision beginning at ∼57 Ma (e.g., Argand, 1924; Tapponnier et al., 2001; Leech et al., 2005). The post-collisional convergence between the two continents likely exceeds 2000 km (Dupont-Nivet et al., 2010). Previous studies suggest that this convergence has been accommodated in part by underthrusting of Indian lower crust beneath the Himalaya (Zhao et al., 1993; Schulte-Pelkum et al., 2005) and for at least 150 km north of the Yarlung Zangbo Suture (YZS) to at least ∼31°N between longitudes 85°E and 92°E (Kind et al., 2002; Nábělek et al., 2009; Shi et al., 2015). However, this amount of underplating can only account for the convergence during the last 10 Ma, given the modern underthrusting rate of 1.6 cm/yr of Indian lower crust under southern Tibet (Wang et al., 2001). How the Indian lower crust was accommodated before this time remains largely speculative. The underplating interpretation of Nábělek et al. (2009) suggests the Indian lithospheric mantle remains attached to the sub-horizontal Indian lower crust to ∼31°N at ∼85°E. In contrast, Kosarev et al. (1999) and Shi et al. (2015) show the Indian lithospheric mantle detaching from the crust ∼50 km north of the surface trace of the YZS at ∼90°E, and ∼50 km south of the surface trace of the YZS at ∼92°E, implying steep subduction may also play an important role in accommodating the vast amount of convergence. How and why the Indian lithospheric mantle transitions from almost horizontal underplating to steep subduction

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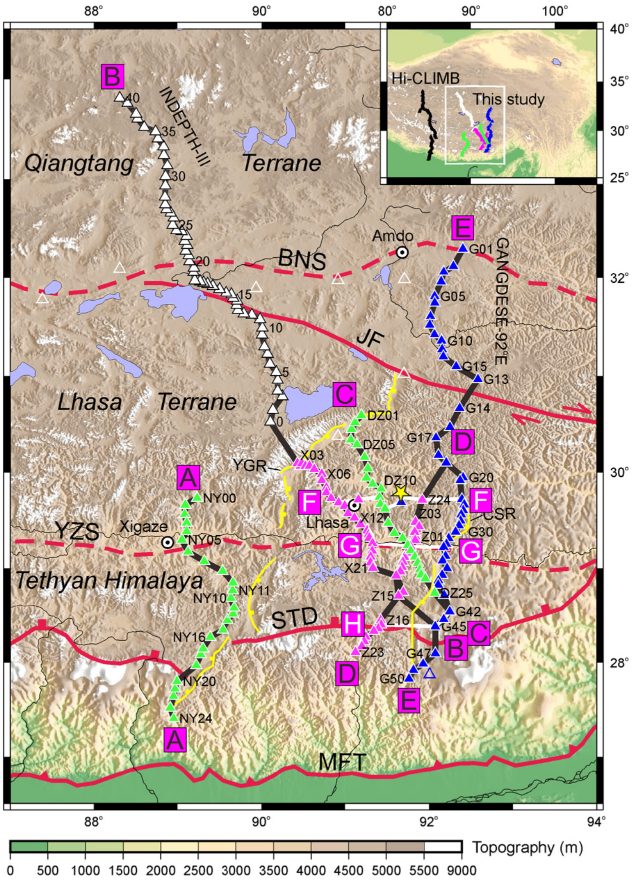

Fig. 1. Gangdese and INDEPTH III seismometer locations superimposed on the topography, east-central India–Tibet collision zone. Blue, pink and green triangles: Gangdese seismic stations deployed in 2011 (Gangdese 92°E: Shi et al., 2015), 2012 and 2014; white triangles: INDEPTH III seismic stations (Kind et al., 2002; Tilmann et al., 2003; Shi et al., 2004). (Open triangles were not used in constructing images in Fig. 2.) Black and white lines connect stations used to form profiles A, B, C, D, E, F, G and H. Dashed red lines mark the Yarlung Zangbo (YZS) and Banggong–Nujiang (BNS) sutures. Red lines delineate the Main Frontal Thrust (MFT), South Tibet Detachment (STD) and the dextral Jiali fault (JF). Yellow lines show bounding faults of the Yadong–Gulu (YGR) and the Cona–Sangri rift systems (CSR) (after Taylor and Yin, 2009). Yellow star symbol indicates a major center of ∼18–12 Ma porphyry deposits. Inset shows the extent of this map (white rectangle) and the Hi-CLIMB main-profile seismic stations (black triangles) on the topographic map of the Tibetan plateau.

