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THRUSTING AND OROGENESIS : THE HIMALAYAN FRONT IN CENTRAL NEPAL

Ramesh BASHYAL*, Bernard DELCAILLAU**, Gerard HERAIL**, Georges MASCLE***

ABSTRACT

In central Nepal, the Siwalik front represents the southernmost and younger thrust zone of the Himalayas. Here the detrital Mio-Pleistocene Siwalik Formations overthrust the Gangetic Quaternary. The morphostructural organization depends on lateral variations of the tectonic environment. Two main types are characterized. Escarped fronts (400 to 600 m. of relative altitude) coincide with steeply dipping structures, strong morphology resulting from a thrust ramp; immediately to the south the Terai alluvium are folded in relation with a blind thrust. The smoothed fronts (100 to 300 m) correspond to a flat lying thrust.

This regional example allows to propose a geodynamic evolutionary model for a foreland thrust front. During the flat thrust motion, thickening and erosion are balanced (smoothed front). In the following time, the southward propagation of the deformation with addition of new units, results in the formation of a frontal ramp which induces a steepening of the structures. The rate of uplift is not compensated by erosion (escarped front).

INTRODUCTION

The Himalayan Chain is characterized by two main thrusting zones. The Tibetan Slab comprising metamorphic series (gneiss, and migmatites) comes into contact with the Midland psammatic - pelitic sediments and metamorphosed carbonates in the Main Central Thrust (M.C.T.) Zone (Gansser 1964, Le Fort 1975, Pecher 1978, Brunel 1983). In the M.B.T. Zone, the Midland Series override the Siwalik Mio-Pleistocene detrital sediments (Gansser 1964) and the Himalayan Front corresponds to the morphostructural zones surrounding that area.

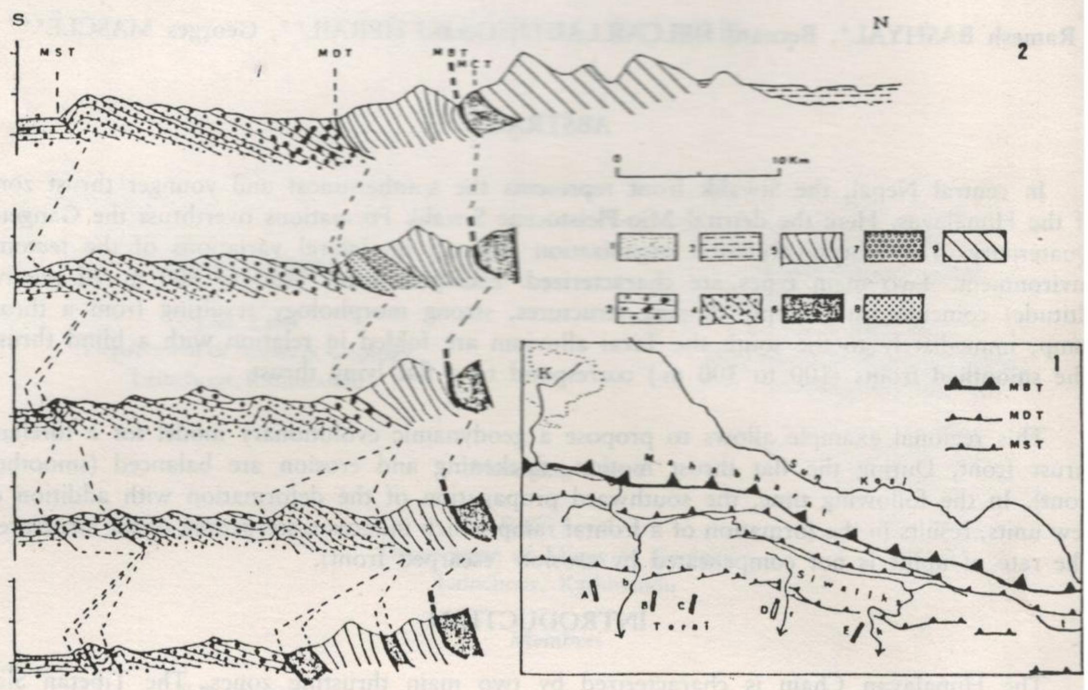
THE HIMALAYAN FRONT : GEOMORPHOLOGICAL ORGANIZATION

The Himalayan Front is a juxtaposition of several morphostructural units : the Terai Plain, Siwalik Hill, Mahabharat Range and Midland Hollow from south to north. These units spread from Pakistan to Assam but they are most clearly individualized in Central Nepal.

