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Structure of the Central Altyn Tagh Fault revealed by magnetotelluric data: New insights into the structure of the northern margin of the India–Asia collision

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ABSTRACT

The Altyn Tagh Fault (ATF) is a left-lateral, strike-slip fault that forms the northern margin of the Tibetan Plateau and plays a significant role in accommodating the convergence between the colliding Indian and Eurasian plates. As a part of the fourth phase of the INDEPTH project, magnetotelluric (MT) data were collected across the central segment of the ATF to determine the lithospheric-scale structure of the fault system. Dimensionality analyses demonstrated that the MT data can be interpreted using two-dimensional approaches, but some localized 3-D effects are seen. Consequently, both 2-D and 3-D inversions were carried out, and a joint interpretation was made on the basis of these two types of models. Inversion models revealed two major conductors beneath the Qaidam Basin (QB) and Altyn Tagh Range (ATR), respectively. The conductive region beneath the QB was interpreted as a ductile layer in the lower crust to upper mantle that might represent flow beneath the western margin of the QB, whereas the large scale south-dipping conductor beneath the ATR is interpreted as a region with high fluid content formed by metamorphism associated with the oblique underthrusting of the Tarim Block beneath the northern Tibetan Plateau. These fluids migrate upwards through the fault system and have formed serpentinized zones in the crust. Combining these interpretations, a structural model compatible with diverse geophysical observations is proposed, in which we suggest the competing end-member rigid block model and continuum model are reconcilable with the continuum model locally dominant for the study region, as evidenced by a thickened crust.

1. Introduction

The ongoing continent–continent collision between the Indian and Eurasian plates has created the spectacular topography of the Tibetan Plateau over the last 50 Myr. The tectonic processes that occurred and are still occurring during this orogeny are still not fully understood and a wide variety of models have been proposed to explain the dynamics of this region (Tapponnier et al., 2001; Tilmann et al., 2003; Yin and Harrison, 2000). Horizontal crustal motion is clearly important, as evidenced by the major strike faults that characterize the Northern and Eastern parts of the plateau (Tapponnier et al., 2001). However, the contribution of horizontal motion on these faults to the overall mass balance of the orogen remains unresolved. Another important tectonic process that may be active is crustal flow (Clark and Royden, 2000; Royden et al., 1997), a process first proposed by Nelson et al. (1996).

The magnetotelluric MT method is a useful tool in studies of continental dynamics because it images subsurface electrical resistivity, which is a rock property sensitive to the presence of fluids and temperature, and can give important constraints on crustal rheology (Pommier et al., 2013). MT data have been used effectively in previous studies to reveal rheological properties associated with active tectonics, including studies of large-scale strike-slip faults such as the San Andreas Fault

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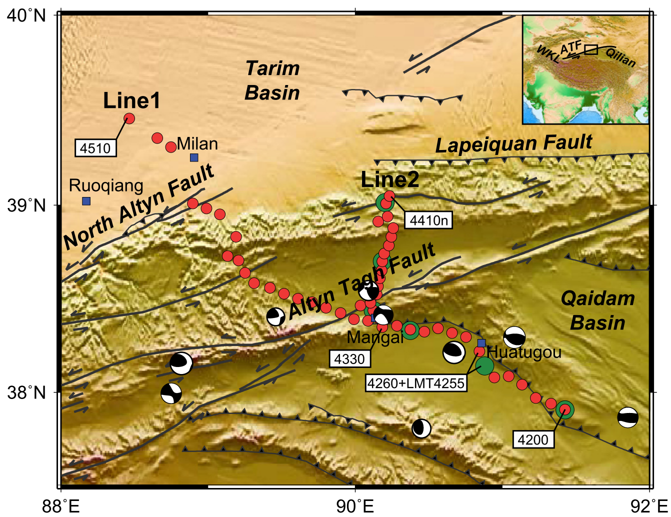

Fig. 1. Topography map showing major tectonic structures and MT station locations in the survey area. Red dots are broadband MT stations, green dots are long-period MT stations, blue squares are cities or towns, and texts in white boxes are station numbers. Figure was generated from GTOPO30 digital elevation data set using GMT (Wessel and Smith, 1995). Fault locations are taken from the HimaTibetMap-1.0 database (Styron et al., 2010). Focal mechanism solutions are from the Global Centroid Moment Tensor (CMT) Project (http://www.globalcmt.org). Abbreviations are: WKL, West Kunlun.; ATF, Altyn Tagh Fault.

