J. Nat. Hist. Mus. Vol. 26, 2012, 15-28

THIN-SKINNED TECTONICS OF THE TANSEN-POKHARA SECTION, CENTRAL NEPAL HIMALAYA

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ABSTRACT

Geological field survey and structural analysis were carried out in the Tansen-Pokhara section of central Nepal in an attempt to unravel the thin-skinned tectonic geometry of the Lesser Himalaya. The Lesser Himalaya in the area forms a foreland-propagating duplex structure, each tectonic unit being a horse bounded by imbricate faults. The Upper Main Central Thrust and the Main Boundary Thrust are the roof and floor thrusts, respectively. The Bari Gad-Kali Gandaki Fault is an out-of-sequence fault. The Pindi Khola Fault is an antithetic back-thrust developed on the hangingwall of the Bari Gad-Kali Gandaki Fault, and the Kusma Fault is a splay-off of the Phalebas Thrust. Deformation of the Lesser Himalaya occurred in distinct three phases namely pre-Himalayan, Eohimalayan and Neohimalayan. The duplex structure was formed in the Neohimlayan stage in the period between Middle Miocene and Early Pleistocene.

Keywords: duplex, horse, lesser himalaya, Nepal.

INTRODUCTION

Geological structures and tectonic processes associated with the shortening and thickening of the crust or lithosphere is known as the thrust tectonics. Deformation and shortening of crust in the contractional regimes are mainly of two types; thin-skinned and thick-skinned (Hatcher 2007). Thin-skinned deformation refers to shortening that only involves the sedimentary cover. This style is typical of many fold-and-thrust belts developed in the foreland of a collisional zone. This is particularly the case where a good basal decollement exists such as salt or a zone of high pore fluid pressure. Thick-skinned deformation refers to shortening that involves basement rocks rather than just the overlying cover. This type of geometry is typically found in the hinterland of a collisional zone (Butler *et al.* 2004). The most commonly seen effect of thin-skinned tectonics is the superposition of older rocks on top of younger rocks, just the opposite from what is expected. The usual explanation is that the layers of older rocks were thrust parallel to the bedding planes over the top of the layers of younger rock, sometimes for hundreds of miles.

The Himalaya is the world's largest and youngest mountain belt formed in the compressional zone between the Indian and Eurasian Plate. Present Himalayan region was occupied by a large sea known as the Neo-Tethys in the Mesozoic-Tertiary (Paleogene). The northward drift of the Indian Plate in the Late Cretaceous and subduction of the ocean floor under the Eurasian Plate progressively narrowed the Neo-Tethys (Molnar and Tapponnier 1975, Patriat and Achahe 1984). The collision of the Indian and the Eurasian Plates around 55-50 Ma along the Indus-Tsangpo Suture Zone, and continuing convergence of the two continents throughout the Cenozoic resulted in the formation of the Himalaya along the leading edge of the Indian Plate (Le Fort 1996). The period after the collision was characterized by thin-skinned tectonic deformation along with crustal-scale thrusting and widespread nappe emplacement (Butler and Coward 1989).

Orogeny shifted progressively from suture zone in the north to the Main Frontal Thrust (MFT) in the south. About 1000 km of continental shortening has occurred in the northern Indian Continent since its collision with the Eurasian Continent (Allègre *et al.* 1984). Stacking of the thrust sheets and thickening of the continental crust caused in the uplift of the Himalaya.

The central Nepal Himalaya can be geologically divided into four tectonic zones namely the Tethys Himalaya, the Higher Himalaya, the Lesser Himalaya and the Sub-Himalaya from north to south, respectively. The Tethys Himalaya consists of about 10 km thick Cambrian to Eocene, shelf-sediments deposited on the northern margin of the Indian Continent (Bodenhausen and Egeler 1971, Bordet *et al.* 1971, Colchen *et al.* 1980, Gradstein *et al.* 1992). The Tethys Himalaya is separated from the Higher Himalaya by the South Tibetan Detachment System (STDS) (Burg *et al.* 1984, Burchfiel and Royden 1985). The Higher Himalaya is composed of about 10 km thick pelitic, psammitic and calcareous paragneisses, granitic orthogneisses and migmatities of amphibolite facies containing kyanite and sillimanite (Colchen *et al.* 1980, Arita 1983). The Higher Himalaya has overthrust the Lesser Himalaya along the Upper Main Central Thrust (Upper MCT) and form a nappe in the Kathmandu area (Stöcklin 1980). The Higher Himalayan rocks have been regarded to be the reactivated basement rocks of the Proterozoic Indian Shield (Gansser 1964).

