Journal of Asian Earth Sciences 163 (2018) 131–141

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

A new shortening rate across the Dushanzi anticline in the northern Tian Shan Mountains, china from lidar data and a seismic reflection profile

Peng Su, Honglin He*, Zhanyu Wei, Renqi Lu, Feng Shi, Haoyue Sun, Xibin Tan, Haijian Hao

Key Laboratory of Active Tectonics and Volcano, Institute of Geology, China Earthquake Administration, Beijing 100029, China

ARTICLE INFO

Keywords:
Fluvial terrace
Dushanzi anticline
Tian Shan Mountains
Lidar
Seismic reflection profile

ABSTRACT

In the northern foreland basin of the Tian Shan Mountains, strata have been intensively deformed as a result of the ongoing Cenozoic Indian-Eurasian collision. The Dushanzi anticline lies in the northernmost deformation belt of the Tian Shan Mountains. Understanding the shortening rate and paleoseismicity of the Dushanzi anticline is important for both understanding the propagation of the thrust front of the Tian Shan Mountains and for assessing seismic hazards in this highly populated area. Here we integrate lidar-derived topographic data, a high-quality seismic reflection profile, and field observations across the Dushanzi anticline to resolve the Holocene deformation history of the anticline. A reconstructed longitudinal profile along the Kuitun River that flows across the Dushanzi anticline demonstrates a Holocene history of both folding and faulting. The total shortening from faulting is 4.4 ± 0.1 m, while the shortening accommodated by folding is 12.6 ± 1.1 m since 7.5–10 ka B.P. A total of 17.0 ± 1.1 m of shortening has occurred across the Dushanzi anticline in the Holocene at a rate of 2.0 ± 0.2 mm/a. This shortening represents up to 18% of the > 11 mm/a total shortening rate across the entire eastern Tian Shan Mountains at this longitude. The Holocene shortening rate of the Dushanzi anticline is ~6 times greater than its long-term average shortening rate (0.3 ± 0.1 mm/a) since 4.8 Ma. Furthermore, we analyzed a displaced terrace sequence at a site along the Dushanzi frontal fault and found that the average coseismic dip-slip displacement is 2.5 ± 0.1 m, with an average recurrence interval of 2.8 ± 0.3 ka.

1. Introduction

The ongoing Cenozoic collision between the Indian and Eurasian plates has made the Tian Shan Mountains one of the most active intracontinental mountain belts on the earth (Avouac et al., 1993; Burchfiel et al., 1999). In the northern foreland basin between the Junggar basin and the Tian Shan Mountains, three sub-parallel roughly east-west-striking fold and thrust belts (A, B and C in Fig. 1) have deformed Mesozoic to Cenozoic strata (Fig. 1) (Avouac et al., 1993), forming a basinward migrating deformation front (Burchfiel et al., 1999; Deng et al., 2000; Fu et al., 2003; Ikeda, 1983).

The northern foreland basin of the Tian Shan Mountains is a seismically active region (Avouac et al., 1993; Deng et al., 1996). The southernmost belt (A) has been inactive since ~30 ka BP (Deng et al., 1996; Zhang et al., 1994). Both field investigations and seismic reflection surveys have shown that the central belt (B) was the source region of the 1906 M 7.7 Manas earthquake (Fig. 1) (Avouac et al., 1993; Deng et al., 1996; Stockmeyer et al., 2014; Zhang et al., 1994). The 2016 M 6.2 Hutubi earthquake also occurred in the central belt (Fig. 1). However, based on the tendency of thrust-fronts to migrate towards basins (in the foreland fold-and-thrust belt) as well as paleoseismic trenching studies, the northernmost belt (C) is considered to be the most likely source of future M 7 earthquakes (Deng et al., 1996; Ikeda, 1983), despite the two historical earthquakes that occurred on the central belt. The region is currently undergoing rapid urban development and there are significant oil fields, so it is of great importance to evaluate the seismic hazards in the northern foreland basin of Tian Shan Mountains.

