Special Publication of the Palaeontological Society of India, No.2, 2005, pp. 141-153

TERTIARY VERTEBRATES FROM THE HIMALAYAN FORELAND OF INDIA: AN EXPLICATION OF LATE EOCENE-OLIGOCENE FAUNAL GAP

B. N. TIWARI
WADIA INSITUTE OF HIMALAYAN GEOLOGY 33, GEN, MAHADEO SINGH ROAD,
DEHRA DUN - 248001

ABSTRACT

Late Eocene – Oligocene vertebrates are missing from the continuous Cenozoic succession of the Himalayan foreland of India. In the foreland sections, the Tertiary vertebrates comprise two discrete sets : Paleocene-middle Eocene set (Kakara-Subathu) and middle Miocene-Pleistocene set (Siwalik) with sporadic early Miocene faunal elements from the intervening Murree and putative coeval horizons.

Subathu's semi-aquatic and terrestrial fossil vertebrates corroborate presence of coastal terrestrial habitat. Forced regression of the Subathu sea destroyed vertebrate habitat on coastal areas by rendering top fertile sedimentary cover due for cannibalization owing to loss of fluvial accommodation. Scenario of unstable sedimentary cover and consequent dwindling basic biomass with incising streams without flood plains in the region presumably exterminated vertebrate communities. This is appropriately portrayed in the Subathu's succeeding horizons (= foreced regressive deposits) as a gap in faunal record from late Eocene to Oligocene.

Initiation of thrusting in early Miocene (along MCT) created foreland basin on the southern flank of the proto-Himalaya. In a reversal, this tectonic event created fluvial accommodation and thereby allowed gradual expansion of flood plains with stable sedimentary cover to support basic biomass by stopping exclusive vertical incision by streams. These changes re-established terrestrial vertebrate habitat in the region as is manifested in occurrence of vertebrate fauna in the sedimentary record. Local early Miocene faunas from the Himalayan foreland represent this phase of the sedimentation history. Since early Miocene aggradational regime continues in the region in prograding foreland basins, these basins, Siwalik and Ganga Plains, bear continuous record of evolving vertebrates of the region.

Key words: Eocene-Oligocene, Vertebrates, Himalayan Foreland.

INTRODUCTION

During Tertiary, a sedimentary succession was laid down in the Himalayan foreland of north India without any major hiatus (Singh, 1978, Srivastava and Casshyap, 1983, Chaudhri, (1968). Late Eocene-Oligocene faunal gap is evident in the succession as Tertiary vertebrates are known from Kakara-Subathu (Palaeocene - early Lutetian; Mathur, 1997) and Siwalik (middle Miocene to Pleistocene) horizons with sporadic occurrence of early Miocene faunal elements from the intervening horizons. These horizons are named as the Murree in the Jammu region (contiguous to Murree in Pakistan), the Dagashai/Kasauli (Simla Hills) and the Dharamsala (Kangra Valley) in Himachal Pradesh. The late Eocene-Oligocene faunal gap in the Himalayan foreland record noticed by earlier workers (e.g. Khan, 1975) incidentally coincides with the duration of change of depositional environment from marine to freshwater.

Recession of Subathu sea was not a normal regression in the wake of low average rate of sedimentation during that time. In the present context, falling sea-level caused forced

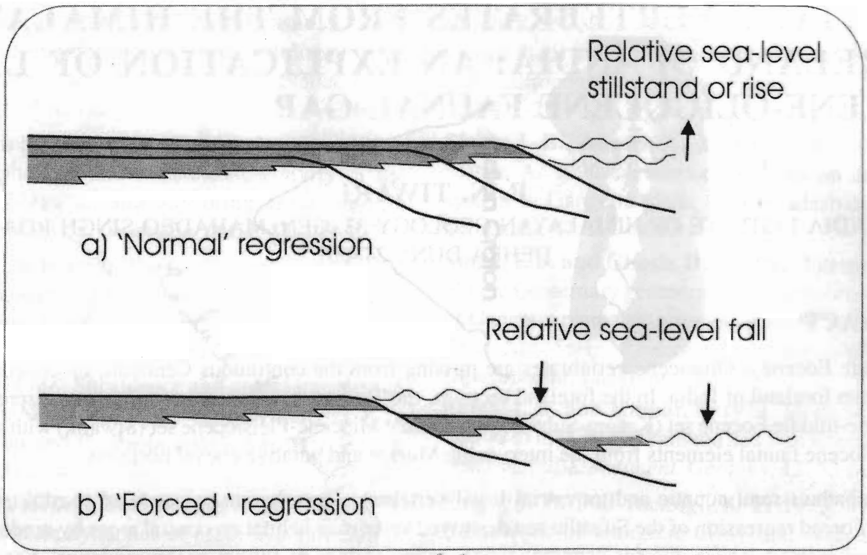

Fig. 1. (a) Normal regression due to incoming unsustainable flux of sediments.
(b) Forced regression due to fall in sea-level.

regression of the Subathu sea and changed depositional environment from marine to nonmarine in marginal marine setting (fig. 1). Besides change in depositional environment, other multiple consequences of drop in sea-level culminate in destruction of biohabitat of the region. Sediments deposited during forced regression are at the top of a marine sequence and are termed the forced regressive deposits or as Falling Stage Systems Traet irrespective of their environment of deposition in sequence stratigraphy (Hunt and Tucker, 1995). As elaborated later on, it is possible to relate forced regression of the Subathu Sea with faunal gap – a vertical manifestation of destruction of biohabitat in the Tertiary succession of the Himalayan foreland. Thus, in a wider perspective of sequence stratigraphy, late Eocene-Oligocene faunal gap in the apparently uninterrupted Tertiary horizons of the Himalayan foreland finds a plausible explication.