The Terai, northern fringe of the Indo-Gangetic Plain, is an area of alluvial accumulation gently sloping south; its slope is of about 0,-1% at the foot of the septentrional relief and is

* Dept. of Mines and Geology, Lainchour KATHMANDU, Nepal
** CIMA-UA 366 - CNRS, Institut de Geographie D. Faucher, 109 Bis rue Vauquelin - 31058 TOULOUSE Cedex, France.
*** Institut Dolomieu - Geologie Alpine (UA 69 CNRS), 15 rue Maurice Gignoux - 38031 GRENOBLE Cedex, France.
** et *** GRECO 130012 CNRS.

Fig. 1. Siwalik structure in Central Nepal.



1 - Map:
K : Kathmandu basin,
A, B, C, D, E : cross section location.
2 - Cross section :
1 : Pleistocene of Terai,
1 : Upper Siwaliks,
3 : Lacustrine sediments of Kathmandu basin,
4 : Middle Siwaliks,
5 : Lower Siwaliks,
6 : Murees,
7 : Dolerites,
8 : Midlands S
9 : Tibetan slab.

less than 0,-02% further south (Geddes 1960, Gole and Chitale 1966). It is a juxtaposition of very flat wide alluvial fans, cross-cut by wandering streams.

The Siwalik Hills are the most southern Himalayan reliefs. In Central Nepal, they are about 10 to 20 km wide, composed of a line of hogbacks parallel to the Himalayan Chain facing south. Their altitudes vary from 700 to 900 m in the south to 1200-1300 m in the north, at the foothills of the Mahabharat. These reliefs are separated by internal depressions, the Duns (about 300 m high).

The Mahabharat Range is the first significant relief which spreads from Kashmir to Assam In Nepal, its width reaches 20 to 25 km, and attends an altitude upto of 2500 m or more. A dense network of dendritic valleys, separated by sharp ridges, cut deeply into this region.

Between the Mahabharat Range in the south and the Great Himalayan Range in the north, spreads the Midland Hollow. It is a hilly area (1000-1500 m high), incorporated with basins (Kusma, and Pokhara, Arughat and Kathmandu) containing lacustrine, fluvial and fluvio-torrential sediments (Bose 1968, Dollfus and Usselman 1971, Hormann 1974, Fort et Freytet 1979, 1983, Fort 1982). Moreover, the main river from the Great Himalayan Range run down 120 km towards south parallel to the hollow axis.

STRUCTURAL ORGANIZATION

The Himalayan Front in Central Nepal consists of several superimposed thrusting slices.

The Himalayan Front Main Thrusts

The Main Boundary Thrust (M.B.T.) brings the Lesser Himalayan metasediments of the Mahabharat over the molassic series of the Siwalik. The Lesser Himalayan sediments consist of the Midland Series (schists, sandstones, limestones and quartzites) and of the metamorphic series of the Tibetan Slab. These two lito-stratigraphic sets are separated by the M.C.T. (Main Central Thrust) and the Mahabharat structures caught in the later thrusts (Brunel 1983).

South of the M.B.T., between the Terai Plain and the Mahabharat, several thrusts lay from north to south (Herail and Mascle 1980, 1982). The Lower Siwalik sediments (Upper Miocene) and Upper Siwalik conglomerates (Plio-Pleistocene) were brought together by the Main Dun Thrust (M.D.T.) in the north. Along this thrusting zone the substratum of the Siwalik series is sometimes brought to the surface. In the Marin Khola (Fig. I) the red and green sandstones assimilated to the Murees resting on dolerites constitute the base of thrusting compartment (Herail and Mascle 1980). In the Bainath Valley, Midland slices come to the surface locally along the M.D.T. and associated thrusts.

The Siwalik Front, overlooking the Terai corresponds to a thrusting zone, i.e., the Main Frontal Thrust (M.F.T.) which brought the Middle or Higher Siwalik Series (Mio-Pliocene) over the Terai (Upper Pleistocene and Holocene alluviums). This thrust is exposed clearly on the east of the Lakandai River of eastern Nepal bordering India.