The Lesser Himalaya is a fold-and-thrust belt comprising Late Precambrian-Early Paleozoic, low- and medium-grade metasedimentary rocks named as the Nawakot Complex (Hashimoto *et al.* 1973, Stöcklin 1980). The low-grade metasedimentary rocks are unconformably overlain by the Gondwana-type, marine as well as continental sediments in the southern part of the Lesser Himalaya named as the Tansen Group (Sakai 1983). The Lesser Himaaya can be divided into the inner (north) and outer (south) belts by the Bari Gad-Kali Gandaki Fault (BKF) (Arita *et al.* 1982, Sakai 1985). The outer belt is a parautochthonous unit overlain by the Palpa Klippe and is distributed mainly in the southern part along the MBT. The inner belt consists of the Thrust Sheet I (TS I) and Thrust Sheet II (TS II) divided by the Phalebas Thrust (PT) (Upreti *et al.* 1980). The northernmost part of the Lesser Himalaya is an intensely sheared and mylonitized MCT zone striking from east to west.

The Lesser Himalaya is followed in the south by the Sub-Himalaya or Siwaliks. The boundary between them is named as the Main Boundary Thrust (MBT). The Siwaliks comprises about 6 km thick fluvial sedimentary rocks such as inter-bedded conglomerates, sandstones and mudstones. They were deposited in the Himalayan foredeep basin between the Middle Miocene and early Pleistocene times (Tokuoka *et al.* 1986). The Main Frontal Fault (MFT) marks the frontal tectonic boundary of the Himalayan range with the Indo-Gangetic Plain.

In the present study geological mapping and structural analysis was carried out along the Tansen-Pokhara section. This paper presents the thin-skinned tectonic geometry and structural evolution of the area.

MATERIALS AND METHODS

This research was based mainly on the field study, and partly on the laboratory analysis of rock samples. The field work was carried out along the Butwal-Pokhara motor road section and Kali Gandaki River section of central Nepal. During the field work, lithological, stratigraphic and structural data were collected from the rock outcrops. Extensive geological traverses were taken along streams, foot trail, road and ridges. Attitudes of bedding, foliation, lineation etc. were measured at every outcrop. At first, geological map of the Tansen-Pokhara area was prepared at 1:50,000 by plotting all the data colleted in the field. The map shows the traces of thrusts, faults and fold axes.

The boundaries were extended to the east and west on the basis of field data provided by Prof. K. Arita, Hokkaido University, Japan. Data have been also taken from the geological map of Sakai (1985), Dihtal *et al.* (1998) and Paudel and Arita (1998). Thus a generalized tectonic map of central Nepal was prepared (Fig. 1A). A generalized cross-section of the area was prepared on the basis of the tectonic map and structural data gathered in the field (Fig. 1B). The depth to the decollement was estimated on the basis of seismic profiling data (Zhao *et al.* 1993) and fault plane solutions for the earthquakes (Molnar *et al.* 1973, Seeber and Armbruster 1981, Verma and Kumar 1987). A schematic 3D model for the duplex structure was prepared on the basis of the geological map and cross section (Fig. 2). Direction of thrust movements were also confirmed by the study of shear-sense indicators in the photomicrographs (Fig. 3). Finally, a model for the tectonic evolution of the area was prepared to show different stages of development of thrusts (Fig. 4).

RESULTS AND DISCUSSION

Major Thrusts and Faults

The Upper Main Central Thrust (Upper MCT), equivalent to the MCT of Le Fort (1975) and Pêcher (1975) and the MCT II of Arita *et al.* (1982), is one of the most prominent structural features observed all along the Himalayan range. It is equivalent to the Mahabharat Thrust in the Kathmandu area (Stöcklin 1980) where it places the Higher Himalaya over the Lesser Himalaya as nappe. The Upper MCT is known by the Vaikrita Thrust in the Indian Himalaya (Valdiya 1980). The Upper MCT is physiographically less expressed in the present study area. However, it is marked by abrupt lithological change, change in deformation style and sharp metamorphic discordance (Paudel and Arita 2002).

The Lower Main Central Thrust (Lower MCT) is one of the most controversial structures in central Nepal. The controversy arises from the fact that some geologist find it as a sharp and discordant structure (Hashimoto *et al.* 1973, Arita *et al.* 1982, Paudel and Dhital 1996) while the others do not recognize the thrust at all (Le Fort 1975, Colchen 1980). The present study shows the structurally discordant tectonic boundary. The Lower MCT is equivalent to the Lower Crystalline Nappe of Fuchs and Frank (1970) and Lumle Thrust of Paudel and Dhital (1996). It coincides with the Munsiari Thrust of Valdiya (1980).