Important corollaries of the issue are early Miocene initiation of foreland basin and thrusting events on the southern flank of the Himalaya. In view of foreland basin definition, post-collisional southward thrusting along MCT in the early Miocene (Windley, 1983) has to be coeval with initiation of the foreland basin in the proto-Himalayan foreland.

Present communication is an analysis of the interplay of eustatics, sedimentation and tectonics in explicating faunal gap of late Eocene-Oligocene duration in NW Himalayan foreland of India. Field studies in the Kalakot (J&K), Dharamsala and Subathu (H.P.) areas and survey of the publised literature enabled the author to conceive a plausible explanation for the faunal gap in theoretical light of updated sequence stratigraphic model. This contribution is an attempt to provide a coarse temporal framework to transformation of marine sedimentation to freshwater foreland basin sedimentation via forced regressive regime besides explicating late Eocene-Oligocene faunal gap in an otherwise complete record of terrestrial Tertiary vertebrates from the region.

RELEVANT THEORETICAL PERSPECTIVE

Stratigraphic Models

Litho- and biostratigraphy continue to be traditional stratigraphic models and together (with limited tectonic input) provide a robust skeletal account of the geological evolution of the basin. With drop in sea-level, in marginal marine setting, environment of deposition changes from marine to nonmarine without any apparent break in sedimentation, whereas terrestrial biota occupies after waiting for development of basic biomass on stabilized vacated region. Thus for largely recycled sediment pile deposited during forced regression faunal and lithological controls are not available in the succession and a stratigraphic model independent of these two parameters is needed for using these horizons in understanding basin evolution. Marine sequence stratigraphic model fits the bill and provides an exposition of physical parameters affecting fauna (Hunt and Gawthrope, 2000) and, therefore, is quite relevant to the problem of late Eocene-Oligocene faunal gap.

Updated marine sequence stratigraphic model consists of four systems tracts. Falling stage systems tract (=forced regressive deposits or FRST) is the fourth systems tract added to the original Exxon model (Gawthorpe et al., 2000). With the introduction of FSST, there is a significant change and, therefore, systems tracts are redefined. Now, HST comes to an end at relative sea-level highstand, FSST is deposited during relative sea-level fall. The LST starts at relative sea-level lowstand and comes to an end when transgression begins the TST (fig. 2). Elaborate discussion pertaining to boundary of the sequence above or below FSST being inconsequential in the present context, will be taken up in subsequent communication while deciding boundary of Subathu sequence. Understandably, the Subathu Group as a transgressive shelfal sequence consists of TST, HST, and FSST and lacks record of LST.

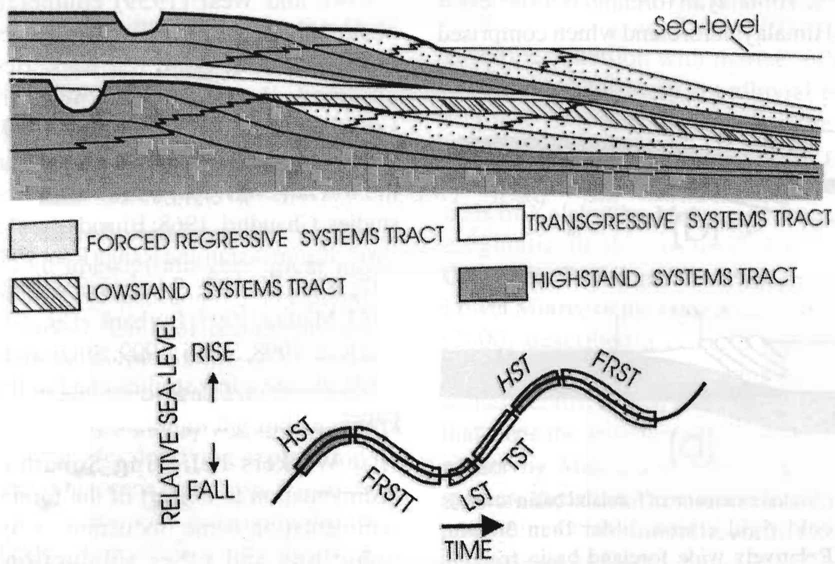

Fig. 2. Systems tracts of the updated marine sequence stratigraphy with respect to their position in a sea cycle (after Gawthorpe *et al.*, 2000).

Foreland basin and its elements

Foreland basin can be defined as an elongate asymmetric basin of potential sediment accumulation in the foreland that develops between a contractional orogenic belt and the adjacent craton in response to supracrustal thrust loading for flexuring of the crust (figs. 5 3a, b and 4a). However, width of the foreland basin depends on the thermal maturity of the lithosphere (Beaumont *et al.*, 1982); young, hot and flexurally weak lithosphere (young than 30 ma) gives way to narrow but deep foreland basin. Conversely, rigid, cold and old (> 30 ma) lithosphere allows wide but shallow foreland basin (fig. 3 a,b).

Decelles and Giles (1996) identify four discrete depozones referred to as the wedgetop, foredeep, forebulge, and back-bulge and add that the longitudinal dimension mathces with that of the fold-thrust or contractional orogenic belt (fig. 4b).

Through it has been used interchangeably in certain publications, 'Himalayan foreland' is not a synonym to 'Himalayan foreland basin'. Further, the Himalayan foreland is a successor of proto-Himalayan foreland which comprised peneplained foreland in the backdrop of proto-Himalaya (= Lesser Himalayan landmass since Precambrian, *sensu* Singh, 1979; crustal upwarp related to Central Asian Baikalian upheavel of ~600 Ma, *sensu* Valdiya, 1984).

