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Active bidirectional tectonic-tilting in a part of the Almora Klippe, Kumaun Lesser Himalaya, India: Insights from statistical analyses of geomorphic indices

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ABSTRACT

The NW-SE trending, synformal Almora Klippe in central Kumaun Lesser Himalaya is actively uplifting along the basal thrust, which is known as North Almora Thrust (NAT) and South Almora Thrust (SAT) along the northern and southern flanks, respectively. Geomorphic indices of 'Basin Asymmetry Factor (AF)' and 'Transverse Topography Factor (T)' of 77 drainage basins of third-order streams developed on this tectonic block have been computed to decipher active tilt-block tectonics of a part of this vast klippe. Statistical analyses of the basins' geomorphic indices revealed differential, gentle to steep, bidirectional tilting of the Almora Klippe vis-à-vis lent insight into correct perspective which these must be used for such studies. The tectonic block of Almora Klippe is partitioned into two minor tectonic blocks along the hinge of the synform. Differential movements along the basal thrust of the klippe have caused westward down-tilting of the northern fold flank ('AF' having χ^2 value of 7.556 for 4 azimuth classes at 90% confidence level, and 'T' having vector mean ($\bar{\theta}v$) of 260° and vector magnitude (r) of 0.25 at p-value of 0.1154), and eastward down-tilting of the southern fold flank ('AF' having χ^2 value of 13.73 for 4 azimuth classes at 90% confidence level, and 'T' having vector mean ($\bar{\theta}v$) of 56° and vector magnitude (r) of 0.26 at p-value of 0.0585). The westward down-tilting of the northern fold flank is due to its faster uplift in the east, along the NAT. Similarly, the eastward down-tilting of the southern fold flank is due to its faster uplift in the west, along the SAT.

1. Introduction

Formed as a result of continent-continent collision between Indian and Asian plates, the Himalaya is the world's youngest and largest active mountain belt. Following collision, the convergence between these two plates deformed the northern margin of the Indian plate and produced stack of crustal slabs one upon the other that built the architectural framework of the Himalaya (Molnar, 1984). In broader architectural setting, deep faults striking parallel to the orographic trend transversely subdivide the Himalaya into four distinct lithotectonic terranes (Gansser, 1964) (Fig. 1a). In the north is the Tethys Himalaya, which lies between the Indus Tsangpo Suture (ITS) zone in the north and South Tibetan Detachment (STD) in the south. To the south of STD is the Great Himalaya, which is thrust southwards over the Lesser Himalaya along the Main Central Thrust (MCT). The Lesser Himalaya is thrust southwards over the Sub-Himalaya along the Main Boundary Thrust (MBT), and finally the Sub-Himalaya is thrust southwards over the vast Indo-Gangetic Plain, along the Main Frontal Thrust (MFT). A number of regional to local scale active faults, which strike longitudinal or transverse to the Himalayan strike further subdivide each one of these four terranes into different tectonic units/blocks (see Valdiya, 2016, and references therein). The convergence between the Indian and Asian plates is incessantly continuing, and a significant amount of the resulting crustal shortening is being accommodated by different Himalayan faults/thrusts and folds (cf. Robinson and Pearson, 2013). Consequently, the individual tectonic blocks are experiencing subtle to discernible crustal deformations.

Identifying, gauging and deciphering the pattern of active crustal deformation in individual tectonic blocks are effective in understanding the ongoing tectonic processes in any region (cf. Burbank and Anderson, 2001). Several studies in different parts of the world have brought out that the tilting of tectonic blocks is one of the most readily recognizable manifestations of active crustal deformation, and thus a reliable proxy of ongoing tectonic activities (e.g. Cox, 1994; Cox et al., 2001; Azor et al., 2002; Garrote et al., 2008; Bagha et al., 2014; Azañón et al., 2015; Daxberger and Riller, 2015; Gaidzik and Ramírez-Herrera,