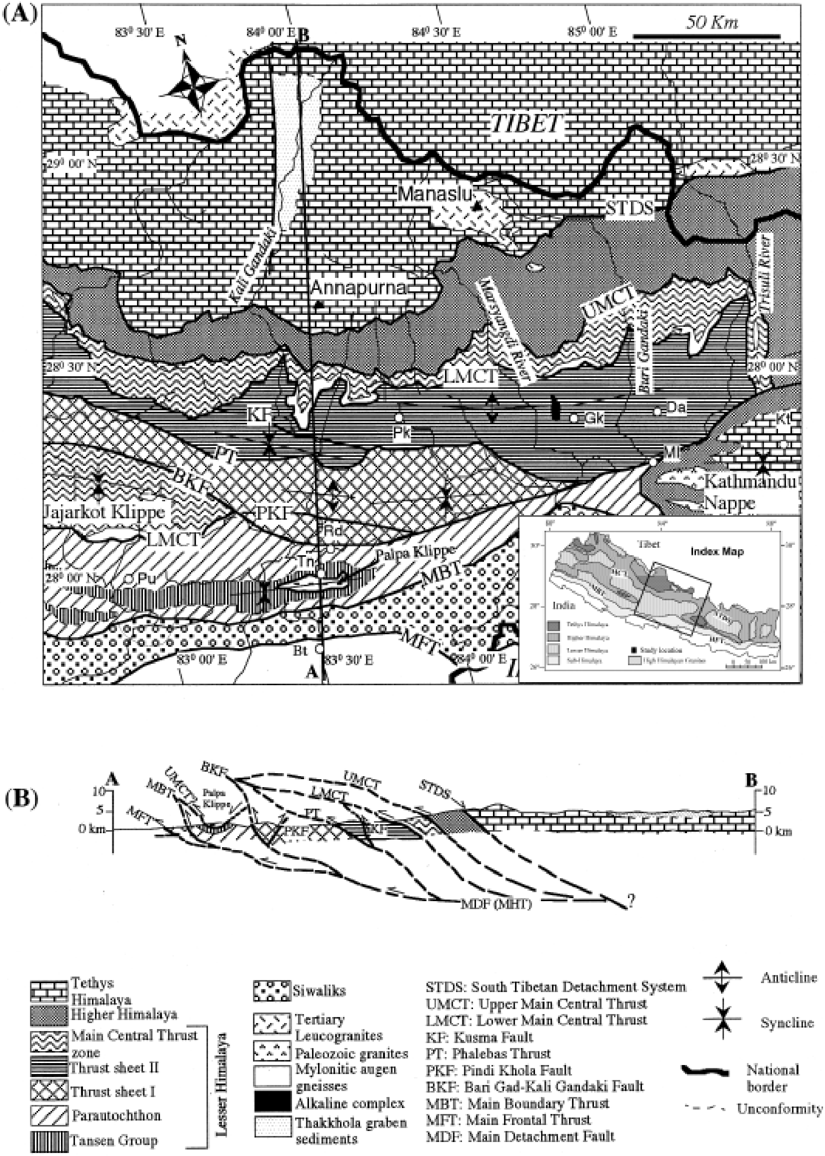

Fig. 1. Tectonic map (A) and geological cross-section (B) of central Nepal (modified from Paudel and Arita, 2000). Prolongation of the cross-section to depth is only speculative based on the assumption that all the faults join to the common decollement (MDF) located about 20-25 km depth from the present outcrop of the Upper MCT (Schelling and Arita 1991). Kt: Kathmandu, Da: Dhading, Ml: Malekhu, Gk: Gorkha, Pk: Pokhara, Rd: Ramdighat, Tn: Tansen, Bt: Butwal, Pu: Pyuthan.

The Kusma Fault (KF), equivalent to the Kusma Reverse Fault of Upreti *et al.* (1980), extends from Syangja to the west. It is very steep to vertical (70º to 90º) at the surface and makes a straight trace on the map. The Phalebas Thrust (PT), named after Upreti *et al.* (1980), is one of the well-recognized tectonic boundaries in central Nepal. The PT is a sharp and very discordant thrust fault in the area. The Pindi Khola Fault (PKF) is one of largest foreland-dipping thrusts recognized in the area. The beds in the hanging wall and footwall of the fault are parallel and always dipping steeply (30 to 50º) to the south.

