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REGIONAL CORRELATION OF THE PALAEOGENE SEDIMENTS OF THE HIMALAYAN FORELAND BASIN

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ABSTRACT

The paper presents a correlation of the Palaeogene sediments across three geographic domains of the Himalayan Foreland Basin. East of Hazara-Kashmir Syntaxis (HKS), a conformable sequence from the marine Subathu/Balakot/Bhainskati (SBZ4-14), through the paralic Passage Beds to the fluviatile Dagshai and equivalent formations has been recently demonstrated. A similar conformable sequence from the Palaeocene-Ilerdian Dungan Formation through the Kirthar Formation to the fluviatile Bugti Member (Chitrawata Formation, Rupelian-Chattian) with its rich vertebrate fauna has also been established in the Sulaiman Range.

The early to middle Lutetian taxa *Assilina spira abrardi and Nummulites discorbinus* (SBZ 13-14) levels, representing global high-sea stand TA 3.2-TA3.3 in the upper Subathu are correlatable with the Kohat Formation and the Habib Rahi Member (Kirthar Formation) of the Kohat region and the Sulaiman Range. The overlying Passage Beds representing low sea-stand are correlatable with the Domanda-Pir Koh-Drazinda (partim) members (Kirthar Formation). Its correlation with the Kuldana Formation representing low sea-stand 3.1 (late Cuisian) as suggested earlier is, therefore, untenable.

In the Kohat-Potwar sub-basin, west of HKS the sedimentation during the greater part of the Cuisian (SBZ10-11) was in restricted evaporitic basins (Jatta Gypsum, Bahadur Khel Salt, Shekhan Formation). Correlatable beds in the Shimla Hills are the paralic beds cotaining the oldest known cetacean *Himalayacetus* corresponding to low-sea stand TA 2.7 (51.5-50.5Ma) predating *Pakicetus* of the Kuldana Formation by 2Ma. The chronostratigraphic gap between the different marine Eocene formations and the overlying fluviatile Murree Formation is attributed here to the uplift of the subsurface Delhi - Sargodha Ridge and its extension below the Potwar plateau which remained a positive area during greater part of late Eocene.

Key words: Palaeogene, Foreland Basin, Himalaya, Correlation

INTRODUCTION

The present paper is a sequel to our earlier publications (Bhatia and Bhargava, 2002, 2003, 2005) wherein we demonstrated a biogeochronological continuity from the Subathu to the Dagshai and equivalent formations of the Himalayan Foreland Basin covering the late Thanetian to early Chattian, thus negating a >10Ma hiatus as opined by Najman, Pringle, Johnson, Robertson and Wijbrans (1997) and DeCelles, Gehrels, Quade and Ojha (1998). Our works cited above dealt primarily with the Palaeogene sequences of the Himalayan Fold-thrust Belt east of Hazara-Kashmir Syntaxis (HKS) and did not attempt any correlation with the sequences west of HKS and of the Sulaiman Fold Belt of the Indus Basin. Such a comprehensive regional correlation is essential to reconstruct an integrated picture of the geological history of the entire Foreland Basin and to decipher the event and sequence stratigraphy.

Of the various correlations, both regional and local, only the one by Eames (1952) is perhaps the most comprehensive and the biostratigraphic framework suggested by him is still valid. Correlations suggested by the Stratigraphic Committee of Pakistan (Fatmi, 1973, Shah, 1977) are generalized, whereas those proposed by Nagappa (1959), Kureshy (1978), Latif (1970, 1976) and Mathur (1978, 1997) were based primarily on larger foraminifera whose taxonomy and zonal significance need updating in the light of the work of Schaub (1981) and the Tethyan Shallow Benthic zonation proposed by Serra-Kiel, Hottinger, Caus, Drobne, Ferrendez, Jauhri, Less, Pavlovec, Pignatti, Samso, Schaub, Sirel, Strougo, Tambareau, Tosquella and Zakrevskaya (1998). Correlation by vertebrate paleontologists, like those by Bajpai and Gingerich (1998) were found to be confusing and contradictory by Thewissen, Williams and Hussain (2001). Similar flaws are apparent in the correlations suggested by Kumar (2000) and Raza (2001) and others who consider the vertebrate bearing Passage Beds (*sensu* Bhatia and Mathur, 1965; Bhatia and Bhargava, 2002) of the Shimla Hills to be coeval with those of the Kuldana Formation west of HKS without interpolating with datable foraminifera.