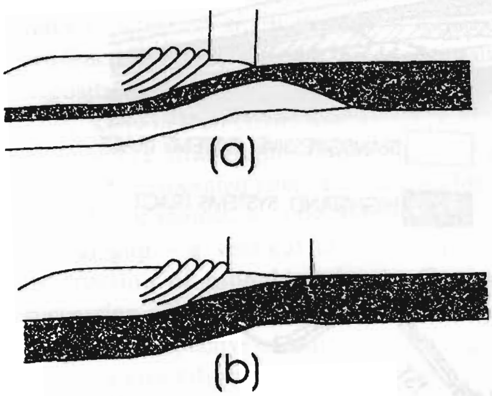

Fig. 3 (a). Limited extension of foreland basin towards cold rigid craton, older than 30 Ma; (b).Relatively wide foreland basin fringing flexurally weak younger craton < 30 Ma.

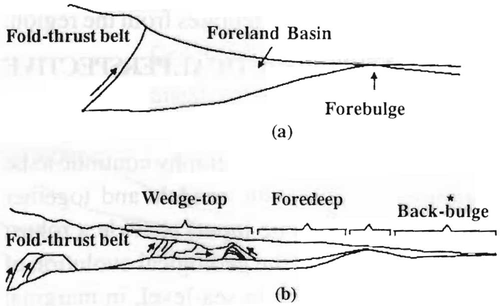

Fig. 4. Elements of foreland basin and location of depozone for Bhainskati, Nepalese coeval of Subathu, envisaged by DeCelles *et al.* (1998).

PREVIOUS STUDIES

Recognition of Sirmur Series comprising Subathu (marine), Dagshai, and Kasauli dates back to pulication of 'Manual of the Geology of India' (Medlicott, 1879). Wadia (1928), Auden (1934), and West (1939) enumerated field observations as a beginning of geological investigation in these horizons. Because of assumed hydrocarbon potential and significance in understanding evolutionary history of the Himalaya, Tertiary horizons of the foreland have persistent record of intense studies. Chaudhri, 1968; Bhandari and Agarwal, 1967; Karunakaran and Ranga Rao, 1976; Singh, 197; Bhatia, 1982; Srivastava and Casshyap, 1983, Mathur, 1997; Burbank *et al.*, 1997; Sahni and Kad, 1998; Sahni, 1999; Singh and Andotra, 2000, etc are a few studies cited in the present paper.

Workers believing Subathu marine sedimentation to be part of the foreland basin sedimentation name obduction of Spongtong ophiolites and other subduction related tectonics in the region (e.g. Singh and Andotra, 2000). Though aware of the presence of "nascent Himalaya", DeCelles and his team proposed a hypothesis depositing Bhainskati, equivalent of Subathu in Nepal, in back-bulge depozone (DeCelles *et al.*, 1998) and tried to explain the late Eocene-Oligocene gap by erosion during southward migration of the back-bulge (fig. 4b). They further concluded, a least probable proposition, that thrusting from Pakistan in the west to Nepal in the east was synchronous.

Some workers subscribe that foreland basin evolved in early Miocene, that is, subsequent to marine Subathu sedimentation in stable shelf conditions in the proto-Himalayan foreland (Singh, 1979, Srivastava and Casshyap, 1983, Srinivasan and Khar, 1996). Singh (1979) observed that deposition of Subathu was similar to the preceding Carboniferous-Permian and Jurassic-Cretaceous deposits in the 'Dogadda-Subathu Zone' which, in turn, was akin to 'Narmada Valley Zone' in the peninsular India. In a subsequent postulation for Kakara-Subathu sediments, Valdiya's (1984) Sirmur basin – a long narrow depression- came into being in the Outer Himalaya during the Karakoram Phase of the Himalayan orogeny.

Many workers, without committing themselves that Subathus were laid in stable shelf or foreland basin setting, lament that with so much data collected from the Himalayan foreland, an appropriate geological model withstanding field tests could not be proposed (Biswas, 1994). Lack of resolution at this stratigraphic level hampered accurate geological modeling of the basin for planning hydrocarbon exploration in the Indian part of the foreland besides depriving explanation for late Eocene – Oligocene faunal gap. It is amazing to know that we are yet to ascertain subsurface limit and extent of principal source rock, that is, Subathu sediments (Agarwal *et al.*, 1994). While on Indian side we have oil and gas-shows and have bored 12 deep wells without any major success, across the border on western side of syntaxis in Pakistan there is an oil-producing field on the foreland (Biswas, 1994). Presumbly this is a reflection that like in oil fields across the Kashmir syntaxis, we do not have adequate marine pile of sediments at the base of foreland basin sequence. Reported Oligocene vertebrates (Welcomme *et al.*, 2001) indicate continuity of their habitat and thereby lead to infer that marine sediments during transgression were deposited in foreland basin setting there and were therefore sufficient for hydrocarbon generation. It is pertinent to point out here that the study of change of depositional environment in our side in the light of latest seuqence stratigraphic model has the potential of explicating contemporary faunal break of the order of ~ 20 million years and in assessing source and reservoir rocks.

Earlier, there was unanimity in considering the Murree and coevals as brackish-water deposits in the absence of definite marine or nonmarine fauna. Later workers considered the Murree and equivalents to be the transitional deposits. However, Singh (1978) proposed estuarine condition with marine influence for the Dagshai followed by alluvial plain with shallow braided streams for the Kasauli sediments (Singh, 2000). Lone record of Oligocene artiodactyl from the basal Murree beds of Kalakot by Mehta and Jolly (1989) is enigmatic in the context of late Eocene-Oligocene faunal gap. Subsequently from the Lower Murree of the same area, Kumar and Kad (2000) described a cricetid rodent of early Miocene age. While elaborating age of the local faunal records, Kumar and Kad (2000) observed that since the artiodactyl *Leptomeryx* recorded earlier by Mehta and Jolly (1989) is a new species, therefore, precise age assigned to it is uncertain. Other faunal records from coeval horizons are by Dogra *et al.*, 1985; Tiwari *et al.*, 1991; Mathur *et al.*, 1996; Feist and Tiwari, 1999.

