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Pliocene episodic exhumation and the significance of the Munsiari thrust in the northwestern Himalaya

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ABSTRACT

The Himalayan thrust belt comprises three in-sequence foreland-propagating orogen-scale faults, the Main Central thrust, the Main Boundary thrust, and the Main Frontal thrust. Recently, the Munsiari–Ramgarh–Shumar thrust system has been recognized as an additional, potentially orogen-scale shear zone in the proximal footwall of the Main Central thrust. The timing of the Munsiari, Ramgarh, and Shumar thrusts and their role in Himalayan tectonics are disputed. We present 31 new zircon (U–Th)/He ages from a profile across the central Himachal Himalaya in the Beas River area. Within a ∼40 km wide belt northeast of the Kullu–Larji–Rampur window, ages ranging from 2.4 ± 0.4 Ma to 5.4 ± 0.9 Ma constrain a distinct episode of rapid Pliocene to Present exhumation; north and south of this belt, zircon (U–Th)/He ages are older (7.0 ± 0.7 Ma to 42.2 ± 2.1 Ma). We attribute the Pliocene rapid exhumation episode to basal accretion to the Himalayan thrust belt and duplex formation in the Lesser Himalayan sequence including initiation of the Munsiari thrust. Pecube thermokinematic modelling suggests exhumation rates of ∼2–3 mm/yr from 4–7 to 0 Ma above the duplex contrasting with lower (<0.3 mm/yr) middle-late Miocene exhumation rates. The Munsiari thrust terminates laterally in central Himachal Pradesh. In the NW Indian Himalaya, the Main Central thrust zone comprises the sheared basal sections of the Greater Himalayan sequence and the mylonitic 'Bajaura nappe' of Lesser Himalayan affinity. We correlate the Bajaura unit with the Ramgarh thrust sheet in Nepal based on similar lithologies and the middle Miocene age of deformation. The Munsiari thrust in the central Himachal Himalaya is several Myr younger than deformation in the Bajaura and Ramgarh thrust sheets. Our results illustrate the complex and segmented nature of the Munsiari–Ramgarh–Shumar thrust system.

1. Introduction

The evolution of the Himalayan orogeny since the early Miocene has traditionally been described as the in-sequence growth and propagation towards its foreland, with progressive southward activation of the main thrusts, the Main Central Thrust (MCT), Main Boundary Thrust (MBT), and the Main Frontal Thrust (MFT; Fig. 1A). There is growing evidence that the lithotectonic units bounded by these shear zones and faults are not single crustal slices but have undergone both in- and out-of-sequence growth (e.g., Hollister and Grujic, 2006; Montomoli et al., 2015; Pearson and DeCelles, 2005). It has been known that the Lesser Himalayan sequence (LHS), bounded by the MCT above and the MBT at the bottom, is a structurally complex tectonic unit. The upper part contains Mid-Proterozoic metasediments and granitoids and has undergone greenschist and higher grade metamorphism. The lower unit preserves the original bedding permitting mapping of numerous horses stacked in different styles of duplexes. The boundary between the two are the Munsiari (MT), Ramgarh, and Shumar thrusts in the western, central, and eastern Himalaya, respectively, which may be a continuous orogen-scale structure (RMT, Pearson and DeCelles, 2005; Robinson and Pearson, 2013). Although most geologists agree on the existence of LHS duplexes, there is no agreement on their time of formation, on the significance of the RMT thrusts, or on the relative timing of deformation (i.e., the sequence of MCT–RMT–MBT; inset in Fig. 1A). In cross section restorations, the RMT is

