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Seismic evidence for the North China plate underthrusting beneath northeastern Tibet and its implications for plateau growth

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ABSTRACT

Lithospheric deformation of the Tibetan plateau is caused by subduction of the Indian (northward) and Asian (southward) plates. The effects of this interaction on inner reaches of the Asian continent, between the Tibetan plateau and the North China craton (NCC) for example, remain uncertain due to poor geophysical data coverage in northeastern Tibet (NE Tibet). We provide here detailed knowledge of the lithospheric structure beneath NE Tibet as determined from a dense broadband seismic profile traversing NE Tibet to the westernmost NCC. Receiver function imaging reveals several significant features, including a north-dipping intracrustal converter (NC), Moho offset/overlap beneath major fault zones, and a low velocity layer (LVL) in the middle-lower crust. The lithosphere–asthenosphere boundary (LAB) is clearly defined and appears as a south-dipping interface that runs continuously from the Alxa interior to the Qilian orogen. Interpretation of these observations, combined with other seismic evidence, implies that the NCC lithospheric mantle has been persistently underthrust beneath the Qilian orogen. This process forms the thick-skinned crustal accretionary wedges, which develop above a middle-lower intracrustal decollement. Our results provide further deep-geophysical constraints on the Cenozoic post-collisional evolution of the convergent boundary between NE Tibet and the NCC and help clarify the mechanism of plateau growth in this boundary area.

1. Introduction

Activation and deformation of the continental lithosphere during Cenozoic collision of the northward-drifting Indian plate and the relatively stationary Asian plate caused formation and growth of the Tibetan plateau. A growing number of seismic observations (e.g., Kind et al., 2002; Nabelek et al., 2009; Zhao et al., 2010, 2011; Zhang et al., 2012b; Yue et al., 2012; Replumaz et al., 2013) have indicated that the post-collisional convergence of India and Asia was accommodated by mantle lithosphere subduction of the Indian plate beneath southern Tibet and the Asian plate component of north–central Tibet, although some studies suggest no south-verging subduction of Eurasian lithosphere (e.g., Ceylan et al., 2012; Liang et al., 2012). Most of these previous seismic profiles did not cover the northeastern margin of the plateau however (i.e., the transition area from the Qilian orogen to the Alxa block), so that the nature of the lithospheric contact between the Tibetan plateau and the North China craton (NCC) in NE Tibet remains obscure.

As the leading edge of the plateau's northeastward expansion, fold and thrust belts in NE Tibet (e.g., Qilian Shan) are currently undergoing shortening/thickening and topographic uplift as they are incorporated into the plateau (Meyer et al., 1998). To understand the tectonic dynamics of convergence between NE Tibet and the NCC, as well as subsequent uplift of this area, we present a comprehensive lithospheric-scale model based on new results and previous profiles, which directly image the lithospheric contact between NE Tibet and the NCC. The images derive from a new, high-quality teleseismic receiver function (RF) dataset from a 550 km profile consisting of 38 densely spaced, broadband seismic stations (Fig. 1). This seismic profile traverses the entirety of NE Tibet and extends northward to the southern Alxa block.

2. Geologic setting

Tectonically, the northeastern Tibetan plateau involves several component blocks to the north of the Jinsha River suture (JRS), including, from south to north, the Songpan–Ganzi (SPGZ), Qaidam–

