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Research paper

Exhuming the Meso–Cenozoic Kyrgyz Tianshan and Siberian Altai-Sayan: A review based on low-temperature thermochronology

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ABSTRACT

Thermochronological datasets for the Kyrgyz Tianshan and Siberian Altai-Sayan within Central Asia reveal a punctuated exhumation history during the Meso–Cenozoic. In this paper, the datasets for both regions are collectively reviewed in order to speculate on the links between the Meso–Cenozoic exhumation of the continental Eurasian interior and the prevailing tectonic processes at the plate margins. Whereas most of the thermochronological data across both regions document late Jurassic–Cretaceous regional basement cooling, older landscape relics and dissecting fault zones throughout both regions preserve Triassic and Cenozoic events of rapid cooling, respectively. Triassic cooling is thought to reflect the Qiangtang–Eurasia collision and/or rifting/subsidence in the West Siberian basin. Alternatively, this cooling signal could be related with the terminal terrane-amalgamation of the Central Asian Orogenic Belt. For the Kygyz Tianshan, late Jurassic–Cretaceous regional exhumation and Cenozoic fault reactivations can be linked with specific tectonic events during the closure of the Palaeo-Tethys and Neo-Tethys Oceans, respectively. The effect of the progressive consumption of these oceans and the associated collisions of Cimmeria and India with Eurasia probably only had a minor effect on the exhumation of the Siberian Altai-Sayan. More likely, tectonic forces from the east (present-day co-ordinates) as a result of the building and collapse of the Mongol-Okhotsk orogen and rifting in the Baikal region shaped the current Siberian Altai-Sayan topography. Although many of these hypothesised links need to be tested further, they allow a first-order insight into the dynamic response and the stress propagation pathways from the Eurasian margin into the continental interior.

1. Introduction

The mountainous landscape of the Central Asian Tianshan and Altai-Sayan predominantly formed as a response to recurrent tectonic deformation (e.g. Hendrix et al., 1992; De Grave et al., 2007; Jolivet et al., 2013). The causes for these episodes of deformation are not yet fully understood. It has been suggested widely that the Meso-Cenozoic punctuated (viz., recurring at interrupted intervals) intracontinental deformation that affected Central Asia, is largely related with distant collisions at the southern Eurasian plate margin, with the most recent pulse of deformation being a far-field response to the India-Eurasia collision (e.g. Molnar and Tapponnier, 1975; Knapp, 1996; De Grave et al., 2007). The India-Eurasia collision not only caused shortening and uplift in the Himalayas and Tibet (e.g. Patriat and Achache, 1984; Harrison et al., 1992; Wang et al., 2001), but also the continuous convergence between India and Eurasia and the growth of the Tibetan Plateau induced convergence-drive (e.g. Abdrakhmatov et al., 1996) and/or flexure-related (Aitken, 2011) stresses that propagated into the Eurasian interior where they deformed the weaker crust of Central Asia (e.g. Knapp, 1996; Wang et al., 2001). Specifically, this deformation is preferentially accommodated by strength heterogeneities such as pre-existing fault zones within the crust of Tibet and Central Asia (e.g. England and Houseman, 1985), resulting in fault reactivation and associated rapid exhumation (Jolivet et al., 2001, 2010; Walker et al., 2007; Clark et al., 2010; Duvall et al., 2011; Glorie et al., 2011a, 2012a,b; Oskin, 2012; De Grave et al., 2013).

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The chronology and dynamics of the India-Eurasia convergence and collision as well as its influence on the exhumation of Tibet and Central Asia have been a matter of debate in recent years. Patriat and Achache (1984) were among the first to argue that the India-Eurasia collision occurred around ∼50 Ma. Rowley (1996) and Clift et al. (2003) proposed a very similar age-estimate based on a review of stratigraphic data. However, more recent palaeomagnetic, biostratigraphic and sedimentological studies suggested that India and Eurasia were still distinctly separated at ∼55–50 Ma and that the collision occurred around ∼35 Ma (e.g. Aitchison et al., 2007). More specifically, Jiang et al. (2015) argued that a Tethyan seaway still existed between India and Eurasia until ∼38–34 Ma, suggesting that the final collision of India with Eurasia must have occurred during or after the Priabonian. This late Eocene age for the collision was later confirmed by several others recent studies as well (e.g. Najman et al., 2010; Bouilhol et al., 2013). In addition, Van Hinsbergen et al. (2012) proposed a model involving two collisions: a 'soft' collision between Greater India and Eurasia at ∼50 Ma and a 'hard' collision of India with Eurasia at ∼25 Ma, suggesting that the collision is more complex than it was originally described.

Within southern Central Asia, widespread tectonic activity has been documented as transpiring since ∼25 Ma (e.g. Hendrix et al., 1992; Yin et al., 1998) which corresponds well with the proposed timing of the 'hard' collision between India and Eurasia (Van Hinsbergen et al., 2012) as well as with the timing of enhanced crustal thickening in Tibet (e.g. Yin and Harrison, 2000). However, recent thermochronological data on major fault zones indicate that Cenozoic tectonic activity may have affected southern Central Asia since the early Eocene (∼55–45 Ma) (e.g. Glorie et al., 2011a), intensifying during the late Oligocene–early Miocene (∼25–20 Ma) and again during the late Miocene–early Pliocene (∼10–3 Ma) as a response to subsequent regional shortening (e.g. Sobel et al., 2006; Macaulay et al., 2014).