The Bari Gad-Kali Gandaki Fault (BKF) is one of the most prominent and topographically well-expressed structural features of central Nepal. The BKF runs parallel to the Bari Gad Khola in the west and the Kali Gandaki valley in the central and eastern parts of the study area. Wherever the BKF passes across the ridges, it is expressed by a wide zone of topographic depression and active landslides. The BKF is clearly observed along the motor road north of Ramdighat. It is always steeply dipping (50-70º) to the north or vertical. It is believed to be one of the recently active faults in central Nepal (Nakata 1982, Kizaki 1994). The Palpa Klippe occurs as an isolated unit of older Nawakot Complex over the younger Tansen Group. It occupies the core of the Tansen Synclinorium.

The Main Boundary Thrust (MBT) is one of the well-recognized and less disputed intracrustal thrusts extending through the length of the Himalaya (Gansser 1964, Valdiya 1980). It is sharply defined both by geological and geomorphic features. It is expressed as a continuous topographic depression throughout central Nepal. It places the Late Precambrian-Early Paleozoic low-grade metamorphic rocks of the Lesser Himalaya on top of the Tertiary Siwalik sediments.

Thin-skinned Tectonic Geometry

The fold-and-thrust zone that lie along the margins of many orogenic belts constitute one of the most widely recognized and best understood deformation features of the Earth (Mc Clay and Price 1981). Although considerable variations exist among many fold-and-thrust belts, the following fundamental characteristics are common in all belts (Chapple 1978):

(i) a basal surface of detachment or decollement dipping towards the interior of the mountain, below which there is little deformation,

(ii) extensive compression and shortening in the material above the detachment, and

(iii) a characteristic wedge-shape of the deformed material tapering towards the margin of the mountain belt.

Seismic refraction profiling from the Tibetan side of the northern Nepal Himalaya shows a mid-crustal reflector at about 25-30 km depth and dipping very gently (~15º) to the north (Zhao *et al.* 1993). Most probably this is the basal decollement of the Himalayan fold-and-thrust belt named as the Main Himalayan Thrust (MHT). Schelling and Arita (1991), based on the balanced cross-section across the far-eastern Nepal Himalaya, have estimated 20-25 km depth for the decollement from the present outcrop of the Upper MCT called the Main Detachment Fault (MDF). Fault plane solutions for the earthquakes in the Himalayan region also suggest that the Lesser Himalaya is underlain by a shallow, north to northeast dipping thrust fault (Molnar *et al.* 1973, Seeber and Armbruster 1981, Verma and Kumar 1987). Based on the above observations, it is inferred that a basal decollement lies at about 20-25 km beneath the present outcrop of the Upper MCT in central Nepal (Fig. 1B and Fig. 2). Most of the major faults of central Nepal are splays-off of the MHT and thus join to the MHT at depth. The Lesser Himalayan wedge forms a foreland-propagating duplex structure bounded by the Upper MCT roof thrust and the MBT floor thrust.

The rocks of the Higher Himalaya with the overlying Tethys sediments occur as nappe and klippe over the Lesser Himalaya in various sections of the Nepal Himalaya (Hashimoto *et al.* 1973). In the Kathmandu area, the Higher Himalayan crystalline rocks almost reach to the Siwaliks (Fig. 1A). The foliation in the Higher Himalayan thrust sheet and the Lesser Himalayan autochthon are parallel everywhere, and both are deformed together to form large scale folds, e.g., the Mahabharat Synclinorium in the Kathmandu area (Stöcklin 1980) and the Arun Anticline and Tamor Khola Dome in eastern Nepal (Schelling and Arita 1991). It shows that the Upper MCT roof thrust was initially horizontal and later folded along with the underlying autochthon in the process of propagation of horses.

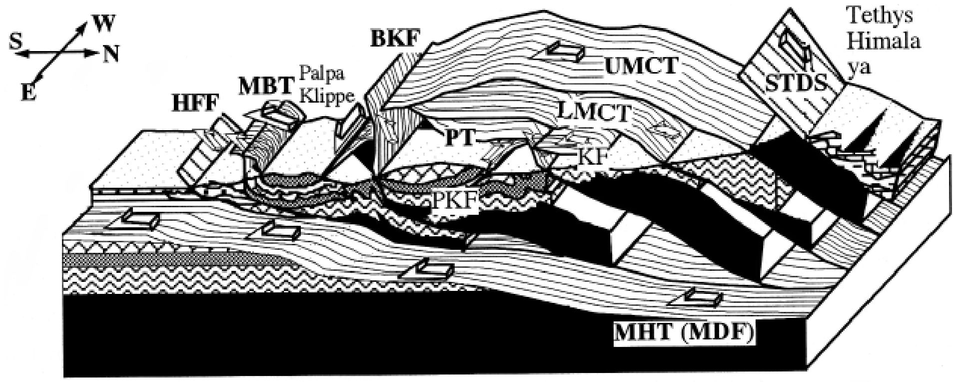

Fig. 2. Thin-skinned tectonic geometry of central Nepal. STDS: South Tibetan Detachment System, UMCT: Upper Main Central Thrust, LMCT: Lower Main Central Thrust, KF: Kusma Fault, PT: Phalebas Thrust, PKF: Pindi Khola Fault, MBT: Main Boundary Thrust, HFF: Himalayan Frontal Fault.