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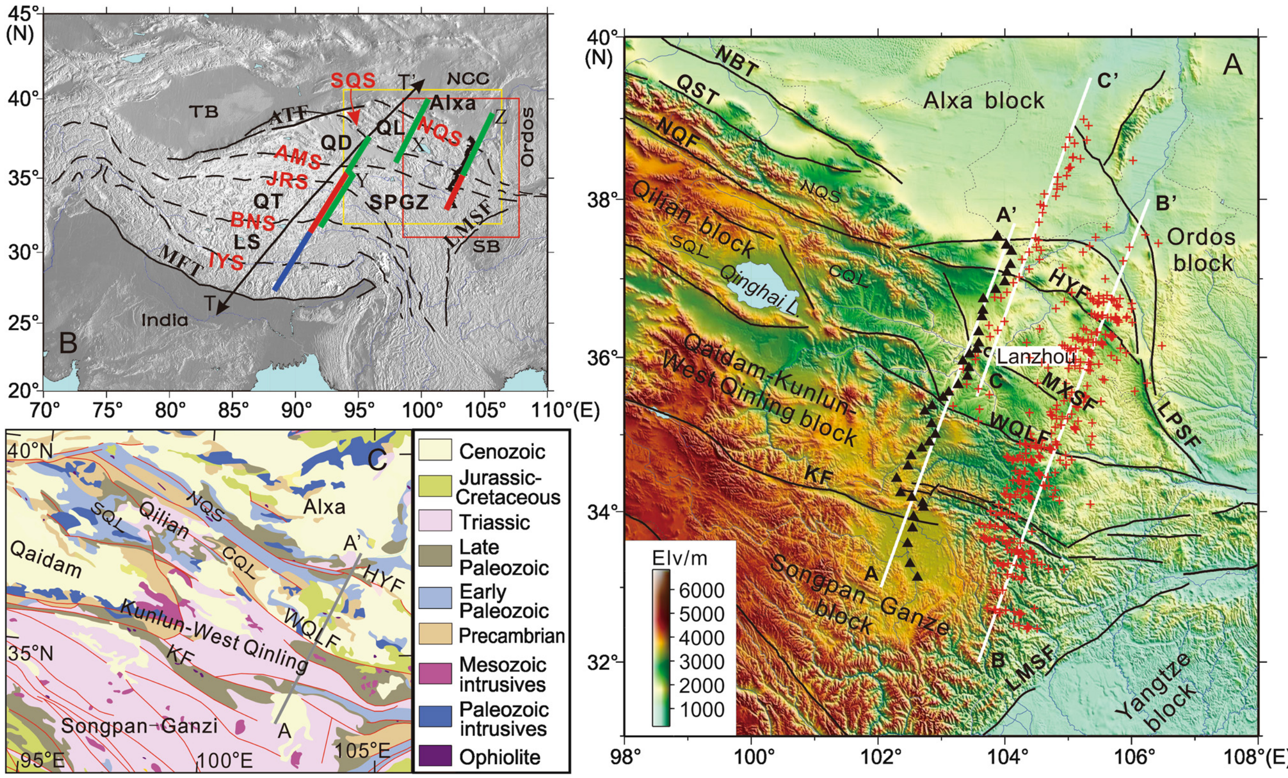

Fig. 1. A: Topographic map of NE Tibet, showing locations of the seismic stations (black triangles). Black solid lines indicate main faults (after Taylor and Yin, 2009). Red crosses show S-to-P conversion points at 150 km depth for involved S-RFs. Solid white lines show P-RF stacking profile (AA') and two S-RF stacking profiles (BB' and CC'). B: Tectonic sketch of the Tibetan plateau. Red and yellow boxes show the map areas of panel A and panel C, respectively. Black triangles mark seismic stations. Bold black bi-direction arrow marks the location of the tomographic transect across Tibet (see Fig. 5D). Colored bars indicate LAB observations: blue = Indian, green = Asian and red = Tibetan LAB, in which X and Y mark previously reported profiles for Tibet (Feng et al., 2014 and Zhao et al., 2011, respectively) and Z marks this study. C: Simplified geologic map of NE Tibet based on the 1:2.5 million scale geologic map of China (Huang et al., 2002) with the gray line indicating our observation profile AA'. Blocks are LS: Lhasa; QT: Qiangtang; SPGZ: Songpan–Ganzi; QD: Qaidam–Kunlun–West Qinling; QL: Qilian (Qilian Shan); NCC: North China craton; TB: Tarim basin; SB: Sichuan basin. IYS: Indus–Yalu suture; BNS: Bangong–Nujiang suture; JRS: Jinsha River suture; AMS: Animaqing suture; SQS: South Qilian suture; NQS: North Qilian suture; MFT: Main frontal thrust; ATF: Altyn-Tagh fault; LMSF: Longmenshan fault; KF: Kunlun fault; WQLF: West Qinling fault; MXSF: Maxianshan fault; HYF: Haiyuan fault; NQF: North Qilian fault; LPSF: Liupanshan fault; QST: Qilian Shan frontal thrust; NBT: North Border thrust (Gao et al., 1999).

