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A BALANCED CROSS-SECTION ACROSS THE CENTRAL NEPAL SIWALIK HILLS ; HITAUDA TO AMLEKHGANJ

by

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(with 3 text figures)

Abstract

A balanced cross-section has been constructed across the Sub-Himalayan Siwalik Hills of the Hitauda-Amlekhganj region of central Nepal in order to determine the structural geometry of the region and to calculate tectonic shortening. The central Nepal Sub-Himalaya is underlain by a basal detachment fault, the Main Detachment Fault (MDF) which lies at a depth of about 6 km beneath the Sub-Himalaya. The Main Boundary Thrust (MBT), the Main Dun Thrust (MDT) and the Main Frontal Thrust (MFT) are all splay thrusts off of the MDF which ramp up-section through the 6 km thick Siwalik sedimentary prism with no major intervening thrust flats; the central Nepal Sub-Himalaya thus has an emergent imbricate-fan geometry. North-south shortening across the Hitauda-Amlekhganj Sub-Himalaya has been approximately 17 km, or 40% shortening. The MBT has accommodated a minimum of another 15 km of horizontal north-south shortening as well.

Introduction

Throughout its 2,500 km length the Himalaya can be divided into four tectonic zones (Gansser, 1964, 1981). These are, from north to south, (1) the Tibetan or Tethys Himalaya, (2) the Higher Himalaya, (3) the Lesser Himalaya, and (4) the Sub-Himalaya (Text-fig. 1). The Sub-Himalaya, which lies between the Lesser Himalaya to the north and the Ganges Plain to the south, is composed of middle Miocene to Plio-Pleistocene molasse sediments (Gansser, 1964, 1981; West and Munthe, 1981; Tokuoka *et al.*, 1986), the Siwalik Group, deposited in the foreland basin of the rising Himalaya (Gansser, 1964, 1981; Lyon-Caen and Molnar, 1985). Bounded on the north by the Main Boundary Thrust (MBT) and on the south by the Main Frontal Thrust (MFT), the Sub-Himalaya is a non-metamorphosed foreland fold-thrust belt amenable to structural analysis using the techniques of balancing cross-sections. The techniques were developed primarily in the

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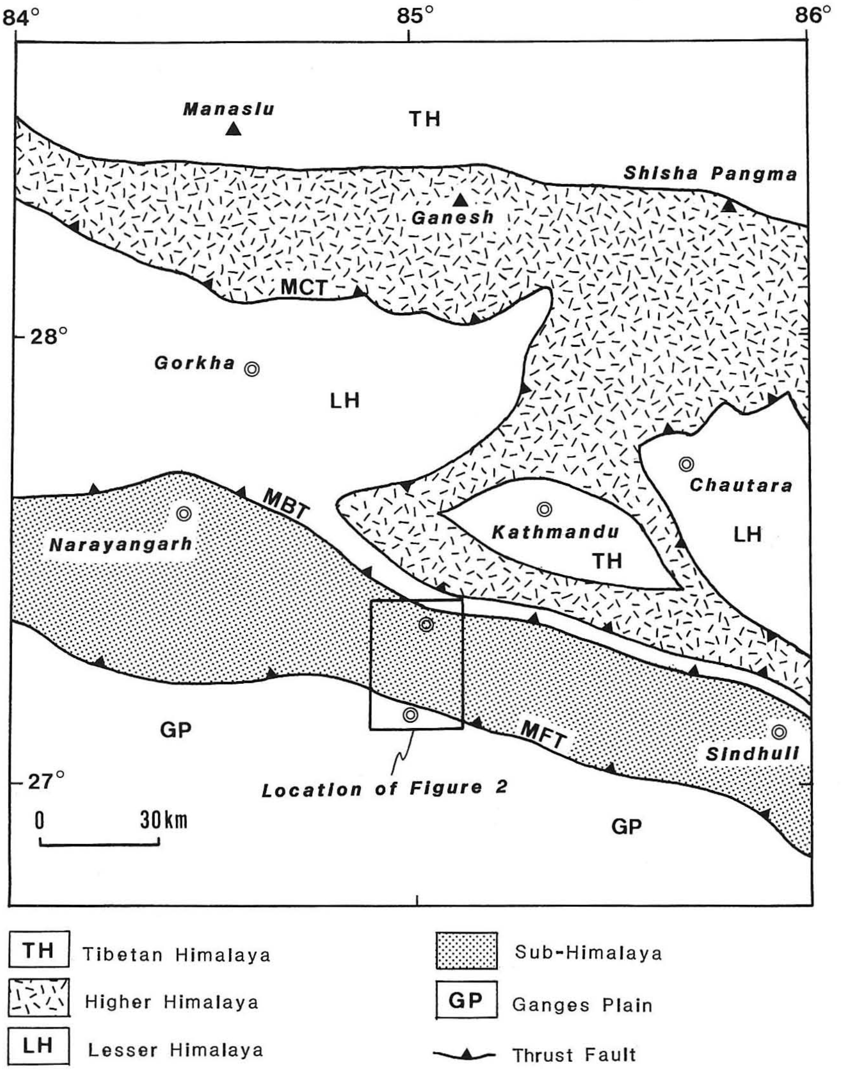
frontal fold-thrust belt of the eastern Canadian Rocky Mountains, characterized by folded and faulted, non-metamorphosed sedimentary sequences, like the Sub-Himalaya. It has been recognized to be valid in restoring deformed-state cross-sections and estimating absolute and relative contraction and extension across a given region (Bally *et al.*, 1966; Dahlstrom, 1969; Elliot, 1983; Hossack, 1979; Cooper and Trayner, 1986). This paper discusses a structural section through the Sub-Himalayan Siwalik (Churia) Hills of central Nepal, the Bainsedhoban-Hitauda-Amlekhganj section, which has been line-length balanced, and the implica-



