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Late Pleistocene shortening rate on the northern margin of the Yanqi Basin, southeastern Tian Shan, NW China

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ABSTRACT

How strain is distributed and partitioned on individual faults and folds on the margins of intermontane basins remains poorly understood. The Haermodun (Ha) anticline, located along the northern margin of the intermontane Yanqi Basin on the southeastern flank of the Tian Shan, preserves flights of passively deformed alluvial terraces. These terraces cross the active anticline and can be used to constrain local crustal shortening and uplift rates. Geologic and geomorphic mapping, in conjunction with high-resolution dGPS topographic surveys, reveal that the terrace surfaces are perpendicular to the fold's strike, and display increased rotation with age, implying that the anticline has grown by progressive limb rotation. Combined with the open sinusoidal curve model and excess area method, we calculated uplift and shortening values for each terrace since abandonment. Using the published exposure ages of each terrace, we found the vertical uplift rate gradually decreased from ~0.43 to ~0.11 mm/a, whereas the shortening rate remained constant at ~0.3 mm/a since the anticline began to grow. A fresh fault scarp, 0.4 ± 0.1 m high, is visible along the southern portion of the Ha anticline, and is interpreted to be the most recent evidence of seismic activity. Using an estimated rupture area and the length of the fresh offset created by this earthquake, we estimate that the main thrust underlying the Ha anticline has generated moderate ($M < 7$) earthquakes in the past. The shortening rates of the Ha anticline from geomorphology agree with current GPS measurements cover-over the fold, and highlight the importance of determining slip rates for individual faults in order to resolve patterns of strain distribution across intermontane belts.

1. Introduction

The Tian Shan, a mountain range in central Asia, is a 300–500 km wide intracontinental mountain belt that extends over a length of ~2000 km from Uzbekistan in the west, to China in the east. The Junggar and Tarim basins flank its margins (Fig. 1b), and several minor sedimentary basins are interspersed between individual ranges within the Tian Shan (such as Issyk-Kul basin, Naryn basin, Ili basin, and Yanqi Basin). The high topography of the Tian Shan, with summits exceeding 7000 m, is a result of the collision of India, and possibly Arabia, with Asia (e.g., Tapponnier and Molnar, 1979; Yin, 2010). Although the Tian Shan has a complex deformational history resulting from multiple collision events during the Paleozoic and Mesozoic (Windley et al., 1990; Hendrix et al., 1992; Carroll et al., 1995; Dumitru et al., 2001; Jolivet et al., 2013), the more recent initiation of uplift and exhumation was diachronous throughout the Tian Shan and started between the late Oligocene and the late Miocene in different parts of the mountain belt (Hendrix et al., 1994; Sobel and Dumitru, 1997; Sobel et al., 2006; Charreau et al., 2006, 2009a). In general, the deformation tends to propagate outward the Tarim and Junggar basins, and part of it is localized along inherited structures (Charreau et al., 2005, 2006, 2009b; Sobel et al., 2006; Jolivet et al., 2010).

GPS studies show that the north–south shortening rate across the western Tian Shan at the longitude of 74°E–76°E is ~20 mm/a and decreases eastward to ~2–3 mm/a over a distance of about 800 km (Reigber et al., 2001; Yang et al., 2008). In recent years,

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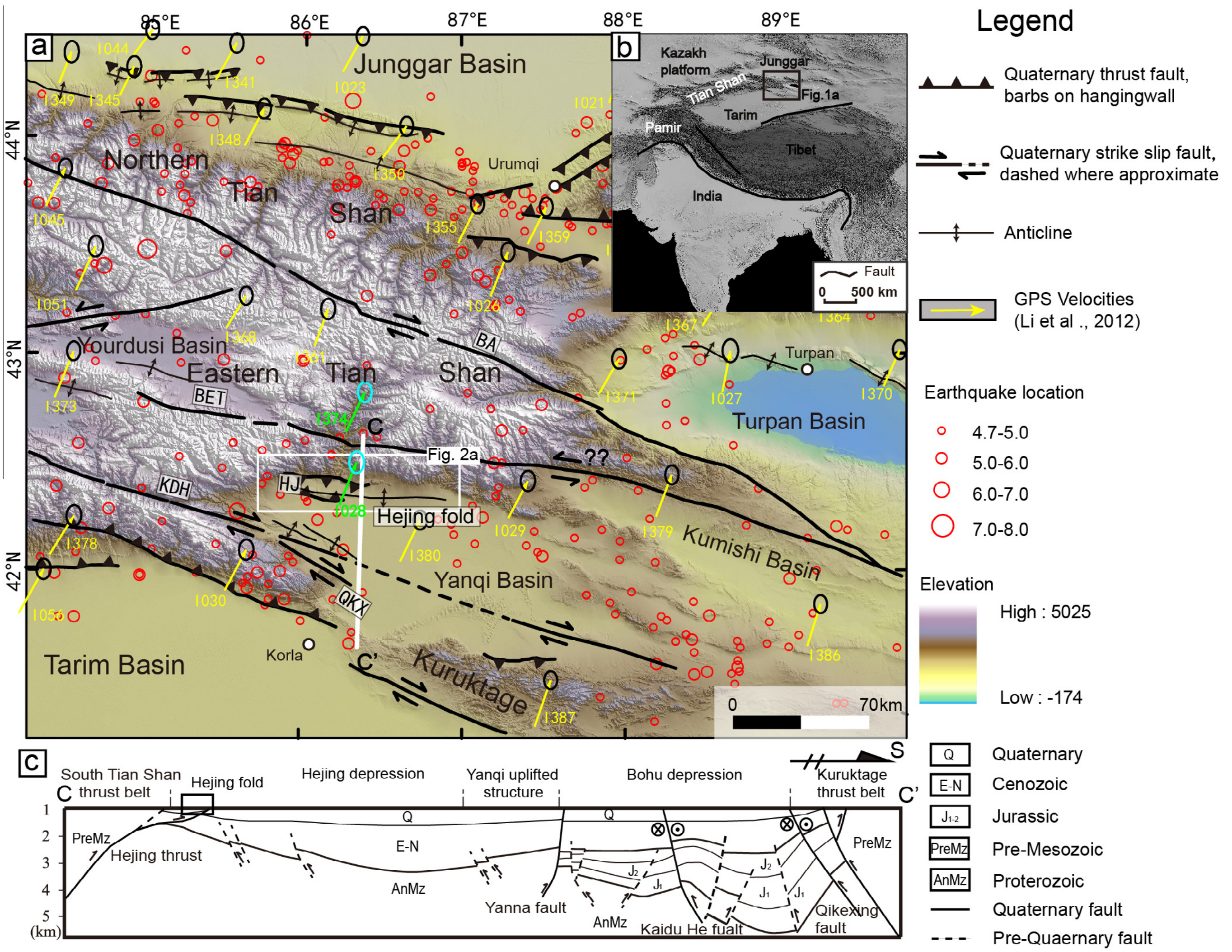