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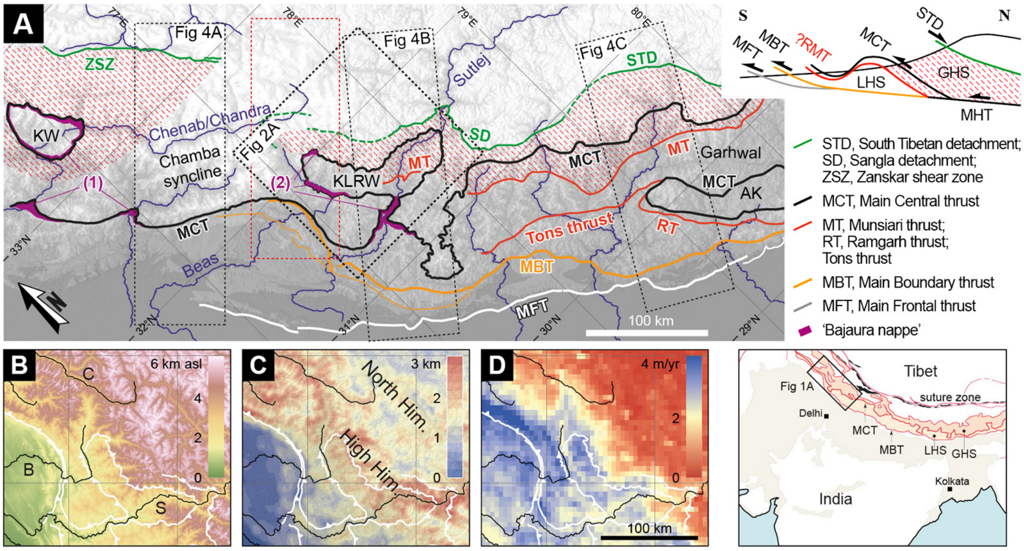

Fig. 1. (A) Tectonic overview of the NW Indian Himalaya (see overview map lower right for location; after Srivastava and Mitra, 1994; Steck, 2003). Black boxes outline study area (Fig. 2A) and cross sections (Figs. 4A–C). Red box outlines Pecube model area. Note the sequence of graphitic schists and mylonitic augen gneiss mapped in the Kishtwar area (1) and in the Beas area (Bajaura nappe, 2). Hatched area outlines the approximate extent of amphibolite facies metamorphic rocks. Schematic cross section in the upper right shows the main tectonic boundaries (LHS, Lesser Himalayan sequence; GHS, Greater Himalayan sequence). A question mark is added to the Ramgarh–Munsiari thrust system (RMT) to indicate that geometries and correlations of these faults vary along the orogen and are disputed (see text and Figs. 4A–C). Further abbreviations are: KW, Kishtwar window; KLRW, Kullu–Larji–Rampur window; AK, Almora klippe. (B) Topography, (C) local relief over a radius of 4.5 km, and (D) calibrated mean annual precipitation (based on TRMM 2B31; Bookhagen and Burbank, 2010) in central and eastern Himachal Pradesh. Outline of Figs. 1B–D corresponds approximately to Fig. 2A. Rivers are C – Chandra/Chenab, B – Beas, S – Sutlej. The physiographic subdivision into North Himalaya and High Himalaya is indicated in (C). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

a passive roof thrust of LHS duplexes and has accommodated on the order of 100 km shortening, comparable to shortening across the MCT and possibly more than the MBT (Long et al., 2011; Robinson and McQuarrie, 2012; Pearson and DeCelles, 2005). Other studies equate the RMT with the MCT shear zone (Searle et al., 2008; Larson and Godin, 2009). Estimates of the timing of the RMT thrusts vary along the orogen. Based on structural reconstructions, early Miocene ages (∼20–15 Ma) have been suggested for western Nepal and eastern Bhutan (Long et al., 2011; Robinson and McQuarrie, 2012). Younger ages have been suggested for Nepal (∼15–11 Ma, Pearson and DeCelles, 2005; ∼11–9 Ma, Kohn et al., 2004) and for eastern Himachal Pradesh (∼10–0 Ma, Vannay et al., 2004 or ∼10–6 Ma, Caddick et al., 2007). These differences may result from the different approaches to constraining the age of movement on a fault (e.g., thermochronological ages, structural reconstructions) or from the inconsistent definition of the thrust(s) and the resulting difficulties in along-strike correlation.