Text-fig. 1 Tectonic map of the central Nepal Himalaya showing the location of the study area. MCT=Main Central Thrust: MBT=Main Boundary Thrust; MFT=Main Frontal Thrust. Modified after Schelling (1989), Stöcklin and Bhattarai (1982) and Hashimoto *et al.* (1973).

tions of balancing the cross section for understanding the structural geometry and development of the Sub-Himalayan foreland fold-thrust belt. Tectonic shortening across the Hitauda-Amlekhganj Sub-Himalaya has been calculated from the balanced and restored sections.

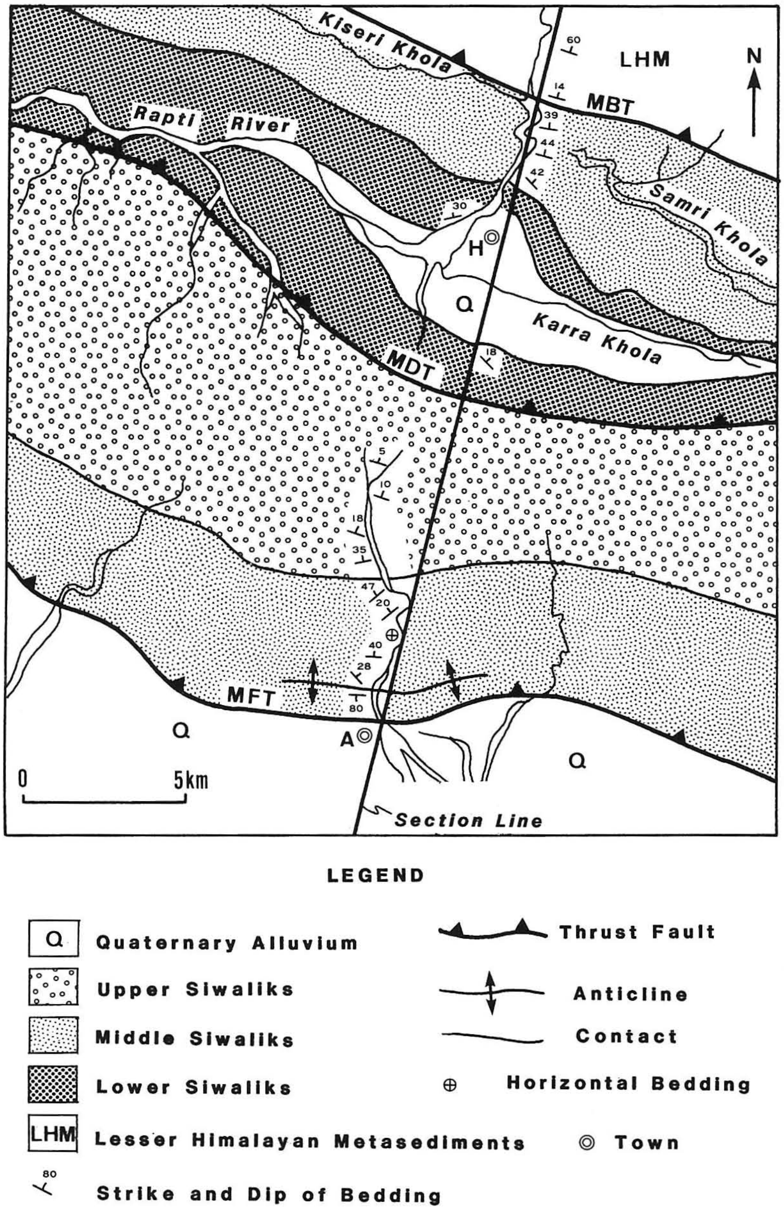
The Siwalik Group

Throughout Nepal the Siwalik Group of the Sub-Himalaya can be divided into three lithostratigraphic units, the Lower Siwaliks, the Middle Siwaliks and the Upper Siwaliks (Hagen, 1969; Itihara *et al.,* 1972; West and Munthe, 1981: Herail *et al.,* 1986; Schelling, submitted). The Lower Siwaliks are composed primarily of variegated mudstones and shales with thin (less than 10 m thick), interbedded sandstone layers. In the Hitauda region the Lower Siwalik sediments are a minimum of 2,700 m thick. The Middle Siwaliks consist primarily of mica-rich (biotite and muscovite), cross-bedded sandstones with occasional mudstone layers and pebble-conglomerate beds. Individual sandstone sequences within the Middle Siwaliks are frequently many tens of meters thick. In the Hitauda-Amlekhganj region the Middle Siwaliks are approximately 2,000 m thick. The Upper Siwaliks consist predominantly of pebble and cobble conglomerates along with minor, intercalated sandstones and mudstones. The Upper Siwalik sediments generally grade upwards into the recent alluvial sediments of the Dun Valleys in eastern and central Nepal; a clear boundary between the Upper Siwaliks and recent alluvial sediments is usually only apparent north of the Main Dun Thrust (in