Despite widespread occurrence of the Higher Himalayan Crystalline nappes in other sections of the Nepal Himalaya, they are absent in the Tansen-Pokhara section. The crystalline rocks, indeed, may have been existed throughout the Lesser Himalaya in central Nepal, and the lateral continuity was destroyed by erosion (Kizaki 1994). However, in contrast to the other sections in the Nepal Himalaya, Nawakot Complex occurs as klippe (Palpa Klippe) over the Tansen Group rocks in the frontal part of the present study area. Its root zone has not been defined yet. I believe that the Palpa Klippe is the leading edge of the Upper MCT that brought a wedge of the Lesser Himalayan sequence.

The MCT zone, TS II, TS I and the Parautochthon are the horses of the southward-propagating duplex bounded by the imbricate faults, i.e., the Lower MCT, PT and the BKF. The PT and the Lower MCT are asymptotic to the Upper MCT. Southward propagation of the thrusts is confirmed by the preservation of textural features in rocks showing top-to-south movement (Fig. 3). Such a shear-sense indicators found in the rocks of the Lesser Himalaya include the sigmoidal porphyroclast with well-developed asymmetric pressure shadows, faulted quartz clast in metasandstone, muscovite fish, garnet porphyroblast with rotated inclusions biotite fish with asymmetric inclusions, asymmetric inclusion in actinolite porphyroblasts, oblique foliation defined by elongated quartz and shear bands of mica.

The Kusma Fault (KF) is a splay-off of the PT. The PKF, which is traced locally in the Syangja area, joins the BKF in the east and west. It is an antithetic back thrust developed on the hanging wall of the BKF. Thus the area between the PKF and PT must have been squeezed in a triangle zone while the area between the PKF and BKF must have uplifted as a pop-up block (Butler 1982). The BKF is steeper (50-70º) than the PT, and cuts through all of the overlying thrusts, i.e., the PT, Lower MCT and the Upper MCT (Fig. 2). It is thus an out-of-sequence fault.

The MBT joins to the leading edge of the Upper MCT, and serves as the floor thrust of the Lesser Himalayan duplex structure. It dips steeply to the north at the surface (about 70-80º) and is parallel to the bedding of both the hanging wall and the footwall. The MBT probably dips more gently at depth and joins the MHT in the north.

Sequence and Chronology of Thrusting

Although it is difficult to determine the exact timing of the development of each thrust and fault in the area, it is possible to estimate approximate timing of activity along major thrusts and the sequence of thrust development with the help of structural relations, geochronologic data and foreland sedimentary records.

The Upper MCT is the highest thrust fault in the thrust pile. It is the oldest thrust in the area because it has been folded and faulted by later thrusts and faults. Overthrusting of the Tansen Group (Early Miocnene and older age) by the Upper MCT indicates that this thrust reached to the southern part of the Lesser Himalaya later than the Early Miocene, probably in the Middle Miocene. But the Upper MCT may have been initiated earlier than this time in its root zone. The Dumri Formation (Early Miocene in age) contains clasts of phyllitic slates derived from the Himalayan terrain (Sakai 1985). It indicates that the uplift of the northern part of the area began at least in the Early Miocene. The uplift may be related to the ramping along the Upper MCT at depth. Assuming that the peak metamorphism in the MCT zone and the anatexis and leucogranite emplacement in the Higher Himalaya were the synchronous events associated with the Upper MCT movements (Le Fort 1975), an early Miocene age (about 22-15 Ma) has been assigned to the movement along the Upper MCT (Macfarlane 1993). Dextral shearing and north-directed detachment along the STDS was almost synchronous with Upper MCT (Guillot *et al.* 1994, Pêcher *et al.* 1991). The movement along the Upper MCT in the Lesser Himalayan nappe zones was terminated between 14 and 5 Ma due to the out-of-sequence thrusting in the Lesser Himalaya (Arita *et al.* 1997). However, there are many younger isotopic ages (8-3 Ma) from the northern root zone of the Upper MCT, implying either continuous movement at the root zone until the late Pliocene (Arita *et al.* 1997) or a late Miocene-Pliocene reactivation of the Upper MCT root zone (Copeland *et al.* 1991, Inger and Harris 1992, Macfarlane 1993, Edwards 1995, Harrison *et al.* 1997).

