Special Publication of the Palaeontological Society of India, No.2, 2005, pp. 65-71

# DEFORMATIONAL PATTERN OF THE SIWALIK SEQUENCE IN THE GAULA RIVER AND NIHAL NADI SECTIONS, KUMAUN HIMALAYA, UTTARANCHAL

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## ABSTRACT

The Neogene Siwalik sequence constitutes the outermost part of the Himalayan mountain chain and represents foreland basin sedimentation. The Siwalik succession is dominantly constituted of sandstone, mudstone, and thin to thick bands of conglomerate horizons. Deformational pattern of these rocks has been studied in the Gaula River and Nihal Nadi sections of Kumaun Himalaya, Uttaranchal. The study reveals that the HFF (Himalayan Frontal fault) seems to be an emergent thrust in the Gaula river section near Kathgodam and the Lower Siwalik rocks in the immediate vicinity show evidence of strong deformation. The surface expression of this major tectonic plane in the area is exhibited by the sharp rise of Siwalik rocks against the Gangetic plain. These rocks in the Nihal *nadi* section are disposed in the form of tens of metres thick horses arranged in an en-echelon series of steep reverse faults. The thrust slices represent the splays/ branches of the sole thrust, which seems to be responsible for detaching the Lower Siwalik rocks in these sections. Small-scale duplex and cleavage refraction are characteristic deformational features present in the hanging wall of the HFF. The present study suggests that the rocks of the Siwalik succession have also undergone layer parallel shortening by producing a variety of deformational features.

**Key words:** Deformation, Siwalik sequence, Kumaun Himalaya, Uttaranchal.

## INTRODUCTION

The evolution of the Siwalik Foreland Basin - a Miocene fill - has been controlled by the orogenic processes in the Himalaya. The northward movement and collision of the Indian plate with the Eurasian plate resulted in large-scale thrusting in the Himalaya (Beaumont, 1981; Leon-Cean and Molnar, 1985; Sinclair *et al.*, 1991). As a result of large-scale thrust sheet loading in the Himalayan region there was down-buckling of the proximal part of the Indian craton, thus creating a deep, but narrow foreland basin. In this narrow and deep, deposition of Murree and Dharamshala sediments and their equivalents took place during the early Miocene times. It is believed that by Middle Miocene, a full-grown foreland basin had developed in which sedimentation of Siwaliks commenced (Beaumont, 1981; Leon-Cean and Molnar, 1985; Sinclair *et al.*, 1991; Dikinson, 1974). Huge sediment loads shed from the newly formed orogen were carried by the Himalayan Rivers, and deposited in the foreland basin forming a 7-8 km thick sequence.

The Siwalik Supergroup is exposed all along the Himalayan foothills forming a continuous belt in the Outer Himalaya. Divided into Lower, Middle and Upper Siwalik (Pilgrim, 1913), and representing the history of 19-20 Ma (Johnson *et al.*, 1985), the Siwalik sequence is characterized by highly differentiated lithology comprising thick sandstone-mudstone couplets, siltstone and conglomerate in the Upper Parts. In the recent years, magnetic polarity dates from the Siwalik succession have provided temporal controls and a refined stratigraphic framework for the Siwalik Supergroup (Johnson *et al.*, 1982; Tauxe and Opdyke, 1982; Tandon *et al.*, 1984; Ranga Rao *et al.*, 1988; Kotlia *et al.*, 2001). The sedimentary prism of Siwalik foreland basin represents alluvial sedimentation without any trace of marine incursions (Willis, 1993; Zaleha, 1997; Sharma *et al.*, 2002; Shukla and Bora, 2003; Bora and Shukla, 2004).

## GEOLOGICAL SETTING

In the present study, two sections of Lower and Middle Siwalik succession exposed between Kathgodam and Ranibagh along Gaula River, and Nihal *Nadi*, have been measured for lithological and structural details. Small to large-scale structural features have been mapped and documented in the field. The study may help to understand the deformational pattern with respect to major thrusts/faults dissecting the sedimentary pile. This may also throw light on the evolution of Siwalik Foreland basin, and its relation to Himalayan orogeny since the Miocene times.

The Lesser Himalayan rocks are thrusted over the fluvial succession of Siwalik rocks along the Main Boundary Fault (MBF, fig. 1). The Siwalik rocks in turn are thrust over the Piedmont zone, the northern most geomorphic element of the Gangetic plain, along Himalayan Frontal Fault (HFF, Nakata, 1972).