the internal zones of the Sub-Himalaya) where there is a pronounced angular unconformity of 40° to 90° between the two units. The often non-horizontal disposition of Quaternary alluvial sediments within the Dun valleys and along the southern margin of the Siwalik Hills attests to the tectonically active nature of the Nepal Sub-Himalaya (Williams, 1982; Herail *et al.,* 1986; Delcaillau *et al.,* 1987; Nakata, 1989).

The upward coarsening nature of the Siwalik Group, from predominantly mudstones through primarily sandstones to predominantly conglomerates, records alluvial progradation during the southward migration of the Himalayan topographic front since the Middle Miocene.

Structure of the Hitauda-Amlekhganj region

The Sub-Himalayan Siwalik sediments of the Amlekhganj-Hitauda region are cut by three major thrust faults, the Main Boundary Thrust, the Main Dun Thrust and the Main Frontal Thrust (Text-figs. 2 and 3). North of Hitauda lies the Main Boundary Thrust (MBT) along which Lesser Himalayan Metasediments (or the Midland Group metasediments) have heen thrust over the non-metamorphosed Siwalik Group. The MBT cuts the erosion surface along the Kiseri Khola and north of the Samri Khola, and trends approximately N70°W. The Lesser Himalayan Metasediments of the MBT hangingwall include slates and phyllites, along with the Bainsedhoban Marbles of Stöcklin and Bhattarai (1982) which form the Kailas Danda north of the Kiseri and Samri Kholas. Bedding and bedding-parallel foliations in the MBT hangingwall strike roughly N75°W, sub-parallel to the trend of the underlying MBT.



Text-fig. 2 Geologic map of the Hitauda-Amlekhganj region of the central Nepal Siwalik Hills. Line of balanced cross-section in Text-fig. 3 shown. H=Hitauda; A=Amlekhganj; MBT=Main Boundary Thrust; MDT=Main Dun Thrust; MFT=Main Frontal Thrust.

