Late Miocene-present exhumation kinematics of the Sikkim Himalaya derived from inversion of zircon (U-Th)/He and apatite fission-track ages using 3-D thermokinematic modelling

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Erosion and exhumation of upper crustal material in the Himalayas results from a combination of tectonic and surface processes (Beaumont et al., 2001; Hodges et al., 2004; Grujic et al., 2006). Although recent studies have well defined the Miocene-Pliocene exhumation history and deformation kinematics along much of the Himalayan arc (Hodges et al., 2004; Wobus et al., 2005; Herman et al., 2010;) , the exhumation history of the Sikkim Himalaya is unknown despite being intriguing. The Sikkim Himalaya (Figure 1) is located in a transition zone between two regions of the Himalaya with substantial structural and geomorphological differences, the Nepal Himalaya to the west (Robert et al., 2011; Whipp et al., 2007) and the Bhutan Himalaya to the east (Grujic et al., 2006; Coutand et al., 2014). Late Miocene-present deformation of the Sikkim Himalaya is driven by slip along the Himalayan basal décollement (Main Himalayan thrust; MHT) and duplex development in the Lesser Himalaya. In addition, coupling and feedbacks between duplexing and efficient fluvial erosion have exposed meta-sedimentary rocks of the Lesser Himalayan Sequence (LHS) in a large, double tectonic window (Bhattacharyya and Mitra, 2009) from beneath the structurally overlying Greater Himalayan Sequence (GHS; Figure 1). The comparative contribution of the two processes is relatively poorly understood in particular in the study area.

This study adopts a multi-disciplinary approach coupling zircon (U-Th)/He (ZHe), and apatite fission-track (AFT) thermochronology with 3D thermokinematic modelling, to define the Neogene-present deformation and exhumation history of the Sikkim Himalaya. 44 rock samples were collected along two N-S-trending profiles across the windows (Figure 1). 15 samples were processed for ZHe and 34 for AFT dating. Published AFT data (Figure 1), collected in the footwall of the South Tibetan Detachment Zone (Kellett et al., 2013; STDZ in Figure 1), were used to augment our dataset. The ZHe cooling ages range from 11.87 ± 0.49 Ma to 1.30 ± 0.07 Ma. Approximately 20-30 km north of the Main Boundary Thrust (MBT; Figure 1), ZHe cooling ages show a marked age decrease; south of this break cooling ages range from 12 to 6 Ma, and north of the break, within the double window and beyond, ages are younger than ~4 Ma. This break corresponds roughly to the southern exposure of the LHS units within the windows. Analysis of AFT samples is ongoing.

The age dataset is inverted using the thermo-kinematic modelling software Pecube (Braun, 2003) to define the Late Miocene-present deformation and exhumation kinematics of the Sikkim Himalaya. We combine our dataset with published AFT (Kellett et al., 2013), structural (Bhattacharyya and Mitra, 2009) and geophysical data (Acton et al., 2011) to define the model input parameters and their ranges. Rock exhumation results from rock uplift determined by the underlying fault kinematics and geometry, and surface erosion, which maintains modern steady-state topography. Late Miocene-present deformation of the Sikkim Himalaya is driven by slip along the Himalayan basal décollement (Main Himalayan thrust; MHT) and duplex development in the Lesser Himalaya. Duplexing is simulated by a zone of enhanced rock uplift focussed on the northward dipping segment of the MHT located in northern Sikkim. Free parameters in the inversions include: basal temperature, radiogenic heat production, convergence rate, the ratio of under-thrusting to over-thrusting, the position of ramp and flat portions of the MHT as well as the location, timing and rate of duplex driven rock uplift. Our numerical models focus on defining the exhumation kinematics (fault geometry, slip rate) over the last 12 Ma that are most consistent with the observed age data for tectonic scenarios with and without upper-crustal duplexing.

We find that duplex-driven rock uplift in the LHS is required to produce the young ages observed in the core of the double tectonic window in the Sikkim region. The tectonic scenario involving slip only on the basal

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décollement and no duplexing does not provide a satisfactory fit to the age data. Specifically, modelled cooling ages from samples in and around the tectonic windows tend to be too old while the samples north of the windows (≥70 km north of the MBT) tend to be too young. Additional uplift as a result of simulated duplexing in the model provides a much better fit to the age data, with many of the predicted cooling ages within the uncertainty of the observed ages. Combined, these results suggest that duplexing is a dominant process in the tectonic evolution of Sikkim during the late-Miocene.

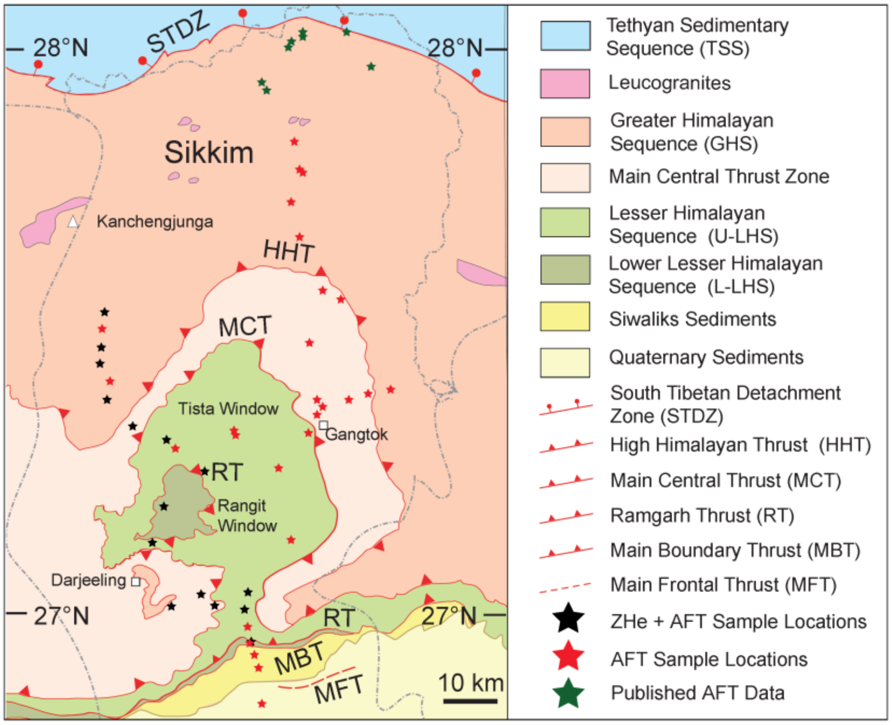

Figure 1. Geologic Map of the Sikkim Himalaya. The Tista and Rangit windows are shown in the centre of the map, bounded by the Main Central Thrust and Ramgarh Thrust respectively. Samples dated by AFT are denoted in by red stars, samples dated using both ZHe and AFT are denoted by black stars. Green stars show previously published AFT data[11]. After Kellett et al., 2013.

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