The present paper discusses these controversies and proposes a comprehensive regional correlation (table 1) based primarily on the Larger Foraminiferal Tethyan Shallow Benthic Zones SBZ (Serra-Kiel *et al.* 1998), with inputs from Nannoplankton zonation (Martini, 1971) and Charophytes Zonal schemes (Riveline, Berger, Feist, Martin-Closas, Schudack and Souliè–Märsche, 1996) and integrating therein the terrestrial and marine vertebrate–bearing horizons on either side of the HKS.

GEOLOGICAL SETUP AND CORRELATION

The Palaeogene sediments of the Himalayan Foreland Basin, south of the Main Boundary Thrust (MBT) form a continuous parautochthonous belt (fig. 1) stretching from the Sulaiman Range (Middle Indus Basin) via Kohat-Potwar-Jammu to Dadhau in the Giri Valley of Himachal Pradesh. East of Dadhau, due to tectonic concealment, the Palaeogene sediments are intermittently exposed in the foot-hills of Uttaranchal, Nepal, Bhutan and Arunachal. Besides this, north of the MBT isolated outliers of the Palaeogene sediments rest over various Precambrian, Cambrian, Permian and Cretaceous sequences.

Based on different stratigraphic set-up and nomenclature, the Palaeogene belt can be grouped under the following three geographic and tectonostratigraphic domains:

East of Hazara-Kashmir Syntaxis, including the Syntaxis

In this domain, the main Palaeogene Belt occurs between the MBT in the north/northeast and the Main Boundary Fault s.s. in the south/southwest. Besides, some outliers of the Palaeogene sediments occur north of the MBT also. The nummulitics are mainly thrust bound in Bhutan-Arunachal, while the Bhainskati Formation in Nepal rests over the Late Cretaceous-?Palaeocne Amile Formation (Sakai, 1983). The Subathu Formation in Garhwal rests over the Maastrichtian Singtali Formation (=Shell Limestone, Auden, 1937; Bhatia, 1980; Mathur and Juyal, 2000). The Kakra-Subathu Formation in the Shimla Hills and Jammu rests over different Precambrian formations (Bhandari and Agarwal, 1967; Bhatia, 1982) and the Balakot Formation in Hazara rests over the Cambrian Abbotabad Formation (Bossart and Ottiger, 1989). In several sections, a bauxite/laterite horizon intervenes between the Palaeogene and older sequences.

The Palaeogene successions mainly comprise grey-green and carbonaceous shale/mudstone dominated sediments intercalated with fossiliferous limestone/marl bands. Not only the lithofacies but also the stratigraphy of the Paleogene sequences is remarkably uniform