The onset of major intra-plate mountain building within Central Asia however already occurred during the early Mesozoic (e.g. Dumitru et al., 2001; De Grave et al., 2007, 2011; Gorie et al., 2010). In fact, most of the Central Asian topography formed during the Mesozoic (De Grave et al., 2013; Jolivet et al., 2013). However, the dynamics of the pre-Himalayan tectonic uplift and deformation in Central Asia are not fully understood either. After a long period of Palaeozoic accretions (e.g. Xiao et al., 2004, 2010, 2013), the crustal architecture of Central Asia was episodically reactivated from the late Triassic onwards (e.g. Jolivet et al., 2007; De Grave et al., 2013). An important phase of regional late Jurassic–early Cretaceous uplift and exhumation has been documented throughout most of Central Asia, which is thought to be associated with the collisions of Gondwana-derived Cimmerian Blocks to Eurasia (e.g. Yin and Harrison, 2000; Jolivet et al., 2001) and/or the elusive Mongol-Okhotsk orogeny in the East (e.g. Cogné et al., 2005; Jolivet et al., 2009; Glorie et al., 2012a). Hence, in a similar way as described for the Cenozoic exhumation of Central Asia, stress-propagation from the southern Eurasian margin induced deformation and mountain building in Central Asia during the Mesozoic as well (e.g. De Grave et al., 2007; Glorie et al., 2010). The Mesozoic Central Asian mountainous landscape was likely widespread and may have been almost continuous from the southern plate margin at that time, to deep in the continental interior. In this regard, it has been suggested recently that much of the Tibetan topography already existed prior to the India-Eurasia collision (e.g. Clark, 2011; Hetzel et al., 2011). Furthermore, preserved early Mesozoic geomorphic features, such as internally drained plateaus or old erosion surfaces, testify to abundant Mesozoic topography in Central Asia as well (e.g. Hetzel et al., 2002; Jolivet et al., 2007; De Grave et al., 2011).

This paper aims to synthesise and discuss the exhumation history of two key-regions within the Central Asian edifice: (1) the Kyrgyz Tianshan (southern Central Asia; Figs. 1 and 2) the Siberian Altai (northern Central Asia; Fig. 1). Both regions will be examined and compared using a broad-scale multi-method thermochronology survey and focussing on (1) the regional relief, (2) major dissecting fault zones which record more recent exhumation events (e.g. Jolivet et al., 2010; Glorie et al., 2011a, 2012a,b) and (3) preserved landscape relics which archive more ancient exhumation events (e.g. Jolivet et al., 2007; De Grave et al., 2011). This approach enables a complete reconstruction of the thermal history and allows discussing the timing of punctuated reactivation events as a response to collisions and crustal shortening at the plate margins. It is furthermore attempted to comment on the timing and extent of Mesozoic and Cenozoic deformation within Central Asia as a response to distant tectonic activity at the Eurasian margins.

2. Thermochronological datasets

During the last decade, the Kyrgyz Tianshan and Siberian Altai-Sayan have been studied intensively, resulting in several recent publications of extensive thermochronological datasets. This

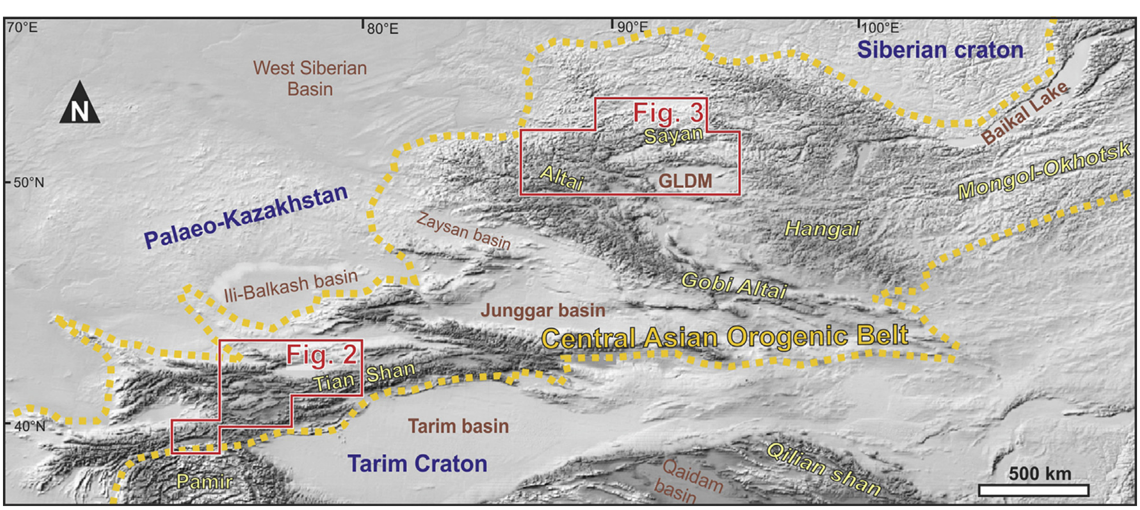

Figure 1. Digital elevation map of the Central Asian Orogenic Belt (CAOB) with indication of the study areas for this paper: the Siberian Altai-Sayan and the Kyrgyz Tianshan. Both locations occupy key-positions in the northern and southern CAOB respectively and both hold major suture-shear zones that were reactivated during the Meso–Cenozoic.