From north to south, the formations affected by the thrusts are more and more recent (Fig. I).

The M.D.T. and M.F.T. are the major Intra-Siwalik Thrusting Zones. Locally these thrusts split and become limit for slices inside which smaller thrusts appear.

Fig.2.- Siwaliks series dipping.
A : between M.D.T. and M.B.T.
B : between M.S.T. and M.D.T.

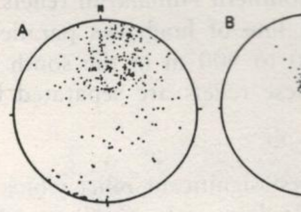


Fig.3.- Alluvial terrace disposition in the M.F.T. zone
Terraces are numbered 1-3 in order, of development ; 4 is the actual talweg.

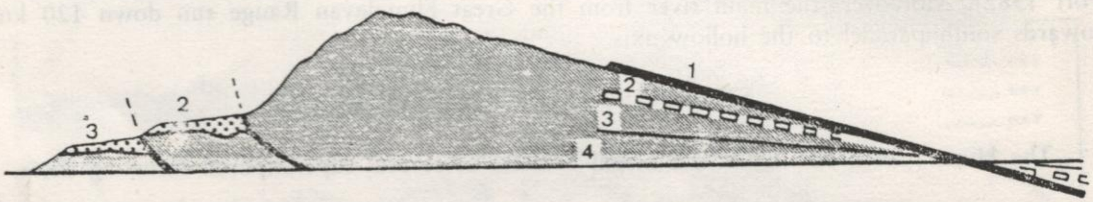
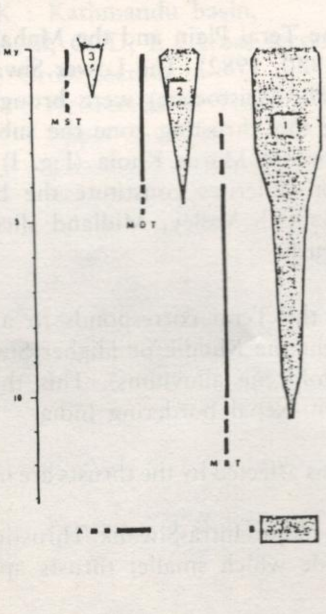


Fig.4.- Thrust and relief, development in the Central Nepal Himalayan Front.
A : Thrust, B: Relied, uplift.
1 : Mahabharat,
2 : North Siwalik hogback,
3 : South Siwalik hogback (Siwaliks Front),
4 : Kathmandu basin.



Deformation inside each thrusting set

On a small scale thrusting is realized by the appearance of duplex of metric width and a system of decimetric reverse throw fractures generally oriented N 110 to N 130; the dip of these fractures vary from 20 to 40. The fractures are associated with subvertical faults oriented N 010 to N 030. The measurements taken on striated planes and their treatment show a compression close to a horizontal line oriented N 010 to N 040.

On a bigger scale, a micro-deformation of sediments consisting of micro-faults in pebbles or quartz grains, can be observed; sometimes the open fractures were filled up with neoformation of calcite; neoformation of calcite is also crystallized in pressure shadow areas; blowed-up quartz and impinged phyllites are frequent. Undulating extinction and mosaic structures exhibited by quartz crystals do not seem to be all inherited structures but may result from recent deformations because their frequency increases at the same time as the frequency of other micro and small structures. Similar micro-deformations have been known since Middlemiss (1890) in Kumaon and have been described (Herail and Mascle 1982, Powell, 1982).

Decrease in deformation intensity from the M.B.T. to the M.F.T.

This phenomenon is shown by a decrease in the density of fractures and in their "penetrativity". In the pelite banks, a slight dragging schistosity can only be observed very close to the M.B.T.

The decrease in deformation intensity is shown by a decrease in the amount of stratum dips from north to south. At the M.B.T. the average dip is superior to that measured between the M.D.T. and the M.F.T. (Fig. 2).

This evolution in deformation intensity has also been recorded by organic matters preserved in the sediments. The coals with a reflecting power between 0,75 and 1,05% (maximum 0,85%) at the M.B.T. are followed by tender lignites and peat/lignites with very low reflecting power (between 0,25 to 0,45%) towards the M.F.T.