At the erosion surface north of Hitauda the footwall of the MBT contains Middle Siwalik sandstones. An erosion-resistant layer of Middle Siwalik sandstones caps the Siwalik Hills ridge north of the Karra Khola, the Rapti River and Hitauda, and south of the Kiseri and Samri Kholas. This ridge trends between N60°W and N70°W, parallel to the Siwalik Group bedding-surfaces (Text-fig. 2). Thus the strike of the MBT is sub-parallel to the strike of bedding in both its hangingwall and footwall.

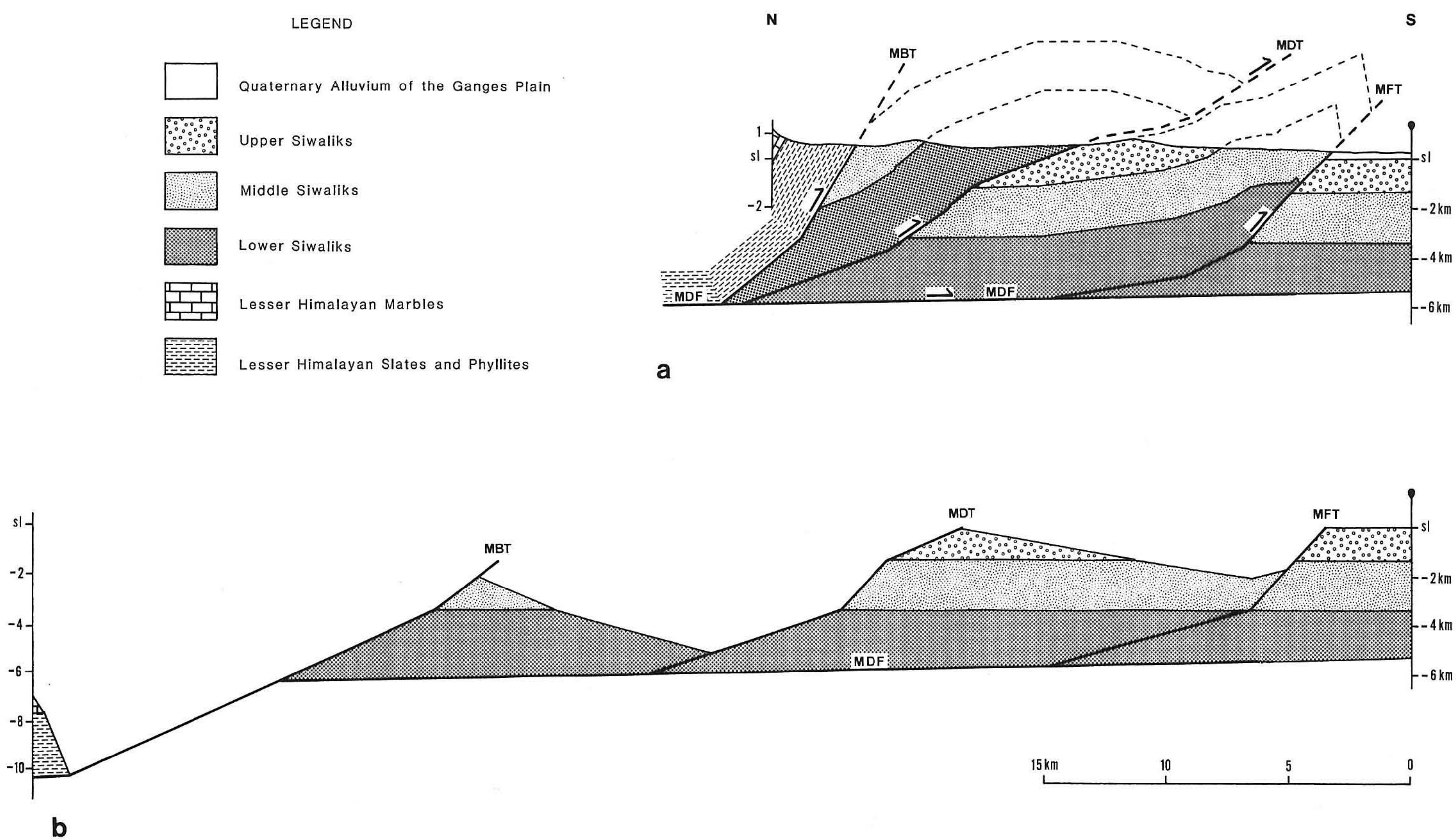
South of the MBT lies the Main Dun Thrust (MDT) which cuts the erosion surface south of Hitauda on the north flanks of the southern Churia Hills (Text-figs. 2 and 3). The MDT can be traced eastwards along the Rapti River to the Chaura-Marin Thrust of the Bagmati River and Marin Khola regions (Schelling, submitted), and westwards along the Rapti River towards Narayangarh and the Gandaki River. The MDT trends roughly N80°W, with local variations, in the Rapti River region. At the surface, along the Hitauda-Amlekhganj section, the MDT contains Lower Siwalik mudstones in its hangingwall and Upper Siwalik conglomerates in its footwall (Text-figs. 2 and 3). The Upper Siwalik conglomerates, well exposed at the Churia Pass S of Hitauda along the Hitauda-Amlekhganj road, form the main ridge of the Churia Hills that lie between the Chitwan Dun and the Rapti River to the north and the Ganges Plain to the south.