To investigate the geometry and kinematics of the Munsiari thrust in the northwest Indian Himalaya, we mapped a transect from LHS rocks in the western Kullu–Larji–Rampur window (KLRW), central Himachal Pradesh, into the Greater Himalayan sequence (GHS) in the MCT hanging wall. We constrain cooling and exhumation histories by new zircon (U–Th)/He (ZHe) ages from this transect and from the central Himachal GHS and integrate this new dataset with previously published data. Using Pecube thermokinematic modelling, we scrutinize the episodic Neogene exhumation histories and unravel the contributions of different tectonic phases on the evolution of the NW Himalaya.

2. Geological background

In Himachal Pradesh, the MCT separates Neoproterozoic to Cambrian meta-greywacke (Haimanta formation) with early Paleozoic granite intrusions from LHS orthogneisses and metasediments (e.g., Frank et al., 1995; Fig. 2A). The Haimanta rocks are mostly greenschist facies to unmetamorphosed; amphibolite-facies rocks are exposed in the valleys of the upper Beas, Tosh, and Chandra Rivers (Epard et al., 1995; Wyss, 2000) and in eastern Himachal Pradesh (Sutlej River section; Fig. 2A). In the Sutlej section, the Sangla detachment correlates with the STD. In the Beas section, presence and location of the STD are disputed, and the lower-grade Haimantas are attributed either to the GHS (e.g., Steck, 2003) or to the Tethyan Himalayan sequence (e.g., Webb et al., 2011). The KLRW exposes the MCT ≥100 km northeast of its frontal trace. The LHS in the window comprises Paleoproterozoic quartzite (Berinag formation) and Wangtu orthogneiss (∼1.8 Ga deposition and emplacement ages; Miller et al., 2000; Fig. 2A). The MCT shear zone is several 10s to 100s meters thick. It comprises mylonitic orthogneiss (Baragaon augen gneiss) with the same magmatic age and isotopic composition as the Wangtu orthogneiss (Thöni, 1977; Frank et al., 1995), graphitic schists and phyllites and, locally, dark limestone bands (e.g., Stephenson, 1997; own observations). In the NW Indian Himalaya including the KLRW and Kishtwar window, the sequence of augen gneiss and graphitic schists is referred to as 'Bajaura nappe' or 'Lower crystalline nappe'. It is either attributed to the MCT shear zone (e.g., Thöni, 1977; Frank et al., 1995; Stephenson et al., 2001) or interpreted as a separate unit (e.g., Steck, 2003; Webb, 2013; Fig. 1A).

The NW Himalayan MCT was active from the latest Oligocene–early Miocene to the middle Miocene (Vannay et al., 2004; Robyr et al., 2006). Rapid exhumation of the metamorphic GHS from mid-crustal depths (peak pressures ∼5–9 kbar) is reflected, for example, in ∼20–21 Ma muscovite $^{40}Ar/^{39}Ar$ (MAr) ages in the Beas and Chandra valleys (Schlup et al., 2011; Stübner et al., 2014, 2017); slightly younger MAr ages in the Sutlej GHS (∼15–17 Ma; Vannay et al., 2004) could be related to the enhanced fluvial incision of the Sutlej river, which led to an estimated ∼10 km of additional erosion compared to the Beas section (Thiede et al., 2005).

The MT is mapped in the Sutlej section as the mylonitic base of a ∼16 km thick amphibolite-facies, pervasively top-to-the-SW sheared sequence of paragneiss and Wangtu orthogneiss (Lesser Himalayan crystalline, LHC; Vannay and Grasemann, 2001). Monazite U, Th–Pb and garnet Sm–Nd ages (∼6–11 Ma) and MAr