(Becken et al., 2011; Unsworth and Bedrosian, 2004), the Alpine Fault (Wannamaker et al., 2002) and East Anatolian Fault (Türkoğlu et al., 2015). MT has played a major role in previous studies of the Tibetan Plateau (Bai et al., 2010; Unsworth et al., 2005; Wei et al., 2001). One key result from the MT studies is the observation of a low resistivity crustal layer along the southern and eastern margins of the Tibetan Plateau, where the resistivity values are consistent with crustal viscosities low enough to permit crustal flow (Rippe and Unsworth, 2010). These studies have also focused on some of the major strike-slip faults in Northern Tibet (Bedrosian et al., 2001; Le Pape et al., 2012; Unsworth et al., 2004). Many of these studies were made as part of the INDEPTH project (InterNational DEep Profiling of Tibet and the Himalaya) which has undertaken a series of integrated geological and geophysical studies across the Tibetan Plateau since 1993 (Nelson et al., 1996). INDEPTH-IV was the final stage of this project and focused on the northern margin of the plateau (Karplus et al., 2011; Wei et al., 2014). As part of this study, MT profiles were acquired across the central Altyn Tagh Fault (ATF) in 2010 to investigate the resistivity structure of the lithosphere and thereby constrain deformational processes and test competing models on deformation patterns along the northwestern margin of the plateau (Fig. 1). In this paper, we present new models of the electrical resistivity structure of the central ATF and discuss their interpretation. Insight gained from the Altyn Tagh Fault can give an improved understanding of orogens where continent–continent collisions are active and major strike-slip zones have developed (Eastern Anatolia), as well as those preserved in the geological record.

2. Previous geological and geophysical studies

2.1. Fault geometry

The Altyn Tagh Fault (ATF) is a major boundary that separates the Tibetan Plateau, with an average elevation of more than 4500 m above sea level, from the Tarim Basin, with an elevation of only about 1000 m (Fig. 1). The ATF extends for at least 1500 km from the West Kunlun Mountains in the west to the Qilian mountains in the northeast, and may extend even further northeast for as much as 2500 km (Darby et al., 2005; Mériaux et al., 2005). The ATF can be divided into three main sections based on its geomorphological expression: (a) the southwestern section west of 84°E, (b) the central section between 84°E and 94°E, and (c) the northeastern section east of 94°E. The central section investigated in this study includes several restraining bends where relatively high elevations have been formed by transpressional deformation (Cowgill et al., 2004).

A major splay of the ATF – the North Altyn Fault (NAF, Fig. 1) is located between 86° and 92°E, and is almost parallel to the main ATF (Cowgill et al., 2000). The NAF bounds the Altyn Tagh Range (ATR) together with the ATF to the south and the Lapeiquan Fault to the northeast (Fig. 1). Two different models have been proposed to describe the tectonics of the ATR. One model suggests that the NAF is a thrust fault formed by the southward underthrusting of the Tarim Block, with the ATF acting as a sinistral strike-slip fault (Avouac and Tapponnier, 1993; Burchfiel et al., 1989; Molnar et al., 1987; Peltzer and Saucier, 1996; Wittlinger et al., 1998; Yue et al., 2004). The other model proposes that the ATR is a strike-slip duplex, comprising a group of imbricated blocks bounded by the strike-slip ATF and oblique-slip NAF (Cowgill et al., 2000). Reconstruction of the ATF based on geochronology studies also suggests that the NAF may have been the active trace of the ATF at an early stage of its development (Cowgill et al., 2003).

2.2. Geology

The MT profiles presented in this paper are focused on the central section of the ATF (see Fig. 1). Within this region, the ATF separates the sedimentary fill of the western Qaidam Basin from the Precambrian basement rocks of the Tarim Basin (Wittlinger et al., 1998). Archean and Proterozoic metamorphic rocks are sheared along the fault zone, with coal-bearing Jurassic sedimentary rocks scattered throughout the region (Chen et al., 2003). As shown in Fig. 2, geological units on both sides of the ATF are well correlated. Precambrian complexes are found to the northeast of the Lapeiquan Fault and the North Qilian Fault, while Paleozoic complexes are located to the southwest of the Lapeiquan Fault and the North Qilian Fault (Sobel and Arnaud, 1999). The surface structure of the ATR and the Qilian Block are comprised of primarily Neoproterozoic to Mesozoic sedimentary rocks. Two belts of High Pressure (HP) and Ultrahigh Pressure (UHP) metamorphic complexes, where samples of eclogites and garnet peridotites are found (Gilotti, 2013; Liou et al., 2009; Yang et al., 2001), are located to the south of the ATR (Liu et al., 2012, 2009) and along the northeastern margin of the Qaidam Basin. Accordingly, it was suggested that the geologic units on both sides of the ATF are offset by 475 ± 70 km of sinistral strike-slip motion (Cowgill et al., 2003; Peltzer and Tapponnier, 1988; Ritts and Biffi, 2000).

2.3. Kinematics

As a major strike-slip fault, the ATF plays an important role in accommodating the convergence between the Indian and Eurasian plates. Two different end-member models have been proposed to explain how this convergence occurs. In one class of models it is assumed that the crust is made up of rigid blocks separated by weak fault zones, and convergence is accommodated by deformation along major thrusts and strike-slip faults bounding these blocks (Calais et al., 2006; Meade, 2007; Peltzer and Tapponnier, 1988; Tapponnier and Molnar, 1976; Tapponnier et al., 2001; Thatcher, 2007). This rigid block model regards the eastward extrusion along the ATF as the dominant tectonic mechanism on the northern margin of the Tibetan Plateau. The other class of