Thrusting associated with strike slip fault movements

At the vicinity of the main thrusts, slanted conical folds and strike slip faluts can be observed. A study of these movements shows a senistral interplay suggesting that there was an eastward displacement of the compartment starting from the Terai Plain. The role played by these movements associated to the north-south compression in the morphology is obvious, and accounts for the indented shape of the main thrust fronts (M.F.T.) and the triangle and lozenge shapes of the duns.

OVERLAPPING DYNAMICS AND APPEARANCE OF THE RELIEFS

Siwalik sediments and their morphotectonic meaning

The sediments composing the Siwalik Series in Nepal can be divided, like in India, into 3 different sets : Lower Siwalik, Middle Siwalik and Upper Siwalik.

The age of these sediments varies from Middle Miocene to Lower to Middle Pleistocene. Fauna known only in the Lower Siwalik have been found in the sediments north of the M.D.T.

in the studied region (Herail and Mascle, 1982; Beden and et al., 1984) and near Butwal (Munthe and et al., 1983). In the Dang Valley, a fauna comparable to that contained in the Pinjor Formation has been found in the sediments attributed to the Upper Siwalik, its age ranging from 2.9 to 1.5 MY (West and Munthe, 1981). On the Himalayan foothills, the Lower Siwalik deposition ended about 10 MY ago, and that of the Middle Siwalik about 5 MY (Johnson and et al., 1982).

The Lower Siwalik outcrops in the north between the M.B.T. and the M.D.T. Besides sandstone sediments the lateral variations in facies comprising conglomeratic beds, silty clay deposits from flood plains and carbonated plaeosoils are important. The conglomeratic banks correspond to well imbricated pebble conglomerates, their petrographic spectrum is characterized by a predominance of elements issued from the erosion of the Midland Series - Gneiss and granite pebbles of Tibetan Slab are extremely rare. The sandstone banks, the most common facies, correspond to fluviatile channels and bars. The sedimentary structures showing a marked sinuosity are rare. These sandstones are made up of quartz, few feldspar and slightly metamorphozed rock fragments. In association with heavy minerals muscovite, garnet, tourmaline, rutile and zircon are found whereas high metamorphic minerals (kyanite and sillimanite) are rare, and are found only as traces in a few samples.

All these facts show that the Lower Siwalik come from the erosion of Midland Series which has wide distribution in Central Nepal between the M.B.T. and the M.C.T.

The Middle Siwalik appears to the south of the M.D.T. Conglomerates are very rare and their pebbles very small (centile: 5-8 cm); whereas sandstones, silts and clays, and carbonated paleosoils are mostly found. The lateral accretion figures reveal the presence of meandering streams, as well as the facies of marshy flood plains. Sandstones are made up of rock fragments, quartz, high proportion of feldspar, and mica. The pebbles and grains of gneiss and granite fragments, are abundant. Apart from the above mentioned species, sillimanite, kyanite and staurolite are present. Thus at the time of the Middle Siwalik deposition, materials resulting from the outcrop erosion reaches the high metamorphism terrains of the M.C.T. Zone (Tibetan Slab).

The Upper Siwalik outcrops south of the M.D.T. and are composed of sands and conglomerates. The sands are found at the base of the Series whereas the conglomerates become more and more abundant and coarser towards the top. This change of facies is associated with a modification in sedimentation regime marked by the change from meandering to torrential braided flows on the alluvial fans. At the end of the accumulation of these materials, the fan apex was situated at the foot of the Dun Thrust Front. The mineralogic and petrographic composition of the Upper Siwalik shows similarity with the Middle Siwalik. Also sediments eroded on the reliefs carved in the Lower Siwalik are present (Herail and Mascle, 1982). Locally, at the top of the Series, near the M.D.T., these elements are very abundant.

The evolution of mineralogic and sedimentologic characteristics of the Siwalik Series shows that the thrusts and consequent reliefs appeared successively from north to south. The M.B.T. appeared first, then the M.D.T. and finally the M.F.T. The M.B.T. and contemporary thrusts in the Mahabharat Range were mainly active at the end of the Lower Siwalik depositional and during the Middle Siwalik depositional period. Its activity slowed down when a more southern thrust, the M.D.T. took place, its movement was mainly noticeable during and after the Upper Siwalik deposition. More recently (less than 1 MY) a more southern (third) thrust zone appeared : the M.F.T. Geophysical observations show that, under the Terai Plain, thrusts which do not yet affect the surface are developing.