A PRIORI INFORMATION

Paleogene eustatic changes : In the foreland, trangression and regression of late Paleocene and middle/late Eocene respectively (more than 10ma duration) represent second-order sea-level cycle (Prothero and Schwab, 1996). The cycle is recorded on western and eastern side of India besides in proto-Himalayan foreland as transgression and regression of Subathu sea (Pandey, 1986).

In view of a logic offiered by Prothero and Schwab (1996) for the second-order sea-level cycle, the Subathu transgression took place in Paleocene because of decrease in ocean volume. The decrease is related to northward drift of Indian plate because the drift allowed speedy outpouring of hot and enormous volume of magma along mid-oceanic ridge and thereby arguably caused temporary (in gelogical terms) reduction in ocean volume. The counter view holding obduction of Spontong Ophiolite responsible for Subathu sea on down flexed northern part of Indian plate is a weak argument in view of presence of Eocene horizons below the ophiolites and existence of proto-Himalaya.

Further, India-Asia collision at ~55 Ma stopped/minimized outpouring of hot voluminous magma. Besides, the earlier lot of magma cooled down with considerable decrease in volume and thereby ocean volume was increased. With increase in ocean volume, consequent drop in sea level caused forced regression of sea, without any apparent interference of tectonics, in the Himalayan foreland.

The Subathu horizons of Paleocene-middle Eocene age were deposited in a transgressive sea arm running oblique to regional strike in proto-Himalayan foreland and are appropriately termed as shelfal deposits (figs. 5 and 6). Oblique trend is inferred on the basis of occurrence of Subathu exposures in the Lesser Himalaya towards east beyound Yamuna rather than in the foothills.

Cooling begins : During early Eocene oceans were distinctly warm up to deep waters with ocean surface temperature about 14°C at poles and 22°C at the equator (Frakes, 1979). Rigorous $\delta\,^{18}O$ studies reveal 1.0‰ increase at early Eocene/middle Eocene (between C21N and C22N) indicating significant decrease in temperature. Another 1.0‰ increase in $\delta\,^{18}O$ at middle Eocene/late Eocene (between C17N and C16N) indicates continued cooling trend. However, during Oligocene increase in $\delta\,^{18}O$ values is ascribed to ice volume increase in the poles (Prothero, 1994).

Himalayan high on the northern side of the Indian Plate : Contrasting mature Lesser Himalayan geomorphic region is a testimony to the existence of proto-Himalaya (= Lesser Himalaya, Singh, 1979) since ~ 500 Ma (Azmi, 1993); proto-Himalaya defined northern limit of transgression of the Subathu sea in the foreland (fig.5). Counter view proposing unhindered Subathu sea up to suture zone manifests lack of circumspection of pertinent regional geology or due to generalization of studies across the syntaxis as scene towards west, beyond Jammu (Sah, 1980) was substantially different.

Early Miocene initiation of Foreland Basin in Himalayan foreland : Earliest thrusting event represented by MCT and dated as early Miocene initiated foreland basin (*sensu stricto*). Initiation of foreland basin prior to early Miocene was restricted towards west up to Kashmir Syntaxis becaue of the presence of an extension of rigid and cold Indian shield and is linked with pre-Miocene western Himalayan orogeny (Welcomme *et al.*, 2001; Bossart and Ottiger, 1989; Pivnik and Wells, 1996). Proven hydrocarbon potential of Tertiary horizons on the west of the syntaxis is closely related with pre-or syn-Subathu initiation of foreland basin allowing accumulation of thicker pile of oil and gas producing marine organic-rich strata.

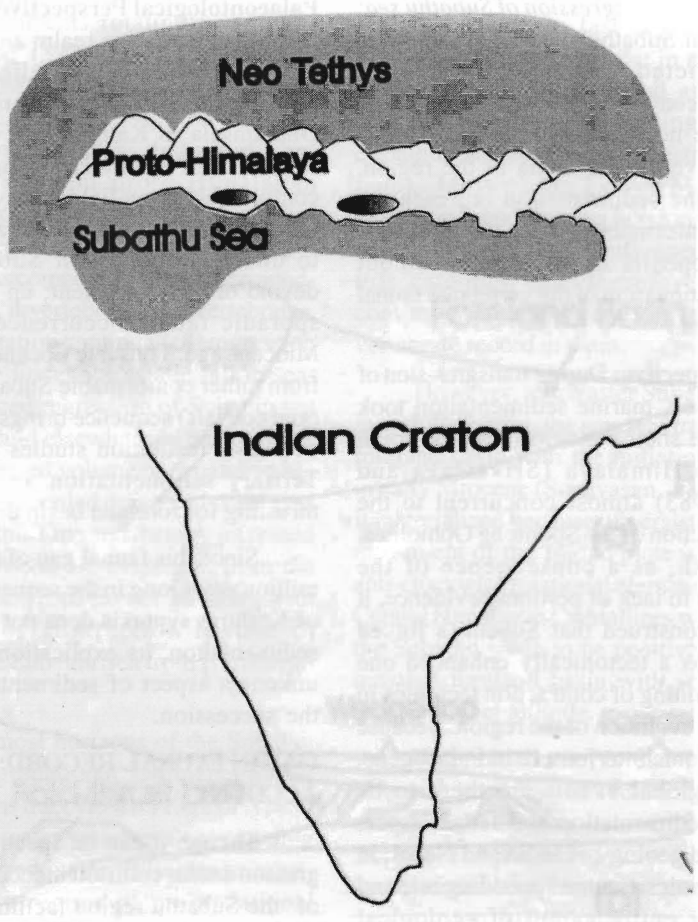

Fig. 5. Portrayal of Subathu sea extending up to Nepal in the proto-Himalayan foreland.