The Main Boundary Fault separating the Lesser Himalayan sequences from the Siwalik

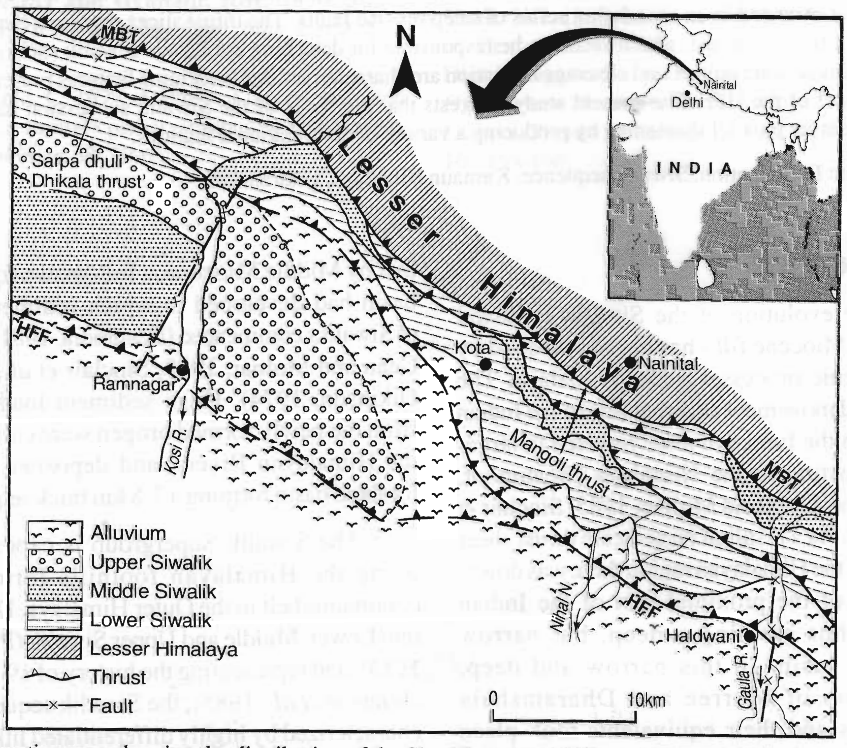


Fig: 1. Location map showing the distribution of the Siwalik rocks and the major tectonic planes in the study area. (redrawn after Karunakaran and Ranga Rao, 1976) rocks is a broad zone with a series of sympathetic reverse faults, defined by extensive gauge zones, uplifted fluvial terraces and landslide debris cones, and in many places by E-W trending narrow valleys (Valdiya, 1988). In the Kumaun Himalaya, the MBF has registered rotational as well as strike-slip movements in the Holocene time (Valdiya, 1992). The NW-SE trending, south vergent HFF is exposed in the form of en-echelon pattern and a series of reverse faults, which are now concealed under the gravely fans of the piedmont belt (Nakata, 1972). It shows a convergence rate of 10-15 mm/yr (Yeats *et al.*, 1992) and forms the main displacement zone between the stable Indian plate and the Himalaya in present-day tectonics. The surface expression of this major tectonic plane in the area is exhibited by the abrupt rise of Siwalik rocks against the Gangetic plain, and gentle (6-9°) northward tilting of Upper–and post Upper Siwalik gravels forming the 'duns' (Kota Dun).

The narrow belt of Siwalik sediments bounded on either side by major tectonic planes is characterised by faults running parallel to axial planes of folds and intrabasinal thrusts (Valdiya, 1992). In the sections studied, starting from south, the Lower Siwalik rocks grade into the Middle Siwalik succession, which in turn are overlain again by the Lower Siwalik rocks and are bounded by a major intrabasinal Mangoli thrust (Valdiya, 1992; Karunakaran and Ranga Rao, 1976) trending roughly E-W. At the contact with the bounding thrust planes, the Siwalik rocks have dips of 70-90° and are highly sheared and shattered. They often show small to large-scale folds, shear planes, slickenside striations produced due to frictional wear and ramp-flat structures. Another set of structural features offsetting the Siwalik rocks almost in N-S direction are NNE-SSW and NW-SE trending conjugate system of strike-slip faults. As evidenced by displacement of Siwalik rocks, alignment of river channels, development of unpaired terraces and entrenchment of drainage within the Siwalik belt, it seems that the terrain is tectonically active (Shukla and Bora, 2003). The neotectonic activities operative along the active faults traversing the Siwalik succession may have also influenced the structural evolution of the Siwalik rocks through the Quaternary times.

