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Crustal Structure of the Northeastern Tibetan Plateau from the Southern Tarim Basin to the Sichuan Basin, China

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ABSTRACT

We present a new crustal cross section of the northeastern Tibetan plateau based on active-source seismic data recorded along a 1600-km-long profile crossing the southern Tarim basin, the western flank of the South-Qilian Shan, the northeastern margin of Qaidam basin, East-Kunlun Shan, Songpan-Ganzi terrane, and Sichuan basin. The crustal P- and S-wave velocity structure and Poisson's ratio outline the seismic characteristics of the crust and provide constraints on the crustal composition. The derived crustal cross section shows several significant features. (1) The crustal thickness varies considerably along this profile, from 48 km to 70 km. (2) North of the Kunlun fault variations in total crustal thickness are mainly caused by variations in lower crustal thickness, whereas south of the Kunlun fault they are caused by thickness variations throughout the crust. (3) North of the Kunlun fault we detect a mid-crustal low-velocity zone that is not apparent south of the fault. (4) The Kunlun fault seems to act as a compositional boundary for the lower crust, with a Poisson's ratio of 0.29 north of the fault (Kunlun-Qaidam terrane) and 0.26 south of the fault (Songpan-Ganzi terrane). Measured Poisson's ratio and P-wave velocity values suggest that the lower crust throughout the Tibetan plateau (South-Qilian Shan, margins of the Qaidam Basin, East-Kunlun Shan, Songpan-Ganzi terrane) is of intermediate composition. Thus the NE Tibetan plateau along our profile is missing a mafic lower crustal layer.

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1. Introduction

The Tibetan plateau is the largest region of elevated topography and thickened continental crust on Earth and is widely considered to be the archetypal example of a continent–continent collision. A complex history of Tethyan oceanic subduction, terrane accretion and continental collision of the Indian and Eurasian plates has lead to the current configuration of the plateau (e.g. Allègre et al., 1984; Argand, 1924; Dewey et al., 1988; Ding et al., 2001, 2003, 2005; Hsü et al., 1995; Masek et al., 1999; Powell, 1986; Searle et al., 1987; Sengör and Natal'in, 1996; Shackleton and Chengfa, 1988; Yang and Yang, 1981; Yin and Harrison, 2000; Zhang et al., 1984). The northeastern portion of the plateau is mainly the result of late Cenozoic deformation (e.g. Dai et al., 2006; Fang et al., 2005; Gilder et al., 2001; Meyer et al., 1998; Pares et al., 2003; Sun et al., 2005; Tapponnier et al., 2001; X. Wang et al., 2003; Y.X. Wang et al., 2003; Yin and Harrison, 2000; Yin et al., 2002). There are two alternative end-member models to describe the widespread deformation of the Tibetan plateau. In the rigid plate model, tectonic deformation is confined to block-bounding faults and thrusts; convergence is accommodated by a combination of crustal thickening by underthrusting and rigid block motion along large-scale strike-slip faults (Kong and Bird, 1996; McKenzie, 1970, 1972; Peltzer & Tapponnier, 1988; Tapponnier & Molnar, 1976; Tapponnier et al., 2001). In the viscous plate model, tectonic deformation is continuous throughout the plateau; convergence is accommodated by a combination of crustal thickening by folding and thrusting in the upper crust and plastic flow within the soft middle and lower crust (Bird, 1991; Clark & Royden, 2000; England & Houseman, 1988; England & McKenzie, 1982; Royden, 1996; Shen et al., 2001; Vilotte et al., 1982). Although many seismological studies provide evidence of a thick (>50 km) crust beneath the northeastern plateau (Cui et al., 1995; Galvé, 2002; Galvé et al., 2002; Herquel et al., 1995; Jiang et al., 2006; Vergne et al., 2002; Wu et al., 1995; Zhu and Helmberger, 1998; Zhu et al., 1995), the specific mechanisms of regional uplift and the accommodation of shortening at depth remain elusive. The seismic velocity structure of the crust provides important constraints on the spatial and temporal evolution of the eastern portion of the Tibetan plateau.

This paper presents results from the wide-angle reflection/refraction seismic surveys across the northeastern Tibetan plateau starting in the Tarim basin and ending in the Sichuan basin (Figs. 1 and 2; Wang and

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Han, 1996). The transect is the southward continuation of a similar seismic transect to the north (LINE 1 in Fig. 1; Y.X. Wang et al., 2003; X. Wang et al., 2003). We present the P- and S-wave velocity structure of the crust and infer the composition of the crust using Poisson's ratio. This allows us to outline the lateral changes of crustal structure across the northeastern Tibetan plateau, and provides new geophysical evidence regarding the evolution of the crust. Some actively debated questions include the nature of deformation processes within the Qilian–Kunlun–Qaidam system (Chen et al., 1999; Meyer et al., 1998) and the geometry of the contact between the East-Kunlun Shan and Songpan-Ganzi terrane at depth along the Kunlun fault (Tapponnier et al., 2001; Yin and Harrison, 2000). We also seek to evaluate lower crustal flow, hypothesized to be the main mechanism for the formation of the eastern margin of the plateau and its steep topographic gradient towards the Sichuan basin (Burchfiel, 2004; Clark and Royden, 2000; Clark et al., 2005; Meng et al., 2006; Royden et al., 1997). The deep crustal structure is essential to elucidate the relevance of this process.