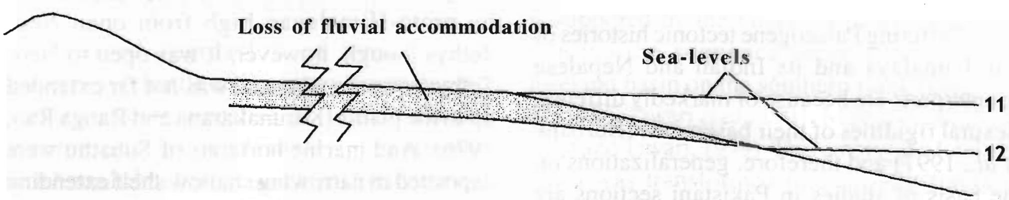

Fig. 6. Depiction of Subathu sea with coastal vertebrate habitat in backdrop of the proto-Himalayas; shown drop in sea-level renders sedimentary cover supporting habitat unstable as strata above dashed line is due for cannibalization.

Fauna and Forced Regression of Subathu sea: Relative fall in Subathu's sea-level in middle Eocene inflicted changes in physical parameters of coastal vertebrate habitat. These changes were not conducive to the continuance of the vertebrate fauna in the region. Subathu marine sedimentation representing HSST was conformably succeeded by forced regressive deposits in the region without sustaining continuation of the vertebrate faunal remains in them.

Tectonic Perspecitve: During transgres-sion of the Subathu sea, marine sedimentaiton took place in stable shelf condition towards south of the proto-Himalaya (Srivastava and Casshyap, 1983) almost concurrent to the ongoing obduction of the Spontong Ophiolites, towards north, as a conseuqence of the collision. Due to lack of pertinent evidence, it can also be construed that Subathu's forced regression was a tectonically enhanced one owing to beginning of contraction tectonics in the geological evolution of the region. Because of limited tectonic interfernece in Palaeogene, imprints of global events are there to be observed in sedimentation and faunal aspect of the foreland geology of India and Nepal. In Neogene, tectonics assumed presiding role and guided rather entire gamut of geological processes by forcing successive versions of the foreland basins (from embryonic foreland basin for early Miocene sediments comprising younger Murree and coevals to Siwalik and finally to Ganga Plain) in the Himalayan foreland of India.

Differing Palaeogene tectonic histories of Pak Himalaya and its Indian and Nepalese counterparts are because of markedly different flexural rigidities of their basements (Burbank *et al.*, 1997) and therefore, generalizations on the basis of studies in Pakistani sections are not feasible. However, these studies provide a good ground for estimating tectonic lag in the regions.

Palaeontological Perspective: Subathus were laid down in marine realm and had terrestrial vertebrates up to middle Eocene age. Succeeding horizons, Murree in Jammu, Dharamsala in Kangra valley, and Dasghai/ Kasauli in Simla Hills, are apparently conformable as per field observation. While the immediately succeeding horizons, in contrast to underlying topmost Subathu beds, are devoid of faunal content; up at higher levels sporadic faunal occurrences are of early Miocene age. Thus late Eocene-Oligocene gap from rather conformable Subathu/Dharamsala (and coevals) sequence brings to fore the need of higher resolution studies regarding early Tertiary sedimentation and beginning of thrusting for foreland basin development.

Since this faunal gap of the order of ~20 million years long in the sequence towards east of Kashmir syntaxis does not denote break in sedimentaiton, its explication exposes as yet unknown aspect of sedimentation history of the succession.

GAP IN FAUNAL RECORD: A PLAUSIBLE ACCOUNT

Though it can be speculated that transgresson and/or collision induced down warping of the Subathu region facilitated invasion of sea; it is most likely that during sea-level rise, sea tansgressed low-lying Subathu area the way it did earlier in Carboniferous-Permian and Jurassic-Cretaceous (Singh, 1979).

Transgressed Subathu sea was delimited (may be with deep incursions towards north) by proto-Himalayan high from open Neo-Tethys though, however, it was open to Neo-Tethys towards west and was not far extended up to the plains (Karunakarana and Ranga Rao, 1976). And marine horizons of Subathu were deposited in narrowing shallow shelf extending upto 84°E in Nepal (Bhandari and Agarwal, 1967).

Partial provenance of the Subathu detritus is evidently from ISZ because of the presence of Cr-spinel (Najman and Garzanti, 2000); coastal currents rotating in an anti-clockwise gyre (Sahni, 1999) possibly transported sediments from ISZ to shelf region. Srivastava and Casshyap (1983) on the basis of petrographic studies deducted that provenance was from proto-Himalayan metasedimentaries. This exclusive marine aggradational regime had some faunal input from coastal areas comprising freshwater-pond-inhabiting algae, invertebrates and vertebrates. Marine sedimentation continued till regression of sea in middle Eocene. Eustatic fall in sea-level caused forced regression of Subathu sea from the region and elsewhere in the world as presumably increased volume of expanding hot mid oceanic ridges cooled down and decreased substantially by this time and thereby increased ocean volume. Available evidences from the middle Eocene horizons do not go along with possible role of contraction regime in withdrawal of the Subathu Sea from Himalayan foreland.

