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Lithospheric velocity structure of the northeast margin of the Tibetan Plateau: Relevance to continental geodynamics and seismicity

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ABSTRACT

We provide teleseismic constraints on the continental collision zone along the SW-NE profile from the Tibetan Plateau to the Alxa block, traversing Lenglong Ling, a topographic boundary of the northeastern Tibetan Plateau. Our seismic profile crosses the Qilian Shan thrust belt, a zone of intense earthquake activity that includes a pair of M_W 5.9 earthquakes (in 1986 and 2016) with a 30-year time interval occurring at the city of Menyuan near Lenglong Ling. A high degree of similarity between the two waveforms and their similar hypocenters indicate that the two events are repeating earthquakes. Both *P*- and *S*-wave receiver functions show contrasting lithospheric structure and crustal seismic properties across the repeating earthquake region, suggesting that Lenglong Ling can be the crustal boundary between the Tibetan Plateau and the Alxa block. High-frequency *P* receiver functions clearly show a SW-dipping underthrusted upper crust beneath the foreland of the Qilian Shan thrust belt. A strong low-velocity feature above the intracrustal underthrust beneath southwest Lenglong Ling indicates a mechanically weak zone developed coeval with the main compressional deformation during the last major tectonic event. Our observed, localized upper-crustal deformation beneath Lenglong Ling can be direct evidence of the lateral growth of the northeastern Tibetan Plateau, and can control the seismicity of the Qilian Shan thrust belt, including the Menyuan repeating earthquakes.

1. Introduction

The Tibetan Plateau is one of the most seismically active regions in the world, and has been actively studied to understand the relationship between the occurrence of large earthquakes and the deep crustal structures from dense array data (e.g., Nabelek et al., 2009). In the northern Tibetan Plateau, numerous large-scale faults have developed since the collision with India (Yin et al., 2008a, 2008b; Yuan et al., 2013). In particular, the Haiyuan fault is the largest strike-slip fault, which connects with the Qilian Shan thrust system and joins the Altyn Tagh strike-slip faults (Fig. 1a). These fault systems form the tectonic border of the northeastern Tibetan Plateau from the Asian blocks (e.g., Alxa and Ordos; Fig. 1a inset).

The complicated geodynamic process in the boundary region associated with the large-scale fault systems (Meyer et al., 1998; Yuan et al., 2013) has caused intense earthquake activity (Fig. 1a). Two notable large earthquakes occurred in this region, which are the M 8.3 Gulang earthquake on 23 May 1927, and the M 8.7 Haiyuan earthquake on 16 December 1920 (Gaudemer et al., 1995), the largest intraplate earthquake ever recorded during the instrumental period. The focal mechanisms indicate that the thrust and strike-slip faulting are dominant in the Qilian Shan thrust system and the Haiyuan fault system, respectively (Fig. 1a).

On 20 January 2016, a M_W 5.9 earthquake occurred at Lenglong Ling ('Ling' means mountain ridge in Chinese) within the Qilian Shan thrust system in the northeast Tibetan Plateau (Fig. 1a). Lenglong Ling is the topographic boundary of the northeastern Tibetan Plateau. This M_W 5.9 event is only ~70 km away from the epicenter of the 1927 M 8.3 Gulang earthquake. Interestingly, its focal mechanism is identical to the one that occurred on almost the same location (~12 km west) and focal depth with the same magnitude on 26 August 1986 (Table 1; Fig. 1a). These events occurred on the fault which dips NE, based on global positioning system (GPS) measurements and focal mechanism solutions (Li et al., 2016). Also, the GPS data suggest that the epicenter region has undergone significant variation of strain (Chen et al., 2016).

The occurrence of the M_W 5.9 earthquake on 20 January 2016 raises two questions. Are these two earthquakes with a 30-year interval repeating earthquakes? If so, what are the seismic and tectonic structures that host such repeating earthquakes? If these two earthquakes ruptured the same fault segment and generate nearly identical waveforms, these earthquakes can be used to understand earthquake recurrence and fault slip rate (e.g., Stein et al., 1988), the temporal variation of