Fig. 1. (a) GPS velocity vectors projected onto a 30 m ASTER Global Digital Elevation Model (GDEM) of the field area. See location in inset figure (b). The locations of faults are from Chinese Active Fault Map published in 2004. Earthquake locations from the China Earthquake Networks Center seismic catalog for the $M > 4.7$ records. (c) Cross section along C–C′ is from interpreted seismic line and drill data from Cai et al. (2008). BA: Boluokenu-Aqikekuduke fault; BET: Baoertu fault, the sense of motion (question mark means we are not sure) was cited by Luo et al. (1996); HJ: Hejing thrust; KDH: Kaiduhe fault; QKX: Qikexing fault; GPS velocities relative to stable Eurasia from Li et al. (2012a).

with increasing amount of regional GPS data, Zubovich et al. (2010) found that the GPS velocity profiles of components perpendicular to the western Tian Shan show a monotonically decreasing rate across the orogen, with steep gradients across the margins of the belt, from the Tarim Basin in the southern part to the Kazakh Platform (Fig. 1b). Studies of active tectonics also demonstrate wide-spread Quaternary faulting and folding across the entire Tian Shan mountains, intermontane basins, and bordering foreland basins. In an analysis of active faulting in the western part of the Tian Shan, Makarov (1977) not only reported active faults at the margins of the Tian Shan, but also described active faulting within the belt. Later, Thompson et al. (2002) showed that the geologic shortening rate across the entire western Tian Shan is roughly equivalent to the present-day crustal shortening rates measured by GPS. Hence, both geological field work and GPS measurements illustrate that the crustal shortening of the western Tian Shan is not localized on the margins of the orogen, but rather is distributed across the interior of the mountain belt (Burbank et al., 1999; Dumitru et al., 2001; Thompson et al., 2002; Bowman et al., 2004; Jolivet et al., 2010; Lü et al., 2013). Nevertheless, little work has been done to quantify the slip rates, magnitudes, and/or timing of faults within basins within the orogen (Thompson et al., 2002; Bowman et al., 2004; Selander et al., 2012; Cording et al., 2014; Goode et al., 2014), unlike the margins of the orogen where numerous studies have described active faults (Avouac et al., 1993; Molnar et al., 1994; Brown et al., 1998; Burchfiel et al., 1999; Hubert-Ferrari et al., 2007; Charreau et al., 2008, 2009b; Li et al., 2013). In fact, in the interior of the eastern Tian Shan, apatite fission track data indicate that uplift of mountain ranges continues during the Quaternary (Jolivet et al., 2010, 2013; Lü et al., 2013). However, the exact position and deformation rates of related active faults are not accurately constrained.

Moreover, GPS studies show that the north–south elastic shortening rate across the interior of the eastern Tian Shan is only ~2–3 mm/a (Li et al., 2012a; Yang et al., 2008). Such a slow shortening rate implies that slowly slipping structures absorb internal deformation in the eastern Tian Shan. Given the relative large uncertainties of GPS data limiting the ability to resolve the slip rates of slowly-slipping faults (slip rate <1 mm/a), only detailed field studies allow for the quantification of deformation rates on slowly slipping faults or folds in the eastern Tian Shan.

This study focuses on the deformation and recent offset on active faults within an intermontane basin, the Yanqi Basin, flanking the southeastern Tian Shan. We constrain the shortening rate