While topmost horizons of the Subathu representing aggradational sedimentation of high stand systems tract yield mixture of typical marine and freshwater vertebrates, succeeding barren forced regressive deposits characteristically represent a regime of progradational sedimentation, which is predominantly recycling of earlier deposited sediments. Further forced regressive deposits were laid down (excepting up slope bypass regions, for example at Dumri Bridge, easter Nepal, DeCelles *et al.*, 1998) unevenly on the Subathu horizons at a low average rate of sedimentation.

Forced regression of Subathu sea rendered top fertile sedimentary cover due for cannibalization because of loss of fluvial accommodation and thereby destroyed vertebrate habitat on coastal areas. And vertical incision by streams in consequence made fresh water ponds on Subathu coastal areas untenable. Cumulative effect of these abiotic factors resulted in fast degradation of the terrestrial vertebrate habitat in middle Eocene on the Himalayan foreland and, therefore, conformably laid succeeding horizons of Subathus are devoid of terrestrial vertebrate fauna. Most of the Lower Murree, Lower Dharamsala and Dagshai horizons, conformably succeeding marine Subathus sequence, fall in this category and, therefore, in spite of continuity in sedimentation lack terrestrial vertebrate record in them.

However, much after Subathu regression in middle Eocene, the area was transformed into foreland basin with the initiation of thrusting in early Miocene (Srinivasan, and Khar, 1996). It materialized because of persistent northward movement of the Inidan plate with additional anti-clockwise rotational element. Along MCT, Central Himalayan Crystallines were thrust over the Subathu basin to be positive area for thus initiated foreland basin with secondary base level at higher altitude.

With initiation of foreland basin in early Miocene, recycling of sedimentary cover due to vertical incision by transverse streams stopped. This stabilized the sedimentary cover - an essential condition - to restore biomass for reviving terrestrial vertebrate habitat in the region. Besides, the flood plains on stream banks widened presumably with interspersed water ponds. Restoration of biohabitat brought early Miocene terrestrial vertebrates with herbivore forms, to begin with (Mehta and Jolly, 1989; Kumar and Kad, 2002). The surmise is suppored by the faunal evidences from the non-marine sequence representing initial foreland basin on the southern flank (Dogra *et al.*, 1985; Tiwari *et al.*, 1991; Mathur *et al.*, 1996; Feist and Tiwari, 1999). This embryonic foreland basin was transformed into Siwalik foreland basin by successive thrusting event activating MBT in middle Miocene.

SUMMARY AND CONCLUSIONS

The approximately 20 million years long faunal gap in the succession cannot be construed as due to equally prolonged break in sedimentation because sedimentological evidences discount this possibility. Sedimentologists working in Subathu/ Dagshadli/Kasauli (Chaudhri, 1968; Singh, 1978; Srivastava and Casshyap, 1983) and Subathu/Murree (Bhandari and Agarwal, 1967) successions have repeatedly stated that sedimentation took place without any major interruption.

While Subathu horizons were deposited in shallow coastal shelf environment, mainly in sehlf mud zone and succeeding lower Murree and Dagshai horizons were deposited in estuarine complex with marine influence and extensive mud flats (Singh, 1978; Singh, 2000). Away from destablized terrestrial habitat of Subathu vertebrates, presumably slow rate of drop in sea-level created extensive mud flat at the site of deposition. Presence and absence of faunal remains in the Subathu and lower Murree/Dagshai horizons respectively may be understood in view of the fact that shallow marine coast with coastal lagoons/ponds support marine and nonmarine vertebrate communities whereas extensive mud flats of estuarine complex do not harbour noticeable vertebrate faunal community. Basic bio-mass and herbivores started appearing as fossils with onset of alluvial plain traversed by shallow braided streams in initial Himalayan foreland basin setting during early Miocene sedimentation.

This exposition reveals the way continental fossil reocrd is affected due to eustatic changes in marginal marine setting. This assertion is at variance to the conclusion drawn by Fara (2002) in the study on the relationship between sea-level variations and quality of the continental fossil record.

1. Marine sedimentation during high stand systems tract was aggradational on the shelf region. Coastal ponds and estuaries supported terrestrial vertebrate habitat prevailed on Subathu sea-coast up to early middle Eocene.

2. Falling stage systems tract represents sedimentation during forced regression. This is a progradationl facies of sedimentation with some bypass areas in up slope region. Exposed slope is cannibalized, flood plains become non-existent, streams carry out vertical incision, average sedimentation rate is too slow, and entire terrestrial habitat is thus rendered unstable; besides meagre rate of sedimentation due to recycling renders forced regressive facies incapable of preserving faunal remains.

3. While non-marine sedimentation took off on eastern side of Kashmir syntaxis after falling stage systems tract of the shelf sequence comprising Subathus and its coevals in India and Nepal, towards west in Kohat Basin non-marine sedimentation started in foreland basin setting even before Subathu marine transgression (Pivink and Wells, 1996). Early Miocene brittle deformation mobilized Central Himalayan Crystalline along MCT and thus initiated foreland basin towards east of Kashmir syntaxis in the Himalayan foreland. As a sequel, tectonics transformed progradational facies into aggradational facies capable of preserving faunal remains of the vertebrates and invertebrates in a foreland basin setting. Hereafter, younger Tertiary horizons were deposited in successive prograding foreland basins with Ganga Plain foreland basin as an end member, promoted and modified by the compression regime owing to persistent northward movement of Indian plate.

4. In a nutshell, application of latest sequence stratigraphic model for continental shelf sedimentation enables us to understand that marine shelf facies was followed by forced regressive deposits. These horizons are devoid of faunal remains manifesting destruction of vertebrate habitat during their deposition. Duration of forced regressive deposition is rather equal to the faunal gap in Subathu and early Miocene Murree vertebrates in marine and non-marine facies deposited on shallow shelf and initial foreland basin setting respectively. This new hypothesis needs support of field and laboratory data for being given a serious consideration in preparing geological model of the basin in exploration studies by industrial geological community.

