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Denudation outpaced by crustal thickening in the eastern Tianshan

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ABSTRACT

The modern high topography of the Tianshan resulted from the reactivation of a Paleozoic orogenic belt by the India/Asia collision. Today, the range exhibits tectonically active forelands and intermontane basins. Based on quantitative morphotectonic observations and age constraints derived from cosmogenic ^{10}Be dating, single-grain post-infrared infrared stimulated luminescence (p-IR IRSL) dating and modeling of fault scarp degradation, we quantify the deformation in the Nalati and Bayanbulak intermontane basins in the central Eastern Tianshan. Our results indicate that at least 1.4 mm/yr of horizontal crustal shortening is accommodated within these two basins. This shortening represents over 15% of the 8.5 ± 0.5 mm/yr total shortening rate across the entire range at this longitude. This shortening rate implies that the Eastern Central Tianshan is thickening at a mean rate of ~1.4 mm/yr, a rate that is significantly higher than the average denudation rate of 0.14 mm/yr derived from our cosmogenic analysis. This discrepancy suggests that the Tianshan range has not yet reached a steady-state topography and remains in a transient state of topographic growth, most likely due to limited denudation rates driven by the arid climate of Central Asia.

1. Introduction

Intracontinental orogenic belts typically form single or double vergent prisms that grow by frontal accretion and underplating (e.g. Willett et al., 2001). In the presence of denudation, a topographic steady-state can be reached in which denudation balances crustal thickening (Avouac and Burov, 1996; Dahlen and Suppe, 1988; Willett et al., 2001). This could result from either crustal shortening of the internal part of the range or underplating due to an accumulation of material which is then thrust under the wedge.

Here, we investigate the Eastern Tianshan in central Asia (Fig. 1), one of the largest and most active intracontinental orogenic belts in the world. The range is composed of a series of E–W striking elevated ranges (>4000 m) and intermontane basins such as the Yili, Bayanbulak, Nalati, Turpan and Yanqi basins (Fig. 1). How fast this particular topography is growing, and whether it has reached steady-state or not are open questions.

Present-day shortening rates, derived from GPS measurements across the entire range, reach 20 mm/yr in the western Tianshan and decrease progressively eastwards, to a value of 8.5 ± 0.5 mm/yr at the longitude of this study (the shortening rate was calculated at 83E, 43.5N using the Euler poles of the Tarim and Dzungar basin) and to even lower rates further east (Yang et al., 2008). This shortening is not focused on the boundaries but is instead distributed across the entire range, and significant evidence for active deformation is observed within the central part of the range at locations probably controlled by Paleozoic structures (Jolivet et al., 2010; Poupinet et al., 2002; Thompson et al., 2002; Wu et al., 2014). In the eastern part of the range, the amount and rate of internal deformation remains poorly constrained (Jolivet et al., 2010; Wu et al., 2014). Quaternary to late Neogene denudation

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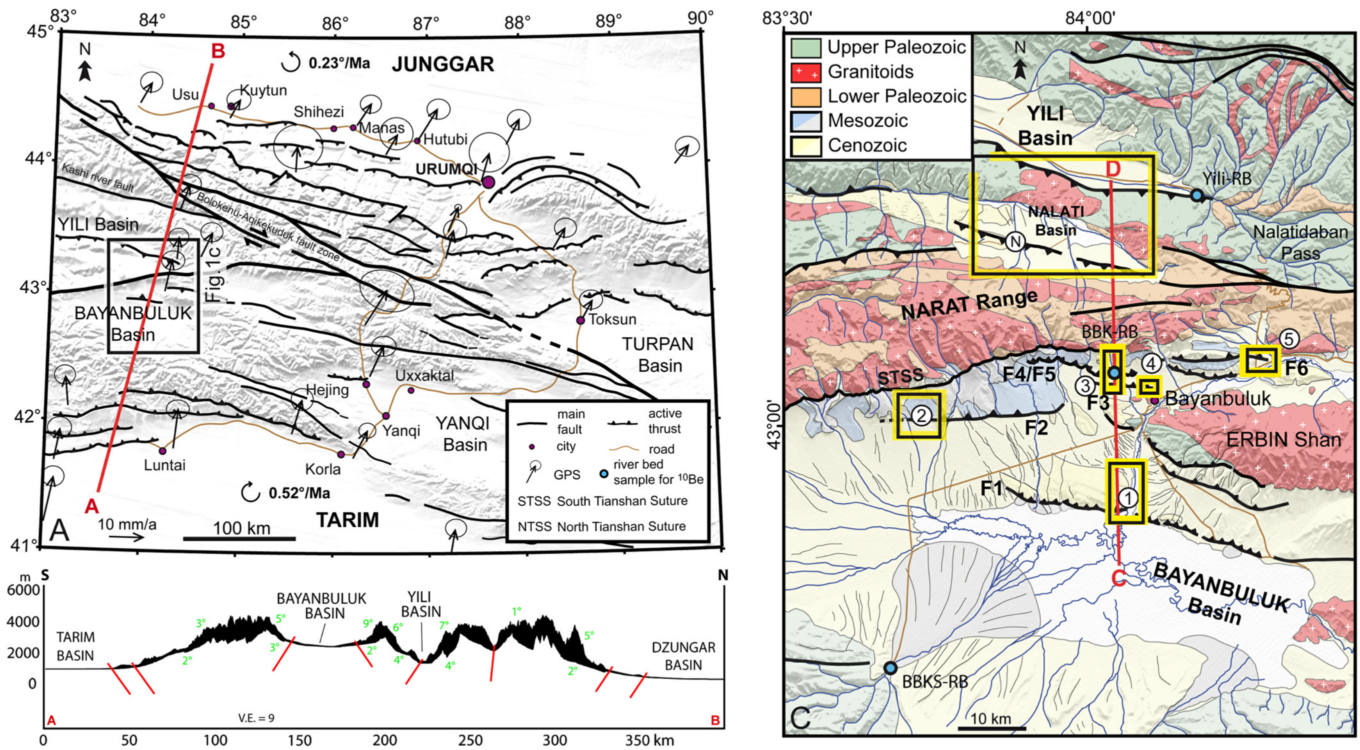