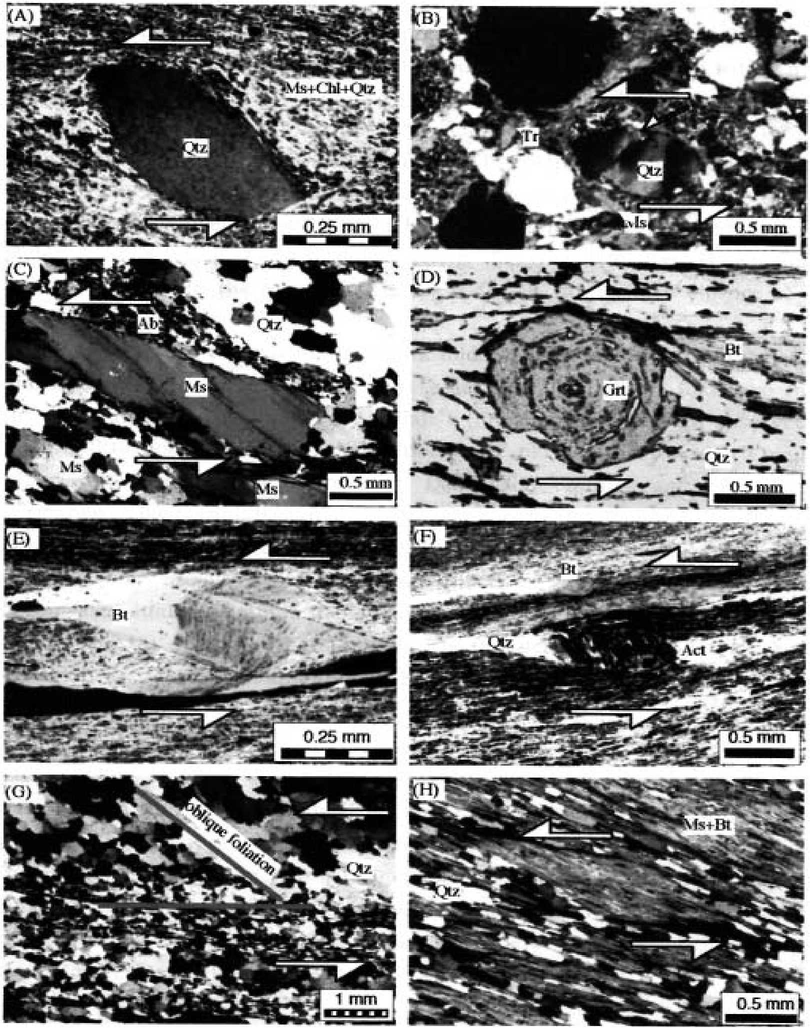

Fig. 3. Microscopic shear-sense indicators in the Lesser Himalaya. (A) Sigmoidal porphyroclast with well-developed asymmetric pressure shadows in a metasandstone from TS I. (B) Faulted quartz clast in metasandstone in the TS II. (C) Muscovite fish (MCT zone). (D) Garnet porphyroblast with rotated inclusions (MCT zone). (E) Biotite fish with asymmetric inclusions (MCT zone). (F) Asymmetric inclusion in actinolite porphyroblast (MCT zone). (G) Oblique foliation defined by elongated quartz (TS II). (H) Shear bands of mica (MCT zone). Qtz: Quartz, Ms: Muscovite, Chl: Chlorite, Tr: Trimolite, Ab: Albite, Grt: Garnet, Bt: Biotite, Act: Actinolite.

The Lower MCT, PT and the BKF propagated successively from north to south in a piggy-back fashion. Although there are no age constraints on the movement along the Lower MCT and PT, the timing of faulting along the BKF (equivalent to the Trishuli-Likhu Fault in Kathmandu area) has been constrained to be between 10-7.5 Ma (Arita *et al.* 1997). The BKF is an out-of-sequence fault, and truncates the overlying thrusts, i.e., the PT, Lower MCT, and the Upper MCT. Therefore, the Lower MCT and the PT must be older than Pliocene. The KF and PKF were probably formed during the time of movement along the MBT by the imbrication of the hanging walls of the PT and the BKF, respectively.