ACKNOWLEDGEMENTS

I thank Professor B.R. Arora, Director, WIHG for facilities and permission to present this paper at Lucknow Seminar and to Professor A.R. Bhattacharya and Dr. Kamal K. Agarwal, Lucknow University for kind cooperation. I am grateful to my colleague, Dr. R.J. Azmi for guidance and help in preparing the manuscript.

REFERENCES

Agarwal, R.P., Prasad, D.N., Samanta, U., Berry, C.M., and Sharma, J. 1994. Hydrocarbon potential of the Siwalik Basin. *Him. Geol.* **15:** 301-320.

Auden, J.B. 1934. The Geology of the Krol Belt. *Rec. Geol. Surv. India,* **64** (4): 374-454.

Azmi, R.J. 1993. Mussoorie Group (Vendian-Cambrian) – a chronostratigraphic analogue of the Haimanta Group: implications in the early evolutionary history of the northwestern Himalaya and the northern Indian peninsula, Abstracts, *Seminar on Himalayan Geology and Geophysics, WIHG,* Dehra Dun : 30-31.

Beaumont, C., Charlotte E. K., and Boutielier, R. 1982. A comparison of foreland and rift margin sedimentary basins. *Phil. Trnas. R. Soc. Lond.* A **305**: 295-317.

Bhandari, L.L. and Agarwal, G.C. 1967. Eocene (Subathus Series) on the Himalayan Foothills of North India. *Publication of CAS in Geology, Panjab University,* Chandigarh **3**: 57-77.

Bhatia S.B. 1982. Facies Flora and Fauna in the lower Tertiary formations of Northwestern Himalayas : a synthesis. *Spl. Publ. Palaeont. Soc. India,* **1**: 8-20.

Bhattacharya, Ajit and Chakraborty, abd Chandan 2000. *Analysis of sedimentary successions, a field manual.* Oxford and IBH Publishing Co.Pvt. Ltd, New Delhi. 443p.

Biswas, S.K. 1994. Status of exploration for hydrocarbons in Siwalik Basin of India and future trends, *Him. Geol.* **15**: 283-300.

Bossart, P. and Ottiger, R. 1989. Rocks of Murree Formation in Northern Pakistan: indicators of descending foreland basin of late Paleocene to middle Eocene age, *Ecogae geol. Helv.* **82** (1): 133-165.

Burbank, D.W., Beck, R.A., and Mulder, T. 1997. The Himalayan Foreland Basin, In Yin, A. and Harrison, M. (Eds.) *The Tectonic Evolution of Asia,* 149-188, Cambridge, Cambridge University Press.

Chaudhri, R.S. 1968. Stratiography of the Lower Tertiary formation of the Punjab Himalayas. *Geol. Mag.* **105**(5): 421-430.

Critelli, Salvatore and Garzanti, Eduardo 1994. Provenance of the Lowe Tertiary Muree redbeds (Hazara-Kashmir Syntaxis, Pakistan) and initial rising of the Himalayas. *Sedimentary Geology,* **89**: 265-284.

DeCelles, Peter G. and Giles, Katherine A. 1996. Foreland Basin Systems, *Basin Research,* **8**: 105-123.

DeCelles, Peter G., Gehrels, G.E., Quade, Jay, and Ojha, T.P. 1998. Eocene-early Miocene foreland basin development and history of Himalayan trusting, western and central Nepal. *Tectonics,* **17**(5): 741-765.

Dogra N.N., Singh R.Y. and Misra P.S. 1985. Palynology of Dharmsala beds, Himachal Pradesh. *Jour. Pal. Soc. India,* **30**: 63-77.

Fara, E. 2002. Sea-level variations and the quality of the continental fossil record. *Jour. Geol. Soc. London,* **159**: 489-491.

Feist, M. and Tiwari, B.N. 1999. Charophytes of the Palaeogene/Neogene transition in the Kangra

Valley (Northwestern Himalaya, India). *IGCP 421 and First Pakistan Palaeontological Convention.* Peshawar. Abstract 8-9.

Frakes, L.A. 1979. *Climates Throughout Geological Time.* New York, Elsevier.

Gawthorpe, R.L., Hall, M., Sharp, I., and Dreyer, T. 2000. Tectonically enhanced forced regressions: examples from growth folds in extensional and compressional settings, the Miocene of the Suex rift and the Eocene of the Pyrenees. From: Hunt, D. and Gawthorpe, R.L. (eds) *Sedimentary Responses to Forced Regression, Geological Society Special Publication* no. 172. p. 1771-191.

Hunt, D. and Tucker, M.E. 1995. Stranded parasquences and the forced regressive wedge systems tract: deposition during base – level fall – reply. *Sedimentary Geology,* **95**: 147-160.

Hunt, D. and Gawthorpe, R.L. (eds) 2000. *Sedimentary Response to Forced Regressions Geological Society Special Publication* no. 172. p. 383.

Karunakaran, C. and Ranga Rao, A. 1976. Status of exploration of hydrocarbions in the Himalayan region – contributions to stratigraphy and structure, *Himalayan Geology Seminar,* New Delhi. 72p.

Khan, Aijaj 1975. Post-Subathu unconformity and the age of Murree rocks, Jammu & Kashmir Foothills, India. *Jour. Geol. Soc. India,* **16**(2): 227-229.

Kumar, K. and Kad, S. 2002. Early Miocene cricetid rodent (Mammalia) from the Lower Murree of Kalakot, Rajauri District, J & K, India, *Curr. Sci.* **82**(6): 736-740.