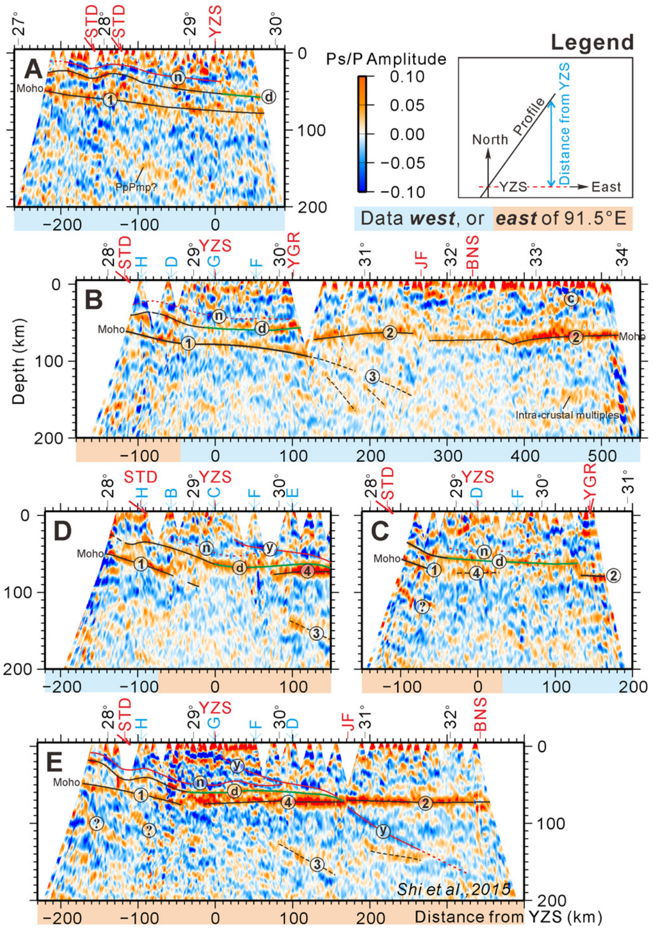

Fig. 2. Seismic images and interpretations of crustal and upper-mantle structure along five closely-spaced, near south-to-north trending profiles showing abrupt west-to-east change in the east-central India–Tibet collision zone. The same images without interpretive lines are shown in Fig. S2. All images are constructed with P-receiver functions, using a fixed horizontal stacking bin width of 3.5 km. Horizontal distances are relative to 29.25°N (latitude of YZS), and depths are relative to sea level. Positive and negative amplitudes are plotted in red and blue, respectively marking interfaces with increasing and decreasing impedance with depth. Interfaces are shown by solid lines when the conversions are strong, and by dashed lines when the conversions are weak or less confidently interpreted. '1', '2' and '4' indicate the conversions from the crust-mantle boundary (or Moho). 'd' denotes the doublet conversion from the top of the Indian lower crust, 'n' the negative conversion tracking above the doublet conversion, '3' the top of Indian lithospheric mantle, 'y' the Yarlung Zangbo converter (Shi et al., 2015). The crossing points of each profile with other profiles are marked above the profiles.

remains uncertain. Here we present new evidence for the rapid spatial transition between these two modes of convergence.

2. Data and method

Between September of 2011 and September of 2012, we deployed our Gangdese-92°E seismic array in southern Tibet. The results from this deployment suggest a steep subduction of the Indian plate in the east-central India–Tibet collision zone (Shi et al., 2015). In order to further clarify Tibet's deep structure, especially how the Indian plate transitions from underplating to steep subduction, we deployed four shorter linear seismic arrays from 2012–2014 (Fig. 1) in the area previously best studied by the INDEPTH II and III arrays (1994 and 1998–1999) (Kosarev et al., 1999; Kind et al., 2002; Tilmann et al., 2003; Shi et al., 2004) and the Gangdese-92°E array. All our new arrays were equipped with Guralp 3ESPCD broadband seismometers, and operated for 12 months. Wherever possible we deployed our new seismic arrays outside of the north–south trending rift systems (Fig. 1) in order to focus on the collisional structure between the two continents. Profiles (Figs. 2 and 3) combining the data acquired by our new arrays and those from the INDEPTH III and Gangdese-92°E experiments, all together comprising 198 seismometer locations, provide us with a better view of the east-central India–Tibet collision zone, from the High Himalaya, across the YZS, to the Banggong–Nujiang Suture (BNS) and central Tibet.

We obtained images of the crustal and upper-mantle structure of the east-central India–Tibet collision zone using common conversion point (CCP) stacks of P receiver functions (PRFs), a well-established method which has been applied in many similar studies of the Tibetan plateau (e.g. Kosarev et al., 1999; Kind et al., 2002; Nábělek et al., 2009; Zhao et al., 2011). This method enhances S waves converted from P waves of distant earthquakes that impinge on seismic interfaces. It detects interfaces and describes their properties based on the time delays between the direct and converted waves that are mainly proportional to the depths of the interfaces, and on the amplitudes of the converted waves that depend on the magnitudes and signs of the velocity contrasts.