The Dushanzi anticline (DA) lies in the northernmost deformation belt (C) of the Tian Shan Mountains (Fig. 1). An understanding of the Holocene shortening rates and paleoseismicity of the DA is not only essential for assessing seismic hazards in the region, but is also critical for understanding the frontal fault propagation processes of the Tian Shan Mountains. However, until now the Holocene deformation and the subsurface structure of the DA have been poorly constrained due to a lack of robust topographic data and/or seismic reflection profiles across the DA. The Holocene shortening rate of the DA is still debated, with estimates ranging from 1.8 to 2.0 mm/a by Yang and Deng (1998) to 5.2 ± 0.4 mm/a by Poisson and Avouac (2004). In addition, while trenching is commonly used for determining the paleoseismic history of

* Corresponding author.
E-mail address: honglinhe123@vip.sina.com (H. He).

https://doi.org/10.1016/j.jseaes.2018.06.008
Received 24 September 2017; Received in revised form 2 June 2018; Accepted 3 June 2018
Available online 04 June 2018

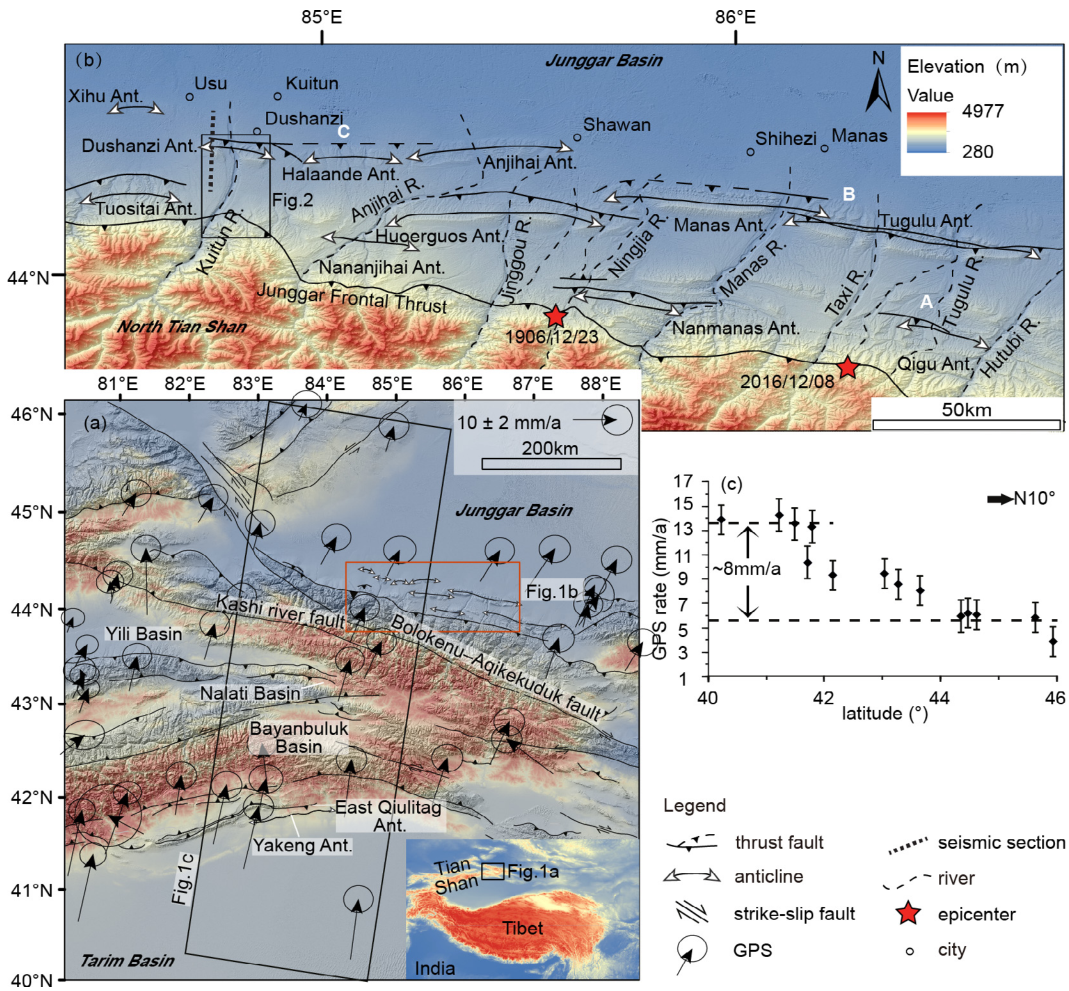

Fig. 1. (a) Regional topographic and tectonic map of the eastern Tian Shan Mountains. GPS velocities from Yang et al. (2008). Inset map shows the location of the eastern Tian Shan Mountains in central Asia. (b) Fold and thrust belts A, B and C along the northern piedmont of the Tian Shan Mountains and drainage systems across them. The black box shows the location of the study area where the Kuitun River cuts through the Dushanzi anticline. The thick dash line indicates the location of the seismic reflection profile in Fig. 9. (c) GPS velocity versus latitude within back box in Fig. 1a (modified from Saint-Carlier et al., 2016).

faults, in the northern piedmont of the Tian Shan Mountains, it is hard to reveal a history of multiple earthquakes by trenching, as the Quaternary deposits in this region are mainly poorly consolidated alluvial fan deposits, and thus trench walls are rarely stable enough to support deep excavation (McCalpin, 2009).

River terraces are remnants of earlier riverbeds, and leave a record that can be used to determine the rate and spatial distribution of deformation (Burbank and Anderson, 2012). A longitudinal profile of fluvial terraces across a structural belt at a large scale can constrain crustal deformation, while displaced terrace sequences near a fault scarp can provide a history of faulting (Burbank et al., 1996; Hu et al., 2015; Huang et al., 2015; Lavé and Avouac, 2000; Lensen, 1964; Li et al., 2015; Li et al., 2012; Liu et al., 2015; Pan et al., 2009; Su et al., 2016; Suggate, 1960; Tian et al., 2009; Zhang et al., 2010).