Mathur, A.K., Mishra, V.P. and Mehra, S. 1996. Systematic study of plant fossils from Dagshai, Kasauli and Dharmsala formations of Himachal Pradesh. *Palaeontologica Indica GSI,* L(New Series): 121 p.

Mathur, N.S. 1997. A comparative study of lower Tertiary biostratigraphic sequences in the northwest Himalaya and their palaeogeographic significance, In: *Geodynamic domains in Alpine-Himalayan Tethys* (edts. Sinha, A.K. *et al*) complex names required Oxford & IBH Pub., New Delhi: 125-158.

Medlicott, H.B. 1879. *Manual of the Geoplogy of India,* 2. Geol. Survey of India, Calcutta.

Mehta, S.K. and Jolly, A. 1989. *Leptomeryx,* an Oligocene artiodactyl from the Lower Murree of Sial Sui (Kalakot Tehil), District Rajauri, J & K, *Curr. Sci.* **58**(11): 625-627.

Najman Y. M. R., Clift, P., Johnson, M.R. W. and Robertson, A.H.F. 1993. Early stages of foreland basin evolution in the Lesser Himalaya, N. India In: *Himalayan Tectonics* (P.J. Treolar and M.P. Searle eds.). *Special Publ. Geol. Soc. London,* **74**: 541-558.

Najman, Y. and Garzanti, E. 2000. Reconstructing early Himalayan tectonic evolution and palaeogeography from Tertiary foreland basin sediments, Northern India, *Geol. Soc. of Amer. Bulletin,* **112**(3): 435-449.

Pandey, Jagdish 1986. Some recent palaeontological studies and their implications on the Cenozoic stratigraphy of Indian Subcontinent. *Bulletin ONGC,* **23**(2): 1-44.

Pivnik, D.A. and Wells, N.A. 1996. The transition from Tethys to the Himalaya as recorded in northwest Pakistan, *GSA Bulletin,* **108:** 1295-1313.

Prothero, D.R. 1994. *The Eocene-Oligocene Transition, Paradise Lost.* Columbia Univeristy Press, New York 283 p.

Prothero, D.R. and Schwab, F. 1996. *Sedimentary Geology, An Introduction to Sedimentary Rocks and Stratigraphy,* W.H. Freeman and Company, New York 575p.

Ranga Rao, A. 1986. Northwest Himalayan foothills: its stratigraphical record and tectonic phases. *Bulletin ONGC,* **23**(2): 109-128.

Sah, S.K. 1980. Stratigraphy and tectonic setting of the Lesser Himalayan belt of Jammu In: *Stratigraphy and correlation of Lesser Himalayan Formations* KS Valdiya and SB Bhatia(eds.) Hindustan. Pub. Corp. Delhi: 152-160.

Sahni, Ashok and Kad, Shashi 1998. Evidence of Tectonic Events in the Foreland Basin: Phase relationship with Himalayan and Tibetan Uplifts. *Him. Geol.* **19**(2): 49-53.

Sahni, Ashok. 1999. India Asia collision: ecosystem changes, *J.B. Auden Lecture, Wadia Institute of Him. Geol.* Dehradun Publication, 27p.

Singh, B.P. and Andotra, D.S. 2000. Barrier-lagoon and tidal cycles in Palaeocene to middle Eocene Subathu Formation, NW Himalaya, India *Tertiary Research,* **20**(1-4): 65-78.

Singh, B.P. 2000. Sediment Dispersal Pattern in the Murree Group of the Jammu area, NW Himalaya, India, *Him. Geol.* **21**(1&2): 189-200.

Singh, I.B. 1978. On some sedimentological and palaeoecological aspects of Subathu-Dagshai – Kasauli succession of Simla Hills, *Jour. Pal. Soc. India.* **21&22:** 19-28.

Singh, I.B. 1979. Some thoughts on the Evolution of the Himalaya and the northern limit of the Indian Shield, *Geol. Rundschau,* **68**(1): 342-350.

Srinivasan, S. and Khar, B.M. 1996. Status of hydrocarbon exploration in the northwest Himalaya and foredeep–contributions to stratigraphy and structure. Proc. Symp. NW Himalaya and Foredeep, Feb. 1995 *Geol. Surv. India, Spl. Publ.* **21**(1): 295-405.

Srivastava V.K. and Casshyap, S.M. 1983. Evolution of Pre-Siwalik Tertiary Basin of Himalaya. *Jour. Geol. Soc. India,* **24:** 134-147.

Tiwari, B.N., Misra, P.S., Kumar, M. and Kulshrestha, S.K. 1991. Microfaunal remains from the Upper Dharamsala Formation, Dharamsala, Kangra Valley, H.P. *Jour. Pal. Soc. India,* **36:** 31-41.

Valdiya, K.S. 1984 Evolution of the Himalaya *Tectonophysics,* **105:** 229-248.

Wadia, D.N. 1928. Geology of the Poonch State (Kashmir) and adjacent portion of the Punjab. *Mem. Geol. Surv. India,* **51**(2): 185-362.

Welcomme, Jean-Loup; Benammi, Mouloud, Crochet, Jean-Yves, Marivaux; Laurent, Metais; Gregoire, Antoine; Pierre-Olivier, and Baloch, Ibrahim 2001. Himalayan Forelands: palaeontological evidence for Oligocene detrital deposits in the Bugti Hills (Balochistan, Pakistan) *Geol. Mag.* **138**(4): p. 397-405.

West, W.D. 1939. Structure of the Shali Window near Simla, *Rec. Geol. Surv. India,* **74**(1).

Windley, B.F. 1983. Metamorphism and tectonics of the Himalaya, *Jour. Geol. Soc. London,* **140**: 849-865.