The MBT juxtaposes the Lesser Himalayan metasediment against the Siwaliks, which are about 14 to 1 Ma in age in central Nepal (Tokouka *et al.* 1986). It implies that the MBT reached over the Siwaliks later than the Lower Pleistocene. However, changes in the sedimentation patterns within the Siwaliks after 11 Ma indicates that initial motion along the MBT started in the Late Miocene (Burbank *et al.* 1996). The MFT places the Siwaliks over the recent Ganges sediments. It is the latest and structurally lowermost fault presently exposed in the area. The BKF, MBT and MFT are believed to be still active (Nakata 1982, Kizaki 1994).

Tectonic Evolution of the Central Nepal Himalaya

The tectonic events of the central Nepal Himalaya occurred in three distinct phases namely the pre-Himalayan (pre-Tertiary), Eohimalayan (Early Tertiary), and Neohimalayan (Late Tertiary to recent).

Pre-Himalayan (pre-Tertiary) Phase

The geological history of the central Nepal Himalaya began with the deposition of the Nawakot Complex on the northern margin of the Indian Continent in the late Precambrian (Fig.4A). Sedimentation of the Nawakot Complex ended in the early Paleozoic due to large-scale crustal disturbance, which Valdiya (1998) relates with the Pan-African diastrophism. The Nawakot Complex experienced first deformation event in the early Paleozoic. The first deformation is characterized by the bedding-parallel flattening due to load. It was followed by the west-vergent folding (Paudel and Arita 2000).

Eohimalayan (Early Tertiary) Phase

Sedimentation continued in the shallow sea in the northernmost part of the Indian Continenteal shelf from the Cambrian to Eocene, which are now known as the Tethys Sediments (Fig. 4B). Similarly, the Tansen Group sediments were deposited unconformably over the Nawakot Complex from the Upper Carboniferous to the Early Miocene. The Indian continent collided with the Asian continent in the Early Eocene (55-50 Ma) along the Indus-Tsangpo Suture Zone. The collision was followed by large-scale compression and resultant crustal thickening, which was, in turn, accompanied by pressure-temperature build-up at depth. Orogeny shifted from the suture zone to the south and a new intracurstal thrust, i.e., the Upper MCT, initiated in the south (Fig. 4B).