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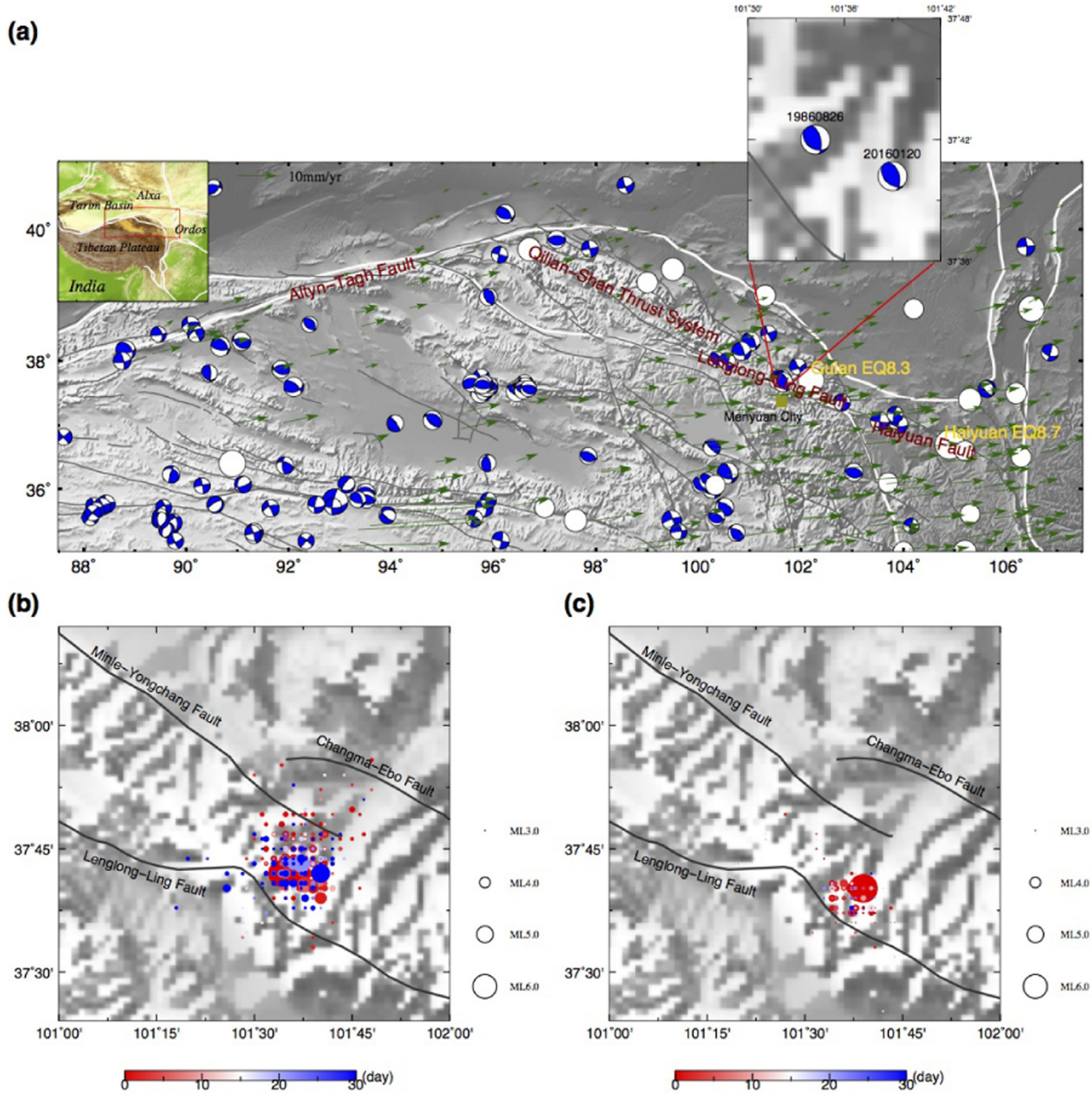

Fig. 1. Seismotectonic map showing the northeastern Tibetan Plateau. (a) Topographic and seismicity map of the study region. Thick white lines denote boundaries of major tectonic blocks (Deng et al., 2003). Gray lines show major faults in the region (Deng et al., 2003). Locations of the two M_W 5.9 earthquakes in the city of Menyuan are indicated in the top right inset. White circles denote locations of the historical earthquakes (http://data.earthquake.cn/data/index.jsp). Beach balls are plotted using the source parameters provided in the website of http://www.globalcmt.org/CMTsearch.html. Green arrows indicate the GPS vectors with a reference frame of the stable Eurasia (Gan et al., 2007; Liang et al., 2013; Chen et al., 2016). (b) Spatial and temporal distribution of aftershocks of the 1986 earthquake (http://data.earthquake.cn/data/index.jsp). (c) Spatial and temporal distribution of aftershocks of the 2016 earthquake (http://data.earthquake.cn/data/index.jsp). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Earthquake source parameters of 1986 and 2016 Menyuan earthquakes.
The source parameters of the 1986 and 2016 earthquakes are taken from http://www.globalcmt.org/CMTsearch.html, and http://earthquake.usgs.gov/earthquakes/eventpage/us10004fv5#moment-tensor?source=us&code=us_10004fv5_mwc_gcmt, respectively.

EQ	Lon (°E)	Lat (°N)	Depth (km)	Mag (M_W)	NP1			NP2		
					Strike (°)	Dip (°)	Rake (°)	Strike (°)	Dip (°)	Rake (°)
1986	101.72	37.80	15	5.9	346	60	113	125	37	55
2016	101.641	37.671	13.9	5.9	343	51	109	134	43	68

Lon: Longitude; Lat: Latitude; Mag: Magnitude; NP1: Fault plane 1; NP2: Fault plane 2.

structures (e.g., Sieh, 1996; Hensch et al., 2016), and changes in fault zone properties (e.g., Vidale et al., 1994). In this study, we constrain deep seismic structure and properties beneath the source region of the two earthquakes with teleseismic receiver functions to clarify the structure and inferred relationships to seismicity, and to understand broad-scale tectonics of the plate collision zone in the northeastern Tibetan Plateau.

2. Tectonic models of the Tibetan Plateau

Various tectonic models have been put forward to explain the formation and the lateral extension of the Tibetan Plateau. In the southwestern region, the subduction of the Indian plate beneath the Tibetan