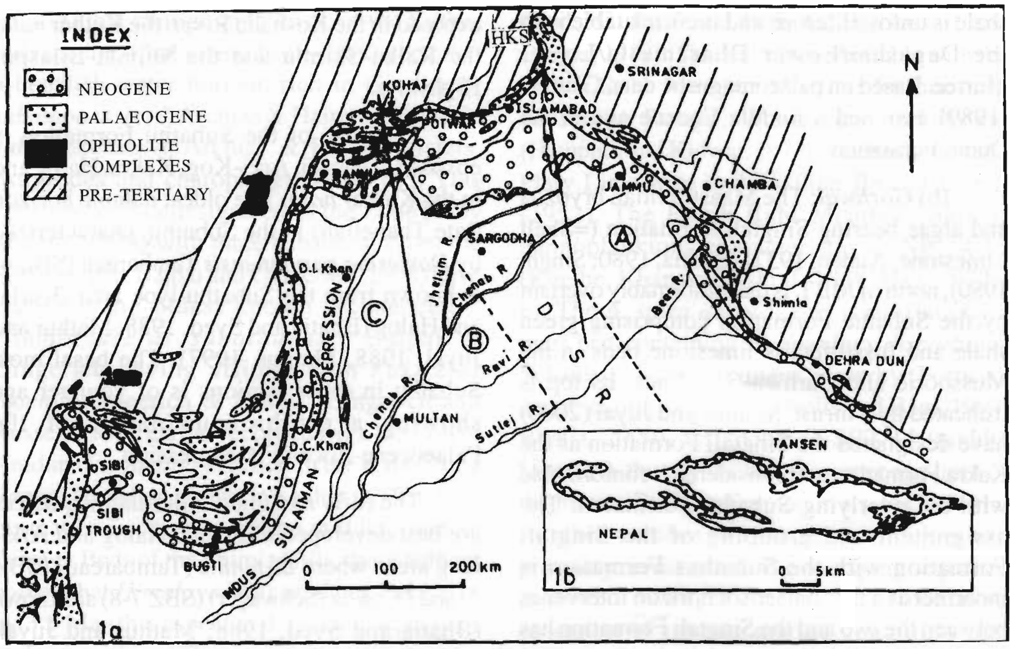


Fig. 1(a). Generalised geological map showing distribution of the Palaeogene sediments of the Himalayan Foreland Basin and the three geographic domains (A. East of Hazara Kashmir Syntaxix (HKS); B. West of HKS; C. Sulaiman Range) and the location of the subsurface Delhi-Sargodha Ridge (DSR). (b). Inset showing Palaeogene sediments in the Tansen area, Nepal.

in this domain.

(a) *Nepal*: In the Tansen area, north of the MBT (fig.1b), the Palaeogene sediments, resting over the Late Cretaceous-?Palaeocene Amile Formation, are divisible into the Bhainskati and Dumri formations (Sakai, 1983).

The Bhainskati Formation, measuring 160m (Sakai, 1983), comprises black shale with several thin calcareous fossiliferous beds in the middle part and variegated green and red purplish shale and red beds in the upper part. The top 32m of the Bhainskati Formation constituted of green and red-purple shale with haematite-rich beds is correlatable with the Passage Beds of the Shimla Hills (Bhatia, 2000; Bhatia and Bhargava, 2005).

Nummulites beaumonti d' Archiac & Haime and *Assilina papillata* Nuttall are known from a 5-10cm thick shaly limetone bed occurring about 50m from the base of the Bhainskati Formation (Matsumaru and Sakai, 1989) indicating a middle Eocene age. Since only these two foraminifera are known, that too from mid-section, the precise lower and upper age limits of the Bhainskati Formation cannot be constrained.

From the Surkhet Valley, about 200km west of the Tansen area, Tewari and Gupta (1976) have reported *Assilina* cf. *granulosa* (d' Archiac), *A. leymerie* (d' Archaic & Haime), *A. granulosa* var. *chumbiensis* Gill, *A. subdaviesi* Gill, *Nummulites* cf. *mamilla* (Fitchel & Moll), *N. atacicus* Leymerie and *N. djokjakartae* (Martin) from what they called as the Subathu Formation. The taxonomy of these needs to be updated.

The overlying Dumri Formation with predominantly fluviatile medium grained, bluish grey quartzose sandstone with red and green shale is unfossiliferous and is correlatable with the Dagashai/Lower Dharamsala/Lower Murree. Based on palaeomagnetic data, Gautam (1989) assigned a middle Eocene age to the Dumri Formation.