## DEFORMATIONAL FEATURES

Along Nihal Nadi (river), which flows to the south and cuts across the Siwalik terrain, mainly Lower Siwalik rocks are exposed in patches forming discrete hillocks. The hillocks are aligned in a row trending almost N-S. About 138 m composite thickness of Lower Siwalik succession has been measured (Bora, 2003), and lithological and structural aspects have been documented. Lithologically, the sequence is highly diversified comprising fine to medium-grained, greenish-grey, compact and small to large-scale cross-bedded sandstone, massive carbonaceous mudstone, grey-brown, laminated silty mudstone and ripple cross-laminated, yellowish buff siltstone, interbedded to form an overall fining upward Lower Siwalik succession. The grain size and thickness of sand bodies decrease upwards (fig. 2). The most common deformational feature of this section is the *ramp and flat* structure. These are sections where the rock sequences cut across the stratigraphically upper (younger) horizons and climb up along relatively gently dipping ramps and for few metres and then merge together. The other common type of structure within the Siwalik rocks is *duplexes* of varying dimensions (few cm to few metres) in the internal domain. In its most general form, these structures occur as wedge between two parallel thrusts (the roof and floor thrusts). The intervening thrusts commonly occur in imbricate fashion and are known as horses (Boyer and Elliot, 1982; Mitra and Boyer, 1986). The individual horses commonly occur as planar to curviplanar units (fig. 3A, 3B). The beds above and below the duplex are more or

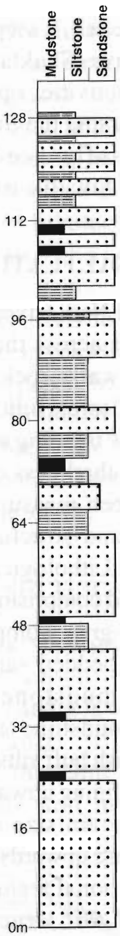


Fig. 2. Litholog showing major facies developed in Lower Siwaliks as exposed along Nihal *nadi* section, Nainital. (after Bora, 2003).

less undisturbed. The duplex structures represent a mechanism for slip transfer from one glide horizon at depth to another at shallower levels (Boyer and Elliot, 1982). The creation of new horses causes added movement along the thrust planes thus resulting into structural thickening.

About 900-1000 m thick Lower Siwalik succession is developed along the Gaula River. The Lower Siwalik succession shows coarsening upward character, and is succeeded by the Middle Siwaliks with a gradational contact. At the lower levels in the sequence, sand bodies alternating with the greyish-black fine-grained horizons are 5-8 m thick. Progressively up in the section, sand body thickness increases (10-20 m thick), and become fine to medium-grained and show domination of large-scale planar and trough cross bedding. Interbedded silt-mud horizons become up to 40 m thick, and show purple –maroon colours, high degree of mottling and calcretization. The Himalayan Frontal Fault is an emergent thrust and is exposed at Kathgodam. The Lower Siwalik rocks here are thrust over the piedmont zone (of Gangetic Plain), and show various types of structural features. Highly fractured and shattered grey siltstones of Lower Siwaliks are exposed near the HFF at the Gola Bridge (fig. 3C, 3D).

## DISCUSSION AND CONCLUSIONS

The Siwalik sedimentation took place in an initially narrow but deep foreland basin, bounded by an emergent Boundary fault (MBF) in the north. It appears from the above that the Siwalik sediments have undergone relatively intense deformation that is certainly not related to the earlier deformational episodes causing the upliftment and evolution of the Himalayan fold thrust belt. One may argue about the presence of above-mentioned deformational features in the Siwalik rocks of the study area, which post-date the main orogenic phases. On the basis of our study, the HFF appears to be mainly an emergent thrust in the study area, whereas it is non-emergent (buried) thrust at most of the other places. The sequence exposed near the Nihal nadi section, where tens to hundreds of metres thrust bounded Lower Siwalik rock slices are exposed may also signify the presence of HFF-related splays (fig. 4). It is therefore quite possible that the Siwalik strata showing duplex structures have undergone structural thickening. The similar observations have also been reported in the Mohand section

