Testing models for the kinematic evolution of the Lesser Himalayan Sequence by balanced reconstruction: Accretion dominant in northwestern India

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Tectonic models of the Himalayan orogen may be categorized as critical taper (e.g., Kohn, 2008) or channel flow (e.g., Beaumont and others, 2004). These models explain the assembly of the three major Himalayan units (the Lesser Himalayan Sequence, Greater Himalayan Crystalline complex, and Tethyan Himalayan Sequence) by deformation concentrated on the two faults that limit the units (the Main Central thrust and South Tibet detachment). Both models accommodate a wide range of possible tectonic histories for the Lesser Himalayan Sequence, which represents the most recent bedrock addition to the growing orogenic wedge. Mechanisms proposed for the construction of the Lesser Himalayan Sequence include: (1) forward-propagating thrusting (e.g., Schelling and Arita, 1991); (2) accretion of thrust horses at upper crustal (e.g., Robinson, 2008) and/or middle crustal (e.g., Bollinger and others, 2004) depth; (3) out-of-sequence thrusting, which may be driven by focused precipitation and erosion (e.g., Thiede and others, 2004); and (4) thrusting both before and after Main Central thrust motion (Célérier and others, 2009a).

Detailed kinematic reconstructions are powerful tools for testing thermal and tectonic models of orogenic wedges (e.g., Célérier and others, 2009b; Malavieille, 2010). We test the Lesser Himalayan Sequence models by constructing and progressively retro-deforming a balanced cross section across the Lesser Himalaya and the foreland basin rocks of the Sub-Himalaya. We target the Shimla region of northwestern India because it contains the richest stratigraphic diversity in the orogen, thus allowing the highest resolution for constraining restoration [major units are the Cenozoic Sub-Himalaya, the Cretaceous-Eocene Subathu-Singtali rocks, the Late Proterozoic-Cambrian Outer Lesser Himalaya Group, the Early-Middle Proterozoic Deoban-Damtha Groups, the Early Proterozoic Berinag Group, and the Early Proterozoic Munsiari Group]. The section is informed by our regional geological map, which integrates literature mapping and analytical results with our own structural and analytical data (from >650 sites). Additional sketch cross sections were made to relate along-strike structural variations to the main section.

Our reconstruction shows a minimum shortening of ~268 km (~57%) across the Lesser Himalaya and Sub-Himalaya since ~14 Ma. We show the progressive evolution with sections representing ~14 Ma, ~5.4 Ma, ~1.9 Ma, and the present. Major thrusts accomplishing shortening via top-to-the-SW motion are the Main Frontal thrust, the Bilaspur thrust, the Krol thrust, the Tons thrust, the Berinag thrust, and the Munsiari thrust. We do not include a Main Boundary thrust, i.e., a structure defined to place the Lesser Himalayan Sequence atop the Sub-Himalaya, because the Bilaspur, Krol, and Tons thrusts all match this description. Shortening of the Deoban-Damtha rocks occurred within an upper crustal duplex; ongoing shortening of the Munsiari rocks occurs within a hinterland, middle crustal antiformal stack. Most shortening has been accomplished by accretion of footwall horses at both middle and upper crustal levels (roughly 75% of shortening) and foreward propagation of the thrust belt into the foreland (roughly 20% of shortening). Out-of-sequence shortening is limited to ~15 km along the Munsiari thrust and <3 km on other structures. The Munsiari thrust has been previously interpreted as an out-of-sequence structure having over 20 km of throw (e.g., Thiede and others, 2004). Our alternative model suggests that the vertical displacement accomplished by out-of-sequence Munsiari faulting may be limited to ~5 km, with remaining uplift accomplished by the Munsiari antiformal stack. The reconstruction does not require any Cenozoic deformation of exposed Lesser Himalayan Sequence rocks prior to Main Central thrust motion; we argue that such deformation is unlikely. The active basal thrust carries a leading fold-and-thrust belt in the south, an upper crustal duplex further north, and the growing Munsiari antiformal stack in the northern hinterland. This kinematic model is broadly similar to analog models featuring a main decollement and a zone of enhanced erosion over the hinterland (cf. Malavieille, 2010). Two possible causes for enhanced erosion over the Munsiari antiformal stack are a local precipitation maximum (e.g., Thiede and others, 2004) or the Sutlej River.

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