(b) *Garhwal*: The Maastrichtian bryozoa and algae bearing Singtali Formation (=Shell Limestone, Auden, 1937) (Bhatia, 1980; Singh, 1980), north of MBT, is disconformably overlain by the Subathu Formation comprising green shale and fossilifeorus limestone beds in the Mussoorie and Garhwal synclines. Its top is truncated by a thrust. Mathur and Juyal (2000) have designated the Singtali Formation as the Kakra Formation and considered it conformable with the overlying Subathu Formation. The assignment and grouping of the Singtali Formation with the Subathus Formation is incorrect as a thin palaeosol horizon intervenes between the two and the Singtali Formation has a distinctive lithology and lacks *Daviesina* assemblage characteristic of the Kakra Formation.

Foraminifera and ostracodes have been recorded at two stratigraphic levels in the Nilkanth area (Mathur and Juyal, 2000). The larger foraminiferal assemblage comprising *Nummulites burdigalensis burdigalensis* de la Harpe, *N. subramondi* de la Harpe, *N. rotularius* Deshayes and *N. increscens* Schaub is indicative of SBZ 9-10 corresponding to late Ilerdian-early Cuisian age.

(c) *Shimla Hills and Jammu*: The biostratigraphy of the Palaeogene succession of the Shimla Hills (where type area of the Subathu Formation is located) and Jammu, has been exhaustively dealt by several workers. (Singh, 1970, 1973, 1980; Mathur, 1978; Batra, 1989; Juyal and Mathur, 1992; Bhatia and Bagi, 1993; Bhatia, unpublished data) who have furnished detailed biostratigraphic lithocolumns. However, nowhere a complete sequence is exposed, it is only by piecing various sections that a full succession can be computed. Good sections of this sequence, however, are exposed in the Koshalia River, the Kuthar *nala*, the Kalka-Shimla and the Shimla-Bilaspur Highways.

The base of the Subathu Formation is epxosed at Morni, Arki-Kog, Kakra, Halog and in the Kuthar *nala*. The oldest datable horizon (late Thanetian) in the Subathu, characterized by *Daviesina garumnensis* Tambareau (SBZ 4) is known from the Subathu type area (Kurla) and Halog (Bhatia and Syed, 1988; Mathur and Juyal, 1988, Mathur, 1997). The basal most Subathu in other sections is of younger age showing a diachronous nature of the Palaeocene-Eocene transgression.

The early and middle Ilerdian sequences are best developed in Kakra, Halog and Arki-Kog areas where *D. tenuis* (Tambareau) (SBZ 5) and *D. ruida* (Schwager) (SBZ 7-8) are known (Bhatia and Syed, 1988; Mathur and Juyal, 2000).

The late Ilerdian successions distinguished only in the Morni area, are characterized by a thick pyritous carbonaceous shale sequence with thin interbedded oyster limestone bands representing a regressive phase of the initial marine transgression. This horizon contains stunted molluscan fauna (Bhatia and Bagi, 1993) and *Assilina pomeroli* Schaub (Bhatia, unpublished work) which denotes SBZ 9.

The major thickness of the Subathu Formation in most sections, comprising grey-green splintery shale with rich foraminiferal bands is of early Cuisian to middle Lutetian age. The base of early Cuisian (SBZ 10) characterized by *Nummulites burdigalensis burdigalensis* de la Harpe and *N. partschi* de la Harpe is well defined in the Subahu type area and the Koshalia River section. The top of early Cuisiasn marked by *N. planulatus* (Lamarck) and *N. praelucasi* Douvillei is observed only in the Koshalia River section (Bhatia and Bagi, 1993).