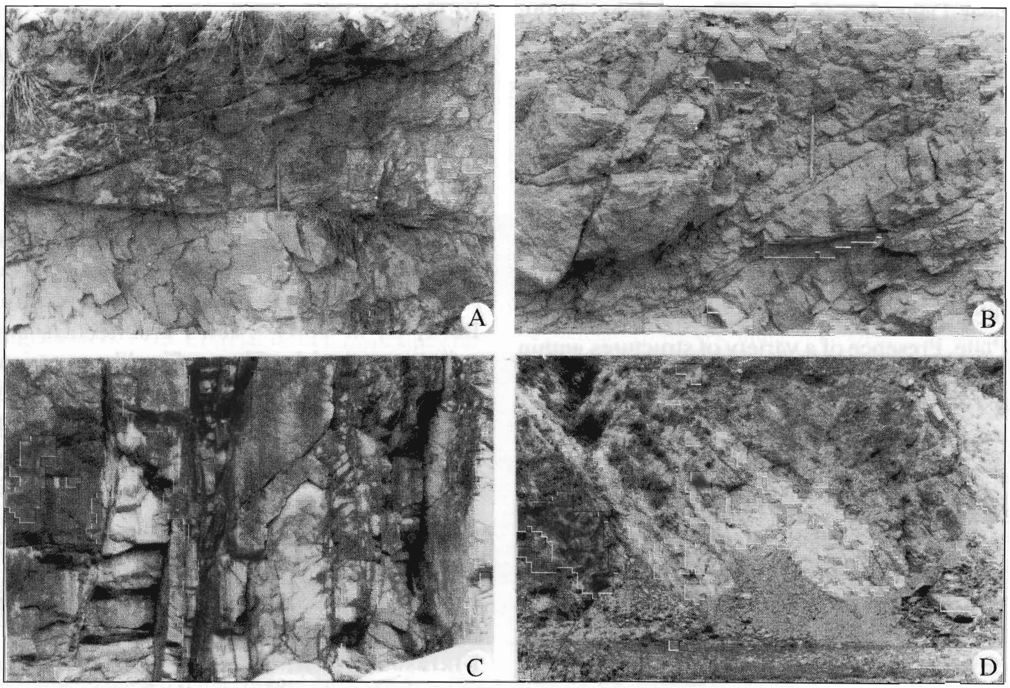


Fig. 3. Some characteristic deformational structures present in the Siwalik succession around Nainital. (A, B) small duplex structures exposed along the Nihal *nadi* showing south directed movement; (C) highly fractured and almost vertical rocks belonging to the Lower Siwaliks near Kathgodam, along Gaula *nadi*, note the cleavage refraction (of relatively softer layers in to the harder layers), which also indicate south directed movement; (D) small-scale horses separated by the south dipping thrusts exposed on the right bank of the Gaula *nadi* 200 metres north of the previous structure.

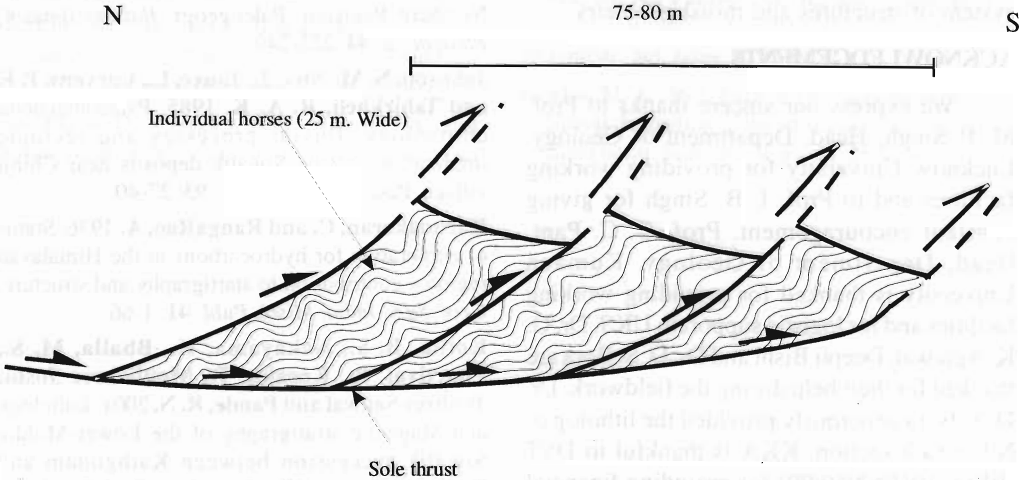


Fig. 4. Diagrammatic sketch of the duplex zone in the Nihal *nadi* section. A number of splays emerge out from the sole thrust detaching ~25 m. wide horses.

near Dehradun (Srivastava and John, 1999; Bhattacharya and Agarwal, 2004).

