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Cenozoic detachment folding in the southern Tianshan foreland, NW China: Shortening distances and rates

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A B S T R A C T

Intracontinental foreland basins with fold-and-thrust belts on the southern periphery of the Tianshan orogenic belt in China resulted from still-active contractional deformation ultimately cased by the India–Asia collision. To quantify the amounts of shortening distance and the rates of deformation, and to decipher the architectural framework, we mapped the stratigraphy and structure of four anticlines in the Kuqa and Baicheng foreland thrust belts in the central southern Tianshan. In the Baicheng foreland thrust belts, Lower Cretaceous Baxigai and Bashijiqike Formations located in the core of the Kumugeliemu anticline are overlain by the Paleocene to Eocene Kumugeliemu Formation, above which are conformable Oligocene through Pleistocene sediments. A disharmonic transition from parallel to unconformable bedding at the boundary of the Miocene Kangcun and Pliocene Kuqa Formations suggests a change from pre-detachment folded strata to beds deposited on top of a growing anticline. Most of the anticlines have steep limbs (70–90°) and are box to isoclinal folds, suggestive of detachment folding or faulted detachment folding (faults that transect a fold core or limb). Shortening estimates calculated from the cross-sections by the Excess area method indicate that the total shortening for the Kelasu, Kuchetawu, Kezile and Yaken sections are 6.3 km, 6.4 km, 5.8 km and 0.6 km, respectively, and the respective depths of the detachment zones are (2.3 km and 6.9 km), 2.3 km, 2.5 km and 3.4 km. Time estimates derived from a paleomagnetic study indicate that the transition to syn-folding strata occurred at ~6.5 Ma at the Kuchetawu section along the Kuqa river. In addition, according to our field observations and previous sedimentary rate studies, the initial time of folding of the Yaken anticline was at 0.15–0.21 Ma. Therefore, the average shortening rate that began at ~6 Ma was ~2 mm/a for the Kelasu, Kuchetawu and Kezile sections. At 0.15–0.21 Ma, the average shortening rate increased to 3–4 mm/a in the Yaken section. Combined with the recent GPS data, the shortening rate in the central southern Tianshan area increased to 4.7 ± 1.5 mm/a at present. We suggest that there was a linear increase in shortening rate in the southern Tianshan foreland basin, which also indicates that the far field stress increased considerably from the late Miocene to Present in response to the India–Asia collision.

1. Introduction

Intracontinental mountain/orogenic belt (Molnar and Tapponnier, 1975) or intraplate transpressional orogenic belts (Cunningham, 2005, 2013) form within continental plates far from any plate boundary in contrast to accretionary and collisional orogenic belts (Cawood et al., 2009). Foreland basins or foredeeps are flexural depressions that develop in front of migrating thrust loads, and may form on the periphery of continent–continent collisional orogenic belts like the Swiss Alps (Sinclair et al., 1991) belts that form as a result of the collision between a continent and

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an accretionary orogen as in the SW Tianshan (see below), and intraplate orogenic belts as in the Cenozoic SW Tianshan documented in this paper.

The Tianshan, which extends for more than 2500 km from the Aral Sea to northern Xinjiang in China (Xiao et al., 2013), was once an accretionary orogen that formed during closure of the Paleo-Asian Ocean in the late Paleozoic and earliest Mesozoic, when it belonged to the Central Asian Orogenic Belt (Jahn, 2004; Windley et al., 2007; Xiao et al., 2015) or Altiads (Sengör et al., 1993; Guo et al., 2012; Wilhem et al., 2012; Wilhem and Windley, 2015). The last stage in this orogenic process was the formation of a peripheral foreland basin with a foreland thrust belt in the late Permian-Early Triassic on the northern margin of the Tarim craton (Chen et al., 1999). In the late Permian, about 1000 m of alluvial or lacustrine sediments were deposited unconformably on early Permian marine foreland basin sediments west of Kepingtag (Zhao et al., 2003).

The Tianshan orogenic belt, has long been the focus of geologic investigations related to tectonic uplift and intracontinental deformation largely in the Cenozoic caused by the far field stress of the Indo-Asian collision (Sobel and Dumitru, 1997; Yin et al., 1998; Allen et al., 1999; Burchfiel et al., 1999; Sun et al., 2009a; Sun and Zhang, 2009; Sun and Jiang, 2013). As a result the Tianshan was redeformed, uplifted and turned into a Cenozoic mountain belt (Windley et al., 1990; Allen et al., 1994) by regional-scale thrusts and oblique-slip faults that link with dextral transpressional faults and thrusts within a 500 km-wide deformation belt sandwiched between the rigid Tarim Craton to the south and the Junggar block to the north (Fig. 1) (Cunningham et al., 1996; Cunningham, 2005, 2013).

Cenozoic foreland fold-and-thrust belts (FTBs) formed in Cenozoic foreland basins on both northern and southern sides of the Tianshan belt, as a result of the migrating thrust loads created by intracontinental crustal shortening (Molnar and Tapponnier, 1975). These foreland FTBs contain key information for understanding the intracontinental crustal shortening of the Tianshan in response to the India-Asian collision. Investigations of the Cenozoic uplift and crustal shortening in the Tianshan foreland basins include: Burchfiel et al. (1999), Scharer et al. (2004), Sun et al. (2007), Sun and Zhang (2009) and Zhang et al. (2014). Using cross-sections across the southern and northern Tianshan belts Burchfiel et al. (1999) calculated 18–21 km and 2.1–6.2 km crustal shortening, respectively, and to the SE at Kashgar Scharer et al. (2004) estimated that shortening of individual folds decreased from a maximum of 6.8 km in the northwest to a minimum of 0.7 km (Fig. 1). Although the earlier works lacked precise seismic profiles, their shortening distances calculated by restoring balance cross-section are viable. However, calculation of the long-term shortening rate from a foreland basin can be difficult, if the initiation time of deformation is not known. Cooling histories revealed by apatite fission tracks suggest that the Tianshan orogeic belt began to uplift in the Late Oligocene-early Miocene (Windley et al., 1990; Dumitru et al., 2001; Sobel et al., 2006; Heermance et al.,