At this stratigraphic level, in the Kuthar *nala* section, Mathur and Juyal (2000) recorded a brackish water horizon rich in *Cordiopsis subathooensis* (d' Archiac & Haime), *Turritella subathooensis* d' Archiac & Haime, oysters, ostracodes and charophytes (Zone IV). This zone was earlier designated as the Zone III by Mathur (1978) with three subzones. From the Subzone IIIc, Bajpai and Gingerich (1998) have recorded the oldest known archaeocete-- *Himalayacetus subathuensis* Bajpai & Gingerich having affinity with *Pakicetus inachus* Gingerich & Russel (Gingerich and Russel, 1981), earlier recorded from the Lower Kuldana Formation exposed in the Kala Chitta Range. Based on the premise that the Kuldana Formation is coeval with the middle Lutetian Passage Beds of the Shimla Hills, these authors opined that *Himalayacetus* predates *Pakicetus* by 3.5 Ma (this aspect is discussed separately in the sequel).

The middle to late Cuisian (SBZ 11-12) distinguished by *Assilina placentula* Schuaub, *A. laxispira* de la Harpe, *A. major* Heim and *A. cuvillieri* Schaub occurs in most of the sections. The late Cuisian (SBZ 12) characterized by *N. friulanus* Schaub is well defined only in the Morni area of the Bilaspur tectonic unit. The late Cuisian sequence in the Koshalia River section is dominated by unfossiliferous sandstones showing hummocky cross-bedding and gutter casts indicating that they are tempestite deposits (Bagi, 1992; Bhatia and Bagi, 1993). This unfossiliferous sequence is correlatable with the Kuldana and related formations west of HKS.

Assilina spira abrardi Schaub (fig. 2), *Nummulites lehneri* Schaub and *N.obesus* d'Archic & Haime, diagnostic taxa of early Lutetian (SBZ 13) are ubiquitously present in a 2-3m thick whitish to cream coloured packstone in almost all the sections of the Shimla Hills, Jammu (Bhatia and Bagi, 1993; Mathur and Juyal, 2000; Bhatia unpublished data) and HKS (Bed 3C, fig.7 and beds G, H, Bossart and Ottiger, 1989). This level is correlatable with the Habib Rahi Member (Kirthar Formation), Sulaiman Range, Waziristan and Kohat (Hemphill and Kidwai, 1973) which incorporates Platy Limestone and *Assilina* Bed of Eames (1952). The Habib Rahi Member contains nannoplanktons characteristic of NP 14-15 (Koethe, Khan and Ashraf, 1988; Haq, 1972a, b). The *A. spira abrardi* Bed is overlain by a marl bed containing *Nummulites discorbinus* Schaub, *Assilina exponens* Sowerby (Form A) and *A. papillata* Nuttall (Bhatia and Bagi, 1993; Bhatia, 2000), assignable to SBZ 14 (middle Lutetian), thus delimiting the upper age limit of the marine Subathu Formation s.s. to Ca 44Ma. In other sections, the upper age limit is not precisely constrained. The overlying sequence is devoid of larger foraminifera, indicating cessation of normal marine conditions and onset of paralic environment.

In the Jammu area, the Kakra-Subathu succession lies disconformably over the Precambrian Sirban Limestone. The biostratigraphy of the Subathu Formation has been dealt with in detail by Singh (1973), Juyal and Mathur (1992) and Mathur and Juyal (2000). The foraminifera listed by the latter indicate that SBZ 4-14 are present in the Jammu sections.

d. Hazara-Kashmir Syntaxis: The geology of the Palaeogene sequence resting over the Cambrain Abbotabad Formation has been designated as the Balakot Formation (Bossart and Ottiger (1989). This sequence was originally mapped as the Murree Formation though not included as part of the Rawalpindi Group by the Stratigraphic Committee of Pakistan. The occurrence of several fossiliferous marl beds within this sequence prompted Bossart and Ottiger (1989) to separate it from the Murree type sequence and name it as the Balakot Formation. This area is structurally complicated, specially in the southwestern part. Bossart and Ottiger (1989) selected a 200 m thick