The Siwalik succession is caught between the MBF (in the north) and the now active HFF (in the south). Such a situation seems to be responsible to produce the observed deformational features in these rocks, which are mainly generated to accommodate the intense compressive forces arising due to the continuous northward push of the Indian Plate. Presence of a variety of structures within the Siwalik suggests a complicated structural history of these rocks, which are basically lithology controlled. The geometry of the individual structures indicates progressive deformation of the early-formed structures. It is quite possible that initiation of deformation may have taken place along the bedding planes (the first-grade anisotropy). This might lead to the formation of bedding-plane thrusts. With progressive deformation later on, the earlier formed structures are modified depending upon the local stress field and rheological factors. The cleavage refraction and small-scale duplex structures might have developed mainly due to space problem and to accommodate the additional stresses in the compressional regime. All this ultimately gave rise to a complicated system of structures and thrust geometry.

## ACKNOWLEDGEMENTS

We express our sincere thanks to Prof. M. P. Singh, Head, Department of Geology, Lucknow University for providing working facilities and to Prof. I. B. Singh for giving constant encouragement. Prof. C. C. Pant, Head, Department of Geology, Kumaun University is thanked for providing working facilities and for logistic support to UKS. Dr. G. K. Agrawal, Deepti Bisht and Dr. D. S. Bora are thanked for their help during the fieldwork. Dr. D. S. Bora generously provided the litholog of Nihal nadi section. KKA is thankful to DST (ESS/23/VES/050/99) for providing financial support to undertake this study.

## REFERENCES

**Beaumont, C.** 1981. Foreland basins. *Geophys. J. Roy. Astron. Soc.* **55**: 291-329.

**Bhattacharya, A. R.** 2005. An "Expanding Mountain Front" Hypothesis for the tectonic evolution of the Siwalik zone, Outer Himalaya. *Pal. Soc. India, Spl. Publ.* **2**: 73-80.

**Bhattacharya, A. R. and Agarwal, K. K.** 2005. Some observations on the Thrust Geometry of the Siwalik zone, Outer Himalayas (MS)

**Bora, D. S.** 2003. Facies architecture and sedimentary models of Lower Siwalik successions between Ramganga and Gaula Rivers in Kumaun Himalaya. Unpubl. Thesis, Kumaun University, Nainital, 214 p.

**Bora, D. S. and Shukla, U. K.** 2005. Petrofacies implications on the Lower Siwalik Foreland Basin evolution, Kumaun Himalaya, India. *Pal. Soc. India, Spl. Publ.* **2**: 163-180.

**Boyer, S. E. and Elliot, D.** 1982. Thrust Systems. *Amer. Assoc. Petrol. Geol.* **66**: 1196-1230.

**Dikinson, W. R.** 1974. Plate teconics and sedimentation. In: Dikinson, W. R. (ed.) *Tectonic and Sedimentation, Spl. Publ.* SEPM, Tulsa, **22**: 1-27.

**Johnson, G. D., Zeitler, P., Naeser, C. W., Johnson, N. M., Summers, D. M., Frost, C.,Opdyke, N. D. and Tahirkheli, R. A. K.** 1982. The occurrence and fission track ages of Late Neogene and Quaternary volcanic sediments, Siwalik Group, Northern Pakistan. Paleogeogr. *Palaeoclimatol. Palaeoecol.* **44**: 223-249.

**Johnson, N. M., Stix, J., Tauxe, L., Carveny, P. F. and Tahirkheli, R. A. K.** 1985. Palaeomagnetic chronology, fluvial processes and tectonic implications of the Siwalik deposits near Chinji village, Pakistan. *Jour. Geol.* **93**: 27-40.

**Karunakaran, C. and RangaRao, A.** 1976. Status of exploration for hydrocarbons in the Himalayan region – contribution to startigraphy and structure. *Geol. Surv. India, Miscl. Publ.* **41**: 1-66.