Neohimalayan (Late Tertiary to recent) Phase

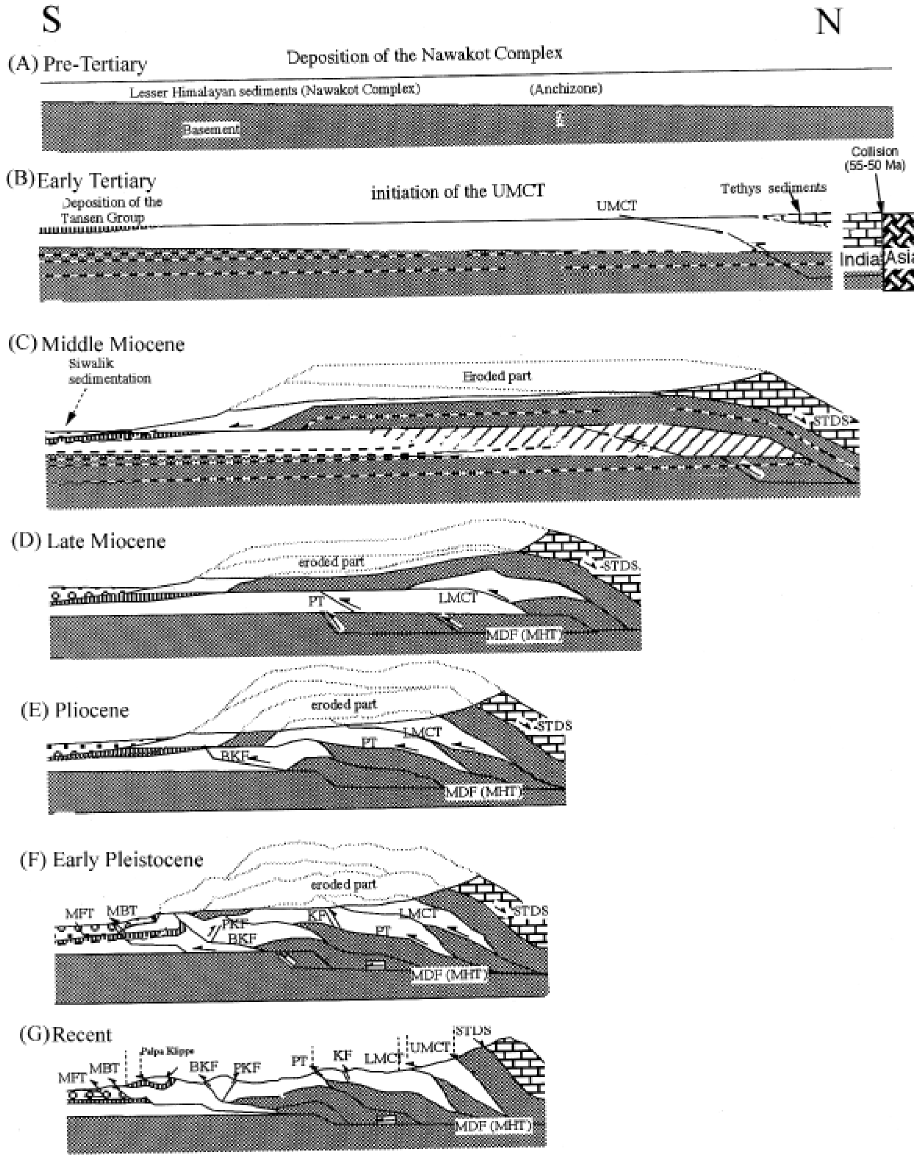

Fig. 4. Conceptual models (not in scale) showing the structural evolution of the Lesser Himalaya in central Nepal. STDS: South Tibetan Detachment System, UMCT: Upper Main Central Thrust, LMCT: Lower Main Central Thrust, KF: Kusma Fault, PT: Phalebas Thrust, PKF: Pindi Khola Fault, MBT: Main Boundary Thrust, HFT: Himalayan Frontal Thrust (Himalayan Frontal Fault).

The period after the initiation of the Upper MCT in the study area is the major phase of tectonism, inverted metamorphism, uplift and exhumation. The Indian upper crust has been continuously imbricated and accreted, and the lower crust has been underplated along the MHT since the collision. The basement rocks along with the overlying sediments were reactivated by the Upper MCT and transported over the Lesser Himalaya in the Early Miocene (Fig. 4C). The reactivated basement rocks finally evolved as the Higher Himalayan metamorphic core. As soon as the Upper MCT thrust sheet start to climb over the footwall ramp, the process of the Himalayan upheaval and erosion in the northern part and Siwalik sedimentation in the foreland basin started. The leading edge of the Upper MCT reached to the frontal part of the Lesser Himalaya only in the Middle Miocene. Most probably the leading edge of the Upper MCT brought a wedge of the Nawakot Complex over the Tansen Group, remnant of which is now known as the Palpa Klippe. North-vergent collapse of the Tethys sediments along the STDS was almost synchronous with the Upper MCT movement. Intense south-vergent bedding-parallel shearing occurred in the Lesser Himalaya due to the movement of the Higher Himalayan Thrust sheet along the Upper MCT.

The post-Upper MCT period was a time of imbrication, duplex formation, out-of-sequence thrusting, back-thrusting, folding, uplift, erosion and exhumation (Figs. 4D, E, F and G). Most of the major and minor folds of the Lesser Himalaya with WNW-ESE trending axes were formed in the process of thrust propagation. Brittle faulting and jointing occurred during the process of uplift and exhumation.

The present tectonic and metamorphic patterns of the central Nepal Himalaya (Fig. 4G) are the results of complex tectonic processes acting for a long period beginning in the Late Precambrian and still continuing in the present time.

The Himalaya is the world's largest and youngest mountain belt formed in the compressional zone between the Indian and Eurasian Plates. The Himalaya is characterized by the thin-skinned deformation that involves the detachment and imbrications of the sedimentary and metasedimentary cover. The Lesser Himalaya in central Nepal forms a foreland-propagating duplex structure, each tectonic unit being a horse bounded by imbricate faults. The detachment is thought to be at about 25 km from the outcrop of the Upper MCT. The Upper Main Central Thrust and the Main Boundary Thrust are the roof and floor thrusts, respectively. The Bari Gad-Kali Gandaki Fault is an out-of-sequence fault. The Pindi Khola Fault is an antithetic back-thrust developed on the hangingwall of the Bari Gad-Kali Gandaki Fault, and the Kusma Fault is a splay-off of the PT. Deformation of the Lesser Himalaya occurred in distinct three phases namely pre-Himalayan, Eohimalayan and Neohimalayan. Thin-skinned deformation and mountain building occurred in the Neohimalayan time.

ACKNOWLEDGEMENTS

I am grateful to Prof. K. Arita for providing data for the preparation of compiled tectonic map of central Nepal.

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