The Kuitun River flows northwards from the Tian Shan Mountains and cuts through the DA, where it has deposited a series of Quaternary terraces (Figs. 1 and 2). In order to better constrain the Holocene deformation across the DA, a high-resolution airborne lidar survey was conducted along the Kuitun River (Wei et al., 2015). Using the lidar data, we reconstructed longitudinal profiles of almost all the terraces along the Kuitun River. Based on these precise profiles, together with a high-quality seismic reflection profile, and field observations of the surficial geology, shortening rates and the paleoseismic history of the DA are quantified.

2. Geological setting

The east-west-trending Tian Shan Mountains separate the Tarim basin to the south from the Junggar basin to the north, and are one of the most active intracontinental mountain belts in the world (Fig. 1). The Tian Shan Mountains have a complex structure resulting from a multiphase tectonic history and contain significant heterogeneity in topography, structure and stratigraphy at all scales (Allen et al., 1993; Burchfiel et al., 1999; Gao et al., 1998; Laurent-Charvet et al., 2002; Windley et al., 1990). A series of fold and thrust belts along the northern and southern flanks of the Tian Shan Mountains have accommodated the uplift of the modern Tian Shan Mountains during the Cenozoic Indian–Eurasian collision (Avouac et al., 1993; Burchfiel et al., 1999; Charreau et al., 2005; Dumitru et al., 2001; Hendrix et al., 1994; Jolivet et al., 2010; Sobel and Dumitru, 1997; Sun and Zhang, 2009; Tapponnier and Molnar, 1977; Yin et al., 1998). The marginal fold and thrust belts deform Mesozoic and Cenozoic sedimentary rocks with shallow listric geometries (Avouac et al., 1993; Burchfiel et al., 1999; Deng et al., 1996, 2000).

There are two levels of decollements in the Junggar basin. The deeper is formed in a Jurassic sedimentary sequence, where many layers of coal and clay exist, at a depth of ~7–9 km; while, the shallower is accommodated by the mud layers of the Paleocene Anjihai Formation, at a depth of ~4–5 km (He et al., 2005; Li et al., 2011; Stockmeyer et al., 2014). Three subparallel fold and thrust belts and the