**Kotlia, B. S., Nakayama, K., Bhalla, M. S., Phartiyal, B., Kosaka, T., Moulishree Joshi, Jaishree Sanwal and Pande, R. N.** 2001. Lithology and Magnetic stratigraphy of the Lower-Middle Siwalik succession between Kathgodam and Ranibagh, Kumaun Himalaya. *Jour. Geol. Soc. India,* **58**: 411-423.

**Lyon-Caen, H. and Molnar, P.** 1985. Gravity anomalies, flexure of the Indian plate and the structure, support and evolution of the Himalaya and Ganga basin. *Tectonics*, **4**: 513-538.

**Mitra, G. and Boyer, S. E.** 1986. Energy balance and deformation mechanisms of duplexes. *Jour. Stru. Geol.* **8**: 291-304.

**Nakata, T.** 1972. Geomorphic history and crustal movements of the foothills of Himalaya. Instt. Of Gegraphy, tohuku University, Sendai, 162-164.

**Pilgrim G. E.** 1913. Correlation of the Siwalik with mammal horizons of Europe. *Rec. Geol. Surv. India*, **43** : 264-326.

**RangaRao, A., Agarwal, R. P., Sharma, U, N., Bhalla, M. S. and Nanda, A. C.** 1988. Magnetic polarity stratigraphy and vertibrate palaeontology of the Upper Siwalik sub-Group of Jammu Hills, India. *Jour. Geol. Soc. India*, **31**: 261-385.

**Sharma, M., Sharma, S., Shukla, U. K. and Singh, I. B.** 2002. Sandstone body aechitecture and stratigraphic trends in the Middle Siwalik succession of the Jammu area, India. *Jour. Asian Ear. Sci.* **20**: 817-828.

**Shukla, U. K. and Bora, D. S.** 2000. Identification of interfluve (Doab) deposits in the Lower Siwalik succession of Kumaun Himalaya: Their tectonic and palaeoclimatic significance. *Symp. On Neogene climate of Indian Ocean and Indian subcontinent, IIT* Kharagpur, pp. 39.

**Shukla, U. K. and Bora, D. S.** 2003. Geomorphology and Sedimentology of Piedmont zone, Ganga Plain, India. *Curr. Sci.* **84**: 1034-1040.

**Sinclair, H. D., Coakley, B. J., Allen, P. A. and Watts, A. B.** 1991. Simulation of foreland basin stratigraphy using a diffusion model mountain belt uplift and erosion: an example from the central Alps, Switzerland. *Tectonics*, **10**: 599-620.

**Srivastava, D. C. and John, G.** 1999. Deformation in the Himalayan Frontal Fault Zone: evidence from small-scale structures in Mohand-Khara area, NW Himalaya. *Mem. Gondwana Res. Gr.* **6**: 273-284.

**Tandon, S. K., Kumar, R., Koyama, M. and Niitsuma, N.** 1984. Magnetic polarity stratigraphy of the Upper Siwalik subgroup east of Chandigarh, Punjab Sub-Himalaya, India. *Jour. Geol. Soc. India*, **25**: 45-55.

**Tauxe, L. and Opdyke, N. D.** 1982. A time framework based on magnetostratigraphy for the Siwalik sediments of the Khaur area, northern Pakistan, *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **37**: 43-61.

**Valdiya, K. S.** 1988. The tectonics and evolution of the central sector of Himalaya. *Phil. Trans. Royal. Soc. London*, **A326**: 151-175.

**Valdiya, K. S.,** 1992. The Main Boundary Thrust Zone of the Himalaya, India. *Annales Tectonicae, Spl. Issue*, **6**: 54-84.

**Willis, B. J.** 1983. Evolution of Miocene fluvial system in the Himalayan foredeep through a two kilometer thick succession in northern Pakistan. *Sed. Geol.* **88**: 77-123.

**Yeats, R. S., Nakata, T., Farah, A., Fort, M., Mirza, M. A., Pandey, M. R., and Stein, R. S.,** 1992. The Himalayan Frontal Fault system. *Annales Tectonicae, Spl. Issue*, **6**: 85-98.

**Zaleha, M. J.** 1997. Intra and extra basinal control on fluvial deposition in the Miocene indo-Gangetic foreland basin. *Sedimentology*, **44**: 269-390.