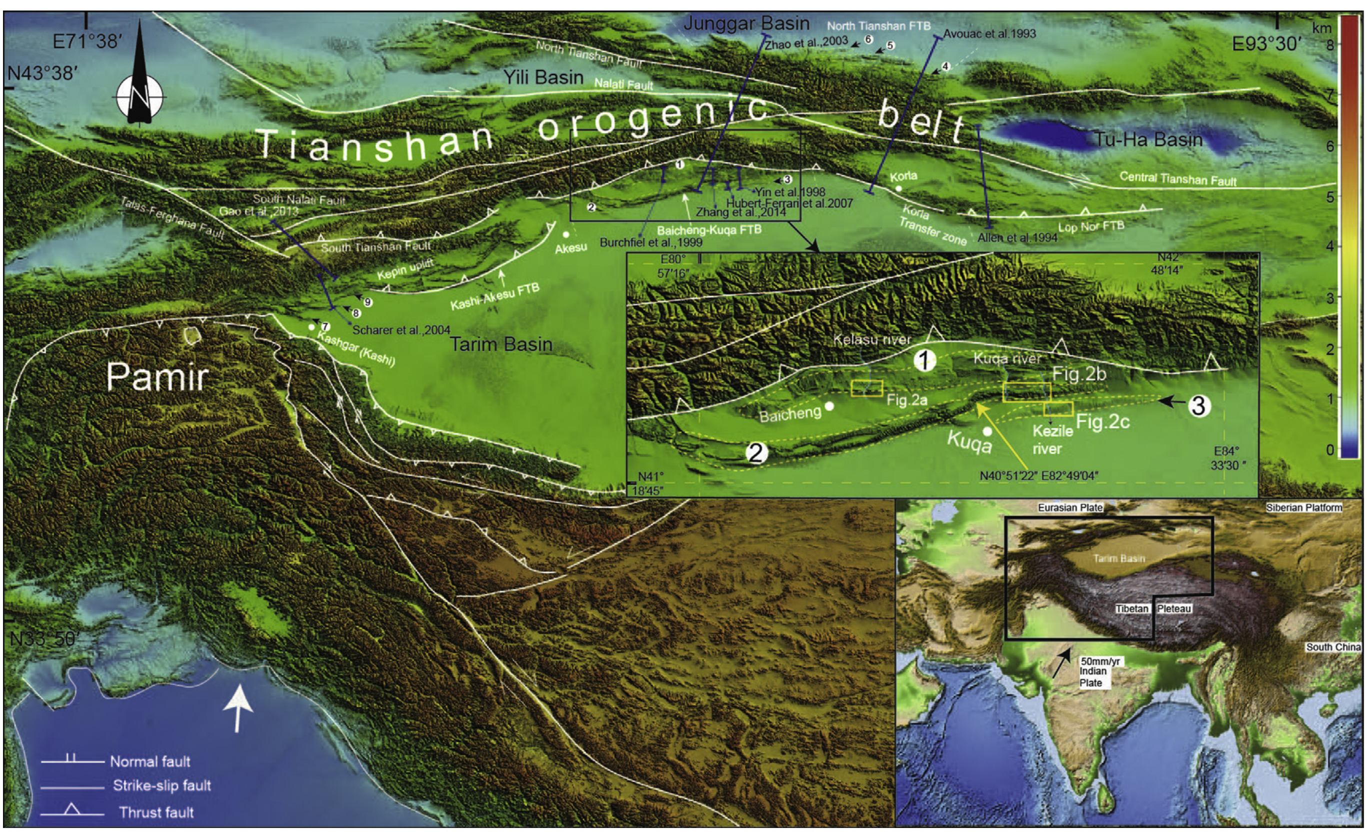

Fig. 1. A digital elevation map of Central Asia created with 90 m digital elevation data (DEMs) download from the USGS ftp site, provided by the NASA Shuttle Radar Topographic Mission (SRTM). Bottom right inset is a DEM map of Asia marks the location of main Fig. 1, which shows the Tianshan orogenic belt that was reactivated and uplifted by the India–Asia collision in the Cenozoic. Major thrusts, strike-slip and normal faults are marked. Both sides of the Tianshan orogenic belt developed foreland basin with thick sediments, strongly deformed in fold and thrust belts (FTBs). In the southern central Tianshan foreland, the Baicheng and Kuqa FTBs contain the Kelasu structural belt, the Qiulitag and Yaken anticlines (marked as 1, 2 and 3, respectively). On the northern side, south of the Juggar basin, there are three parallel ridges of anticlines (Marked as, 4, 5 and 6). In the southwest Tianshan, the Kashgar-Akesu FTB contain many anticlines including Mingyaole, Kashgar, Atushi-Talanghe and Mutule (marked as 7, 8 and 9, respectively). Our study area, located in the Baicheng-Kuqa FTB, is marked by a black rectangle containing Fig. 2a,b and c. Locations of cross-sections from Avouac et al. (1993), Allen et al. (1994), Yin et al. (1998), Burchfiel et al. (1999), Zhao et al. (2003), Scharer et a.(2004), Hubert-Ferrari et al. (2007), Gao et al. (2013) and Zhang et al. (2014) are shown.