Fig. 2. Section of the *Assilina spira abrardi* packstone - a marker bed of early Lutetian age (Tethyan Benthic Zone SBZ 13), found ubiquitously in the Subathu and equivalent formations in all the three domains of the Foreland Basin; a. *Assilina spira abrardi* (Form B); b. *Nummulites obesus;* c. *N. praediscorbinus,* X9.

section along the Kagan road as the stratotype. Contrary to the views of Najman, Pringle, Godin and Oliver (2001) that biostratigraphy is not useful in clastic sequences, the chronological order of the appearance of larger foraminiferal marl beds particulary C-D, E-F, G-H indicate that the younging direction has been correctly determined by Bossart and Ottiger (1989). Consequently, the section shown by Najman *et al.* (2001) is untenable. The section here commences with the beds equivalent to the Lockhart/Patala formations assignable to SBZ 5-8. Apparently, the sampling was not carried out at close intervals, as a result the assembalge shows faunas of different benthic zones. The Sample locality B is assignable to SBZ 8. The Sample localities C-D with *Assilina leymerie* (d' Archiac & Haime), *A. adrianensis* Schaub and *A. pomeroli* Schaub are assignable to SBZ 9. The foraminiferal assemblages in localities E and F indicate assignment to SBZ 10-11, while those of G and H containing *Nummulites friulanus* Schaub, and *Assilina spira abrardi* Schaub are assignable to SBZ 12-13. The marl beds G and H (Bossart and Ottiger, 1989, fig.7, Bed 3c) are correlatable with the *A. spira abrardi* Bed of the Shimla Hills and Habib Rahi Member of the Kohat area and the Sulaiman Range (Bhatia and Bhargava, 2002).

The Ilerdian to Lutetian sequences SBZ 4-14 or a part thereof are well represented in the Shimla Hills, Jammu and HKS. However, the beds containing the characteristic fossils, unlike west of HKS and Sulaiman Range, show little variation in lithology and are also not thick enough to constitute mappable units. A similar set-up exists in the area southwest of HKS. Calkin, Offield, Abdulla and Ali (1975) used the name Kala Chitta Group for the equivalent beds.

West of Hazara-Kashmir Syntaxis

This domain includes 120-400m thick Palaeogene sequences exposed in the Salt Range and Kohat-Potwar fold belt. The Palaeogene sequences are tectonically bound by the MBT, the Salt Range Thrust, the Jhelum Fault and the Khurram Thrust in north, south, east and west, respectively (Kazmi and Rana, 1982). The Palaeogene sequences rest over (a) the Late Cretaceous Kawagarh Formation (Calkin *et al.,* 1975) in Hazara, (b) The Late Cretaceous Darsamand Formation (Meissner, Jan, Master, Rashid and Hussain, 1974) in Kohat and (c) various Palaeozoic and Mesozoic sequences in Salt Range.

These sequences represent environment varying from shallow marine (Lockhart Formation), lagoonal (Patala Formation), isolated evaporitic (Panoba Formation, Bahadur Khel Salt, Jatta Gypsum, Shekhan Limestone), fluvial-deltaic (Mami Khel Formation) to continental and molassic (Murree Formation) (Kazmi and Jan, 1977). The Palaeogene sequences having varying lithology show considerable facies variation and grade into each other making precise correlation difficult.

The oldest formation in this domain is the sandy Hangu Formation, at the base of which a ferruginous pisolitic sandstone (=the laterite/ bauxite horizon of the areas east of HKS) ubiquitously intervenes. The occurrence of *Lockhartia haimei* Davies, *Daveisina langhami* Smout, *Miscellania miscella* (d' Archiac & Haime), *Epistominella dubia* Haque and other fossils suggest that the formation belongs to SBZ 3-4 (late Thanetian). The overlying Lockhart Formation comprises grey massive limestone. The presence of *Assilina dandotica* Davies, besides *M. miscella* (d' Archiac & Haime) and *D. khatiyahi* Smout are indicative of SBZ 4-5 (late Thanetian-early Ilerdian). The overlying Patala Formation with subordinate limestone and coal beds, has an assemblage similar to that of the Lockhart Formation and is also assignable to SBZ 4-5.