Relief linked to thrusts appeared from north to south too but with a certain delay. Thus the Mahabharat Range only became an important relief about 2,9 to 1,5 MY ago as can be deduced from the age of part of the lacustrine sediments contained in the Kathmandu Basin (West and Munthe, 1981). Upto that period, the uplift speed of Mahabharat Range was of a similar order to that of the entrenchment of the waterstreams, which enabled the drainage towards the pidemont. There was an acceleration of the uplift (about 2,9 MY ago) when the M.D.T. was already active. The Siwalik northern hogback appeared after the Mahabharat Range and had its actual position soon after the end of the Upper Siwalik depositional period. Nevertheless, at the time of the hogback uplift, the M.F.T. was already active as can be seen from the analysis of the directions of the water flows carrying Upper Siwalik sediments.

Post-Siwalik sediments, their deformation and their morphotectonic meaning

Alluvium posterior to the Siwalik Formations include the alluvial covers of the terraces, the filling of the Duns and the Terai alluvial fans. They correspond to a phase when dissection was predominant in the Siwaliks and when the accumulation zone of the erosional products of relief stratum was departed further south.

The arrangement of these materials enables a characterization of most recent periods of the evolution of thrusts near the topographic surface. The alluvial terraces situated at the foot of the M.F.T. front overlap and sometimes folded. On the contrary, on the back slope of the thrust, the alluvial terraces were tilted towards the Dun, the older terraces having a steeper slope than the more recent ones (Fig. 3). This design shows that the relief associated to the M.F.T. was due to the still active thrust of a slice of terrain moving southward towards syntectonic fluviatile alluvium of the Terai. As a consequence of this displacement, a relief appeared, and as the overlapping process developed, the slices lifted up and their dip increased. The relief associated to the front of the thrust heightens whereas the Duns drop. This morphostructural evolution of the M.F.T. and that of the associated reliefs affected the M.D.T. Zone also.

Ahead of the M.D.T., at the foot of the Thrust Front, overlapping terraces have not been observed, but numerous proofs of subsidence of Duns can be noted, and post-Siwalik sediments were frequently affected by conjugate normal faults heavily slanted when compared to the M.D.T. These faults play a direct morphological role which accounts for the endentment of the Hetauda, Kamala-Tawa and Trijuga Duns in the northern borders. Along the M.D.T., the subsidence zones, where these faults are numer ous, are separated by rapid uplift zone as can be proved by alluvial terrace strips dissected and carried several hundred metres higher than their equivalent which were kept in the Duns. This morphostructural evolution is interpreted as a result of transverse movements parallel to the direction of the thrust front. From the fact that these structures are nearest around the M.D.T., and that they affect recent sediments (alluvial terraces), we can presume that the strike-slip faults played their part later than overlapping. They palyed a direct morphological role, provoking the lozenge shaped opening of some Duns.

CONCLUSION

The orogenic and structural evolution of the southern part of the Himalayan Front, Mahabharat and Siwalik (Fig. 4) are characterized by the successive appearance of the thrusts and reliefs more and more recent from north to south (Herail and Mascle 1982). The development of this phenomenon, which lasted for tens of millions of years is comparable to an accretion prism (Mascle and Herail 1982). The disposition of the structures, from the M.B.T. to the M.F.T., can be assimilated to a piggy back thrust sequence (Dahlstrom, 1970; Butler 1982). As the thrusting process developed the structures, only slightly slanded at first, lifted up, and the overlapping zone was affected by transverse movements. The reliefs, consequence of the overlapping, appeared later; thus it does seem that Mahabharat was more uplifted when the M.D.T. was active than when the M.B.T. was the only active accidental feature; the Nepal Midland Depression (Kathmandu Basin) was hollowed during that period too. The transverse movements associated with Intra-Siwalik thrust caused a morphological change of the Duns, and the appearance of high zones separating those depressions. The morphostructural evolution of the Himalayan Front is linked to the development of a similar structural mechanism, the characteristics of which changed during the deformation sequence.

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