The southeastern end of our profile crosses the epicentral region of the 12 May 2008 Wenchuan earthquake (Burchfiel et al., 2008; Zhang et al., 2010). Knowledge of the crustal structure of this region is important for the modeling of recorded waveforms from this earthquake, and for an understanding of the tectonic setting (Hubbard and Shaw, 2009; Li et al., 2010; Wang et al., 2007).

2. Geologic setting

The study area covers the northeastern and eastern margin of the Tibetan plateau (Fig. 2). The seismic profile starts at the city of Dunhuang, north of the Altyn Tagh fault, and ends near the city of Chengdu in the Sichuan basin. It crosses the southern Tarim basin, the South-Qilian Shan, the northeastern and eastern flank of the Qaidam basin, the East-Kunlun Shan, the Songpan-Ganzi terrane, and ends in the Sichuan basin in the northwestern Yangtze craton (Fig. 2).

2.1. The Tarim Basin (shot point SP11 in Fig. 2)

The Tarim basin is covered by a thick foreland sequence of Mesozoic to Cenozoic continental sedimentary rocks which reach a maximum thickness of 17 km (Li and Mooney, 1998). Along the profile the sequence is 6 km thick. Beneath the younger sediments of the Tarim basin, late Paleozoic shallow-marine sedimentary rocks and Late Proterozoic rocks floor the entire basin (Allen et al., 1991; Jia et al., 1991; Sobel, 1999). Possible Archean basement intruded by early Paleozoic calc-alkaline granite is exposed at the southern boundary of the Tarim basin.

2.2. South-Qilian Shan (between shot point SP 11 and SP 13 in Fig. 2)

This area consists of complexly deformed early Paleozoic magmatic arcs that formed at the southern margin of the North China craton before it was offset by the Altyn Tagh fault in the Cenozoic (Yin and Harrison, 2000). The middle-late Silurian was a period of intracontinental orogeny in south Asia, when intracontinental subduction is suggested to have caused lateral terrane accretion, igneous activity, including batholith intrusions, and the thickening of the crust. Thus, the Qilian terrane is a Caledonian-aged tectonic belt (BGMRG, 1989; Chen et al., 1996). The area was reactived in the Pleistocene as an orogenic belt within the northernmost part of the Qinghai–Tibet plateau (Tapponnier, 1992).

2.3. The Qaidam Basin (shot point SP13 to SP15 in Fig. 2)

The Qaidam basin forms a triangular area bounded by the Altyn Tagh fault to the northwest, the South-Qilian fault to the northeast, and the North-Kunlun thrust to the south. Limited exposed rocks indicate that the basement of the Qaidam basin is comprised of accretionary complex, magmatic arc-type and ocean floor assemblages (Gehrels and Yin, 2003; Hsü et al., 1995; Sengör and Natal'in, 1996).

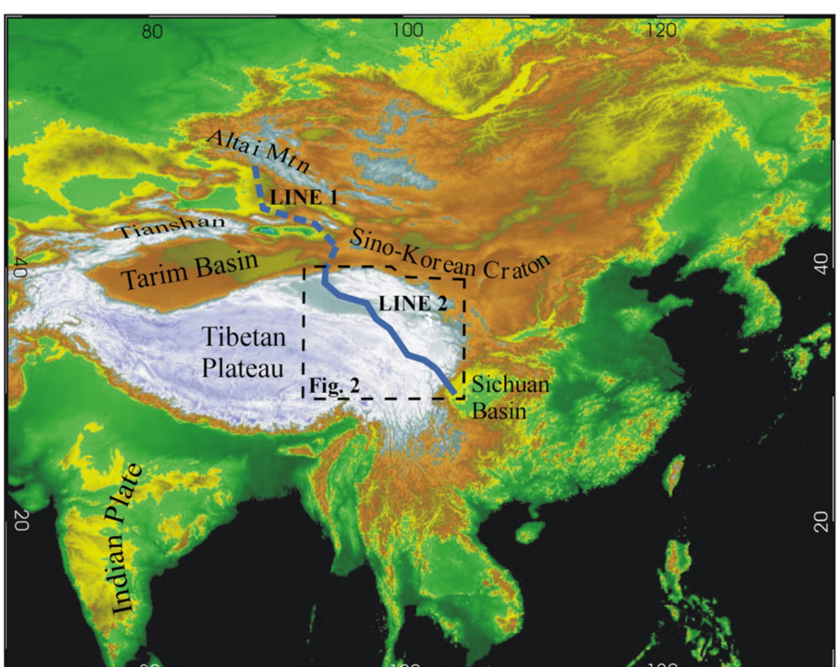

Fig. 1. Topographic relief map of south-east Asia with seismic-refraction/wide-angle reflection transect indicated by a heavy dark blue line. The entire transect is located within the northeastern Tibetan plateau, and crosses from the southern Tarim basin in the northwest to the Sichuan basin in the southeast. The box indicates the area depicted in Fig. 2. The heavy dashed line to the north is the northward continuation of the seismic transect reported by Y.X. Wang et al. (2003), X. Wang et al. (2003).