Fig. 1. A: structural map of the eastern Tianshan (GPS velocities relative to stable Eurasia from Yang et al., 2008). B: interpretative cross section. C: Geological map of the Bayanbulak basin. In Fig. 1c, the labels 1, 2, 3, 4 and N refer to the study site and to Figs. 2A, 2B, 3A, 3B, 4 and 6 in the main text, respectively. D: Interpretative cross section of the Bayanbulak basin. E: Topographic slope attitudes across the eastern Tianshan. Elevation data were extracted from the 1 arc second SRTM dataset, along a N10°E 10 km stacked profile crossing the Bayanbulak and eastern termination of the Yili basin.

rates on both sides of the range are relatively low (0.2–0.4 mm/yr) (Guerit et al., 2016; Jolivet et al., 2010; Puchol et al., 2017). Because Cenozoic denudation is very limited, even low temperature thermochronometers are of limited use to document the exhumation over the longer term, except for within the most active zones (Dumitru et al., 2001; Jolivet et al., 2010). To better understand how the Tianshan is growing and to determine whether this range has reached steady-state topography, more quantitative constraints on the distribution of deformation across the range and its evolution through time, as well as estimates of the associated denudation, are required, especially in the inner regions.

This study focuses on the Central Eastern Tianshan and investigates recent tectonics in the Bayanbulak and surrounding Nalati and Yili intermontane basins (Fig. 1). Evidence for active tectonics in this region has been reported but is poorly quantified. We use different techniques to quantify deformation and denudation rates. We demonstrate that crustal thickening outpaces denudation and conclude that, despite its long geological history and high topography, the Tianshan range is still in an early stage of topographic growth due to the extremely low erosion rates in the region.

2. Geological setting and evidence for active deformation in the intermontane basins

After a long Paleozoic geological history of mountain building due to oceans closure and collisions, numerous intermontane basins were created by a post-orogenic phase of transtensive deformation during the Permian to Late Triassic (Charvet et al., 2007; Jolivet et al., 2010). These basins are still partially preserved, though the range was strongly rejuvenated and shortened in the Late Cenozoic in response to the on-going India/Asia collision (e.g. Tapponnier and Molnar, 1979).

The Bayanbulak, Nalati and Yili basins are such large intermontane basins, situated ∼1500 to ∼2400 m (Fig. 1B) and surrounded by high elevation ranges with peaks at >4000 m composed mainly of Paleozoic meta-sedimentary and igneous basement (Fig. 1C).

The Bayanbulak basin is located between the South Tianshan range to the south and the Narat range to the north. The Northern edge of the basin exhibits clear evidence for recent deformation along several northward-dipping E–W trending parallel stepped faults and associated ∼10 km long topographic scarps (Figs. 1C, 2, 3 and 4). These faults deform numerous alluvial fan surfaces that were fed by southward flowing rivers that drain the Narat range (Figs. 2 and 3).

Located to the north, the Nalati basin is a relatively small basin trapped within the northern piedmont of the Narat Range and bound to the north by the >2000 m high Nalati range. At least two parallel reverse faults, trending roughly E–W and dipping to the south, can also be mapped within this basin (Fig. 5). The first lies at the base of the main reliefs of the Narat Range and affects quaternary glacial deposits. The second of these faults clearly offsets the most recent alluvial sediments of the Nalati Basin (Fig. 5).

The Yili basin lies at a lower elevation north of the Nalati range and is limited to the north by the Borohoro range. The basin is relatively narrow in the east but rapidly widens toward the west in Kazakhstan. High E–W striking topographic steps can be observed along its southern border (Fig. 5D). The nearby E–W flowing Yili river located at the center of the basin might also have left E–W striking terrace risers, and thus the tectonic origin of the topographic steps might be questioned. However, the presence of reverse and convex slopes is suggestive of a tectonic origin.

During the Late Quaternary, the region experienced strong aridification, which led to widespread deposition of loess over the pre-existing alluvial deposits (Long et al., 2014; Song et al., 2012; Yi et al., 2012).