At the topographic front of the Sub-Himalayan Siwalik Hills lies the Main Frontal Thrust (MFT) (Text-figs. 2 and 3). The MFT has thrust Middle Siwalik sandstones over the recent alluvial sediments of the Ganges Plain in the Amlekhganj region. A tight, asymmetric and southvergent, hangingwall-anticline is exposed in the Middle Siwalik sediments just north of the MFT (Text-figs. 2 and 3).

Balanced Cross-Section

The balanced cross-section in Text-fig. 3 shows the probable structural geometry of the Sub-Himalayan Siwalik Hills in the Hitauda-Amlekhganj region. The section has been drawn perpendicular to the strikes of bedding and the trends of emergent thrust faults in the study area, and perpendicular to the general structural trend of the central Nepal Himalaya, and thus the line of section approximates the direction of shortening across the central Nepal Sub-Himalaya.

In the Hitauda region the Siwalik Group is approximately 6 km thick. However, 40 km south of Amlekhganj, in the vicinity of Raxaul, the Siwalik Group is only 4 km thick (Rao, 1973; Sastri *et al.*, 1971; Yoshida and Arita, 1982). Thus the Siwalik Group displays a southward thinning wedge geometry in central Nepal. Using the Siwalik sediment thickness of 6 km north of Hitauda and 4 km at Raxaul, after section-restoration (Text-fig. 3b) southward thinning of the Siwalik sediments is seen to be about 1 km per 40 km horizontal distance. The base of the Lower Siwalik sediments, and the unconformity which separates the Siwalik sedi-



Text-fig. 3 Balanced geologic cross-section (3a) and restored cross-section (3b) across the Hitauda-Amlekhganj region of the central Nepal Siwalik Hills. Line of section shown in Text-fig. 2. Note that the MBT in the restored-section has been drawn to show only minimum stratigraphic displacement and thus minimum horizontal shortening; the lack of corresponding footwall and hangingwall fault bedding cut-off lines prevents the precise determination of stratigraphic separation and shortening along the MBT. MBT=Main Boundary Thrust; MDT=Main Dun Thrust; MFT=Main Frontal Thrust; MDF=Main Detachment Fault. No vertical exageration.

ments from the underlying sub-Siwalik (Lesser Himalayan?) sediments, thus, has an average dip of 1.5° to the N (arctan $(1/40)=1.43°$) as shown in the balanced and restored cross-sections (Text-fig. 3).

The MFT in the Amlekhganj region is believed to originate within or at the base of the Lower Siwalik sediments for two reasons. First, the MFT contains exposed Lower Siwaliks in its hangingwall to both the east, along the Bagmati River (Schelling, submitted) and to the west in the Butwal region (Herail *et al.*, 1986), showing that, at least locally in central Nepal, the MFT does originate within the Lower Siwalik sediments. Second, the absence of an exposed fault-bend anticline within the Main Dun Thrust sheet suggests that the MFT branches off of the MDT within the Lower Siwalik sediments; if the MFT branched off of the MDT within or at the base of the Middle Siwalik sediments a fault-bend anticline would be seen north of the MDT.