In the Salt Range area, the Patala Formation is overlain by the Nammal Formation having fossil assemblage characteristic of SBZ 6 (early Ilerdian). This formtion is overlain by the Sakesar Formation which, in addition to other fossils, contains *Sakesaria cotteri* Davies characteristic of SBZ 7-8. The succeeding Chorgali Formation is assignable to SBZ 9?, 10-11 on the basis of *Assilina placentula* Schaub. This formation is uniformly overlain by the red beds of the Murree Formation with a conglomerate at the base containing reworked nummulitics.

In the Kala Chitta Range and Potwar area, the Margala Hill Formation is equivalent to the Nammal and Sakesar formations. This formation, besides other fossils, contains two diagnostic fossils viz. *Nummulities atacicus* Leymerie and *N. globulus* Leymerie (SBZ 8). The Margala Hill Formation is also overlain by the Chorgali Formation which laterally grades into the Jatta Gypsum. This stratigraphic level, assignable to SBZ 10, is correlatable with Zone III of Mathur (1978) and Zone IV of Mathur and Juyal (2001) which comprise variegated gypseous shales with intercalated oyster beds containing brackish water ostracodes and charophytes besides the cetacean *Himalayacetus* (see discussion in the sequel). The Chorgali Formation, in turn, is overlain by the Kuldana Formation which in lower part is chiefly red-purple mudstone intercalated with fresh water limestone containing molluscs and algae, suggestive of a terrestrial depositional regime (Raza, 2001). The Upper Kuldana comprises thicker limestone interbeds rich in oyster and benthic foraminifera, indicating reversion to marginal shallow marine environment. The Lower Kuldana is extremely rich in terrestrial and aquatic vertebrate fossils. The upper Kuldana is conformably overlian by the Kohat Formation which on stratigraphic ground as well as nummulitic assemblage can be placed in SBZ 13. The Kohat Formation is unconformably overlain by the Murree Formation.

In the Kohat area, the beds correlatable with the Margala Hill Formation are designated as the Panoba Formation with evaporitic sequence called the Bahadur Khel Salt Formation into which it laterally grades. In this area the Jatta Gypsum and its lateral variant, the Shekan Limestone conformably overlie the Bahadur Khel Salt and Panoba Shale formations respectively. Only a few fragmentary leaf impressions are found in the Bahadur Khel Salt Formation and the Jatta Gypsum. The Shekan Formation and the Jatta Gypsum are overlain conformably by the Mami Khel Formation comprising brown-red clays, sand and interbedded sandstone and conglomerate. This formation is rich in fresh water molluscs and oysters and is correlatable with the Kuldana Formation of the Kala Chitta Range and with the Baska Formation of the Sulaiman Range. The Mami Khel clays conformably passs into the Kohat Formation.

The Kohat Formation is overlain by the Kirthar Formation which in the Sulaiman Range is divisible into four members. The lowermost member of the Kirthar Formation, the Habib Rahi Member, was originally classified as the upper most member of the Kohat Formation by Meissner *et al.* (1974) and accepted as such by the Stratigraphic Committee of Pakistan. We prefer to follow Hemphill and Kidwai (1973) and Shah (1977), who consider the Habib Rahi Member as the lowermost member of the Kirthar Formation. The Habib Rahi and the two overlying Sirki and Pir Koh members of the Kirthar Formation are dealt with in detail under the Sulaiman Range. The Pir Koh Member is overlain by the Muree Formation along an erosional unconformity.