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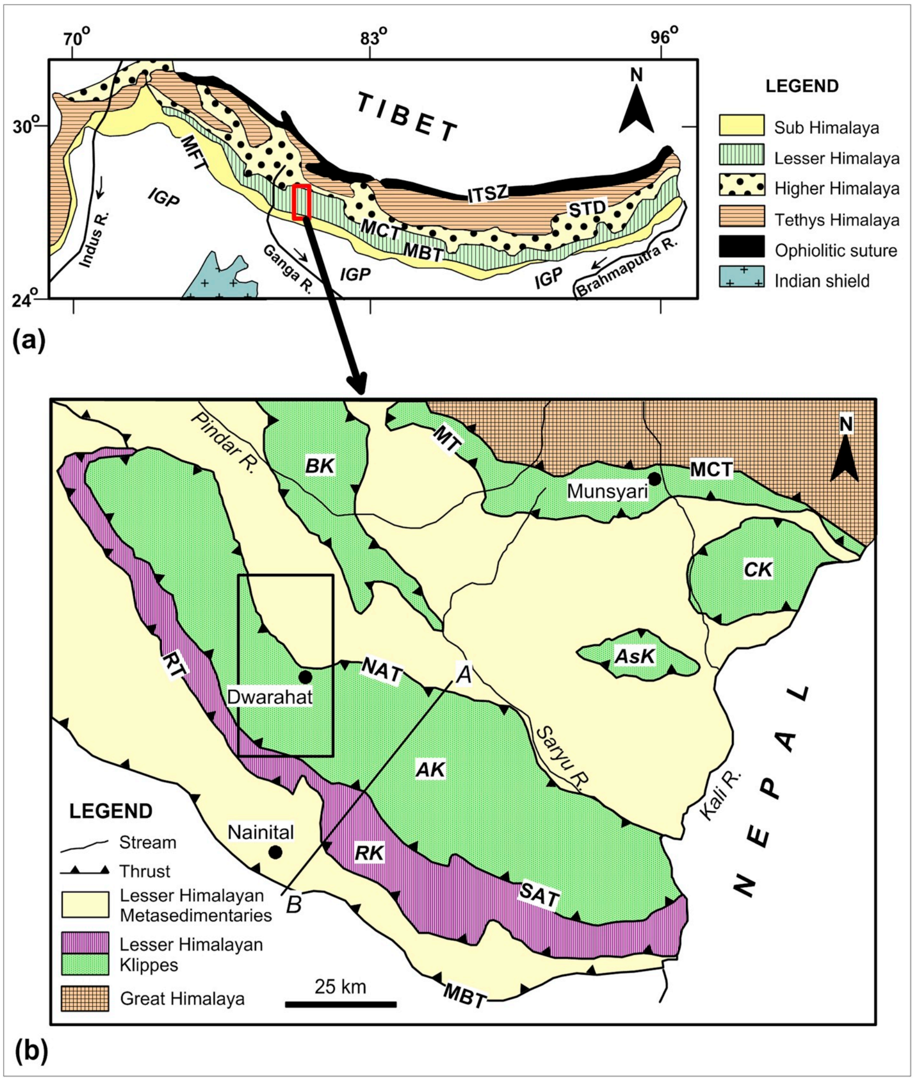

Fig. 1. (a) Generalized map showing four lithotectonic terranes of the Himalaya. IGP, Indo-Gangetic Basin; ITSZ, Indus Tsangpo Suture Zone; MBT, Main Boundary Thrust; MCT, Main Central Thrust; MFT, Main Frontal Thrust; STD, South Tibetan Detachment. (b) Tectonic map of the Kumaun Lesser Himalaya (modified after Valdiya, 1980). AK, Almora Klippe; AsK, Askot Klippe; BK, Baijnath Klippe; CK, Chhiplakot Klippe; MBT, Main Boundary Thrust; MCT, Main Central Thrust; MT, Munsyari Thrust; NAT, North Almora Thrust; RK, Ramgarh Klippe; RT, Ramgarh Thrust; SAT, South Almora Thrust. Rectangle marks location of the study area. Line AB marks the section, along which cross-section shown in Fig. 2 is drawn.

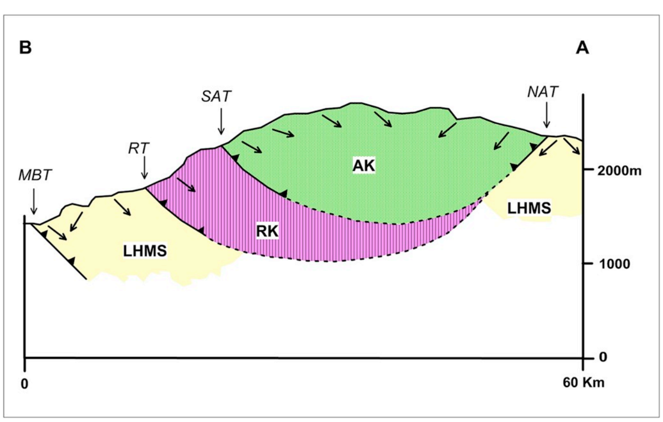

Fig. 2. Generalized cross-section drawn along AB section shown in Fig. 1 showing tectonic blocks of the southern Kumaun Lesser Himalaya (based on Valdiya, 1980). Arrows show generalized dips of the strata. LHSS, Lesser Himalayan Metasedimentaries; remaining abbreviations are same as used in Fig. 1b.

2017). Nonetheless, there have been only limited studies to identify and measure the extent of Himalayan tectonic blocks' tilting, and thus understanding the pattern and extent of ongoing tectonic activities in the region (Virdi et al., 2006; Agarwal and Sharma, 2011; Goswami and Deopa, 2012; Kotlia et al., 2018). In the present study we address this crucial active tectonic aspect of the Lesser Himalaya in Kumaun region of India.

The Kumaun Lesser Himalayan terrane is made up of two parts. The lower part comprises thick Proterozoic metasedimentary pile, whereas the upper part consists of a sequence of klippes of metamorphic rocks that are placed one over the other in a descending chronological order (Fig. 1b) (Valdiya, 1980, 2016). This study pertains to the uppermost and oldest of these Kumaun Lesser Himalayan klippes, which is known as the Almora Klippe (Heim and Gansser, 1939). Geomorphic evidences reveal active uplift of the Almora Klippe (Valdiya and Kotlia, 2001), but nevertheless the extent and pattern of attendant crustal deformation in it has not yet been determined. The present study is aimed at understanding ongoing tectonic activities in central part of the Almora Klippe through identification and measurement of active tectonic tilting (Fig. 1b).

2. Geological setting

A detailed account of the Kumaun Lesser Himalayan geology has been given by Valdiya (1980). In southern Kumaun, the Lesser Himalaya is made up of three distinct lithotectonic-stratigraphic units; from bottom to top, these are, Krol-Belt metasedimentaries (parautocthon), and Ramgarh and Almora klippes (Auden, 1934; Heim and Gansser, 1939; Valdiya, 1980) (Figs. 1b and 2).