The geometry of the MFT hangingwall-anticline suggests that near the surface the MFT dips to the north at about 45°. South of Amlekhganj, in the vicinity of Raxaul, the Siwalik sediments are flat-lying or dipping slightly northwards (Rao, 1973) and thus the MFT fault-bedding cut-off angle may be close to 45° near the surface, though it is possible that blind thrusting within the Siwalik sediments south of the MFT has resulted in north-dipping Siwalik sediments in the MFT footwall and that the fault-bedding cut-off angle is less that 45°.

The gradual flattening of bedding-dips to the north within the Main Frontal Thrust sheet suggests that the MFT has an overall listric shape and that the MFT has approached the regional detachment fault, the Main Detachment Fault (MDF), under the surface exposure of the MDT (Text-fig. 3). The lack of any fault-bend anticlines within the Main Frontal Thrust sheet suggests that the MFT climbs directly to the surface from the MDF with no major intervening thrust flats. The tight, asymmetric, south-vergent hangingwall-anticline seen just to the north of the MFT is interpreted here as being a fault-propogation fold.

While bedding dips in the footwall of the Main Dun thrust (MDT) are sub-horizontal, bedding dips in the MDT hangingwall north of Hitauda are 35° or greater. Fault-bedding cut-off angles are generally 35° or less several kilometers below the syn-orogenic erosion surface (Elliot, 1980) and thus the fault-bedding cut-off angle between the MDT and the Middle Siwalik sediments is probably not significantly greater than 35°. Therefore, the MDT is believed to have a hanging-wall flat geometry. In addition, the extensive outcrop of Lower Siwalik sediments along the MDT in its hangingwall, along the entire length of the MDT in eastern and central Nepal (Itihara *et al.*, 1972; Herail *et al.*, 1986; Delcaillau *et al.*, 1987) suggests that the Lower Siwaliks are a lithic unit in which thrust flats form. The corresponding MDT footwall thrust-flat within or at the base of the Lower Siwalik sediments is believed to coincide with the MDF. The MDF is thus believed to lie at a depth of about 6 km (the thickness of the Siwalik Group in central Nepal) underneath the central Nepal Sub-Himalaya (Text-fig. 3). As with the MFT, bedding orientations within the Main Dun Thrust sheet north of Hitauda suggest that the MDT cuts directly up-section through the Siwalik sediments with no major intervening thrust-ramps.

Lesser Himalayan Metasediment bedding-foliation dips of about 60° in the hangingwall of the MBT suggest that the MBT dips 60° or more to the north at the surface. However, the MBT must flatten-out as it approaches the MDF at a depth of about 6 km (Text-fig. 3). The MBT-Middle Siwalik bedding cut-off angle is between 15° and 30°.

Restoration of the Hitauda-Amlekhganj section shows that the Sub-Himalaya, between the MBT and the MFT, has undergone approximately 17 km of north-south shortening, or about 40% shortening (Text-fig. 3). Thrusting along the MBT has accommodated a minimum of another 15 km of horizontal north-south shortening (Text-fig. 3).

After restoration of the Hitauda-Amlekhganj section the MBT is found to lie about 17 km north of its present location (Text-fig. 3) and therefore a footwall ramp along the MDF (=MBT) within the Lesser Himalayan Metasediments must lie a minimum of 20 km north of the present surface exposure of the MBT. The MDF is thus believed to remain at a depth of about 6 or 7 km beneath the Mahabharat Lekh, the E-W trending mountain range lying north of the Siwalik Hills.

Conclusion

A balanced cross-section constructed across the central Nepal Sub-Himalaya in the Hitauda-Amlekhganj region suggests the presence of an underlying basal detachment, the Main Detachment Fault (MDF), at a depth of about 6 km. The Main Boundary Thrust (MBT), the Main Dun Thrust (MDT) and the Main Frontal Thrust (MFT) are all emergent splay thrusts off of the Main Detachment Fault and cut up-section through the 5.5 km to 6 km thick section of Siwalik sediments to the surface without any major intervening thrust-flats. The central Nepal Sub-Himalaya thus displays an emergent imbricate-fan geometry. Total north-south shortening across the Amlekhganj-Hitauda section, south of the Main Boundary Thrust, is approximately 17 km, or 40%. The MBT has accommodated another 15 km or more of north-south shortening within the Himalayan Orogen.

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