Kunlun–West Qinling (QD), Qilian (QL), Alxa and Ordos blocks. NE Tibet is itself bound by the Kunlun fault (KF) system to the south and the Altyn Tagh–Haiyuan fault (ATF–HYF) system to the north. Surrounding NE Tibet are the Alxa and Ordos blocks to the north and northeast, the Tarim basin to the northwest, and the interior Tibetan plateau (Qiangtang and other blocks south) to the south (Fig. 1B).

Thick and pervasively folded Triassic strata, commonly referred to as the Triassic flysch complex (Dewey et al., 1988; Burchfiel et al., 1995; Yin and Harrison, 2000), cover expansive areas of the SPGZ terrane and Kunlun–West Qinling (KL–WQL) ranges, conformably overlying Paleozoic shallow marine sequences of the passive continental margin of North China (Zhou and Graham, 1996) and South China (Burchfiel et al., 1995). The vastly distributed Triassic flysch deposition south of the West Qinling fault (WQLF) is thought to be attributed to the erosion of the WQL orogenic belt in the late Triassic after the SPGZ terrane was accreted to the Qaidam–Kunlun–West Qinling terrane during the late Permian (Dewey et al., 1988; Yin and Nie, 1993; Zhou and Graham, 1993; Yin and Harrison, 2000). Later, the closure of the Animaqing suture (AMS) was completed in the early Jurassic (Dewey et al., 1988). To the north of the WQLF, the Qilian orogen divides (from north to south) into the early Paleozoic North Qilian suture zone (NQS), Central Qilian (CQL) and South Qilian (SQL) belts. Song et al. (2006) suggested that both the Qilian block and the Qaidam block may belong to the same stable Proterozoic "craton" (informally referred to as the Qilian–Qaidam craton) and the Qilian–Qaidam craton collided with the Alxa block when the northward-subducted North Qilian ocean closed along the NQS in the late Ordovician (Yang et al., 2002; Song et al., 2006). The united Qilian orogen is dominated by an imbricate thrust belt (Nan Shan thrust) of Precambrian basement overlain by Paleozoic sedimentary sequences. The Cenozoic Nan Shan thrust belt marks the eastern termination of the ATF system and accommodates shortening along Tibet's northeastern edge (Fig. 1C, Song et al., 2006; Yin and Harrison, 2000).

During the early Cenozoic, shortly after the India–Eurasia collision, the deformation had propagated to NE Tibet (Fang et al., 2003; Duvall et al., 2011), leading to successive reactivation of the old sutures (Gehrels et al., 2003; Ding et al., 2004; Wang et al., 2013) and then crustal shortening/thickening accelerated in NE Tibet during middle to late Miocene (Fang et al., 2005; Lease et al., 2007), which was accompanied by lateral extrusion of continental blocks and controlled by the reactivated strike-slip faults and thrust faults (e.g., the HYF and the KF, Meyer et al., 1998). Using late Mesozoic and Neogene horizons as markers, a minimum of ∼150 km of Neogene shortening has been estimated for the region between the northern edge of the Qilian Shan and the KF (Meyer et al., 1998). Based on the amount of left slip along the eastern ATF, Yin and Harrison (2000) inferred that ∼340 km of north–south shortening have occurred in the Cenozoic across the Nan Shan thrust belt. Recent geological studies document active NNE–SSW directed crustal shortening along the thrust faults at the northeastern margin of the Qilian Shan at a rate of 1–2 mm/yr over the past 10 Ma (e.g. Zheng et al., 2010; Hetzel, 2013). The Global Positioning System (GPS) measurements