As already discussed, the stratigraphy and lithology of the Palaeogene sediments west of HKS is quite distinct from that developed east of HKS. One significant difference is in the development of small local basins in the

Kohat region, beginning NP 9/SBZ 5-6 (middle Ilerdian) and continuing up to NP 12/SBZ 10 (middle Cuisian) with extensive development of carbonate ramps, evaporites (sabkhas) and red beds (Wells, 1983; Pivnik and Wells, 1996). The sedimentation during this period was perhaps controlled by tectonism of Waziristan-Khost ophiolite belt in the immediate vicinity of the passive western marign (Warwick, Johnson and Khan, 1998; Raza, 2001). The second significant difference (table 1) is the presence of a major intra-late Eocene unconformity (mega sequence boundary *sensu* Crampton and Allen, 1995), which spearates the underlying Eocene continental margin sediments from the overlying foredeep-fill sediments – the Murree Formation – of late Eocene-early Miocene age. The erosional gap at the base of the Murree mega sequence varies considerably across the Salt Range-Kohat-Potwar sub-basin. The minimum gap is in the northwest in Kohat where the Murree sediments rest over the Pir Koh Formation assignable to SBZ 15/NP 16 (Bhatia and Bhargava, 2005). In the central part (Kala Chitta/ Potwar) the Murree sediments rest over the Kuldana Formation (SBZ 12) and also over the Kohat Formation (SBZ 13) (Shah, 1977; Raza, 2001). The maximum erosional gap is in the Salt Range in the south where the Murree sediments rest over the Chorgali Formation (SBZ 10-11).

The craton-ward increase in the erosional gap (chronostratigraphic gap) by the foredeep sediments on to the unconformity is commonly attributed to migration of the forebulge (Crampton and Allen, 1995; DeCelles and Giles. 1996). In the case of Salt Range-Kohat-Potwar we attribute the chronostratigraphic gap to the uplift of the Delhi-Sargodha Ridge (DSR) or Sargodha-Shahkot Ridge (Kazmi and Jan, 1997), a subsurface basement high which is still seismically active (Molnar *et al.,* 1973; Farah, Mirza, Ahmed and Butt, 1977). The surface expression of this ridge-the Precambrian basement-is exposed near Kirana, just southeast of Salt Range. The DSR slopes 10° due SW and 2°-3° towards NE (Farah *et al.,* 1977). Seismic reflection studies, gravity anomaly and bore-hole data have shown that the DSR possibly extends below the Salt Range and the Potwar plateau in the form of a gentle basement warp having 1° - 4° northward inclination (Lillie, Johnson, Yousaf, Zamin and Yeates, 1987; Kazmi and Jan, 1997). According to Virdi (1994), the DSR bulge was formed due to overloading of frontal edge of the Indian Plate by southward advancing thrust sheets.

In the Punjab Shelf, a number of minor digitations or spurs extend from the DSR to the frontal fold belt. Some of the unconformities in the Kalakot region are controlled by the Chenab Spur (Raiverman, Kunte and Mukherji, 1983). According to Yeates and Lawrence (1984), the DSR came into existence in post-Eocene-Oligocene time. Virdi (1994), however, opines that due to loading and bending of the Indian shield the DSR started appearing as a bulge in the Indian Shield about 34 Ma ago. We propose that the DSR and its northwestward continuation (Salt Range-Kohat-Potwar) constitutes a forebulge that started rising around 44 Ma in the middle Bartonian, coinciding with the final withdrawl of the sea from the foreland thrust belt. The DSR forebulge was finally exposed to erosion in late Eocene (?early Oligocene). The Salt Range being farthest from the orogenic front, remained exposed (*sensu* Crampton and Allen, 1995) for a longer duration, resulting in the erosion of the bulk of Eocene sediments overlying the Chorgali Formation and the subsequent filling up of the basin by the foredeep sediments of the Murree Formation. The maximum age of the Murree sediments in different sections/ loacalities can possibly be estimated by identifying precisely the age of the reworked larger foraminifera in the basal conglomerates in different sections of the Murree Formation, particularly that of the Fatehjang Member.

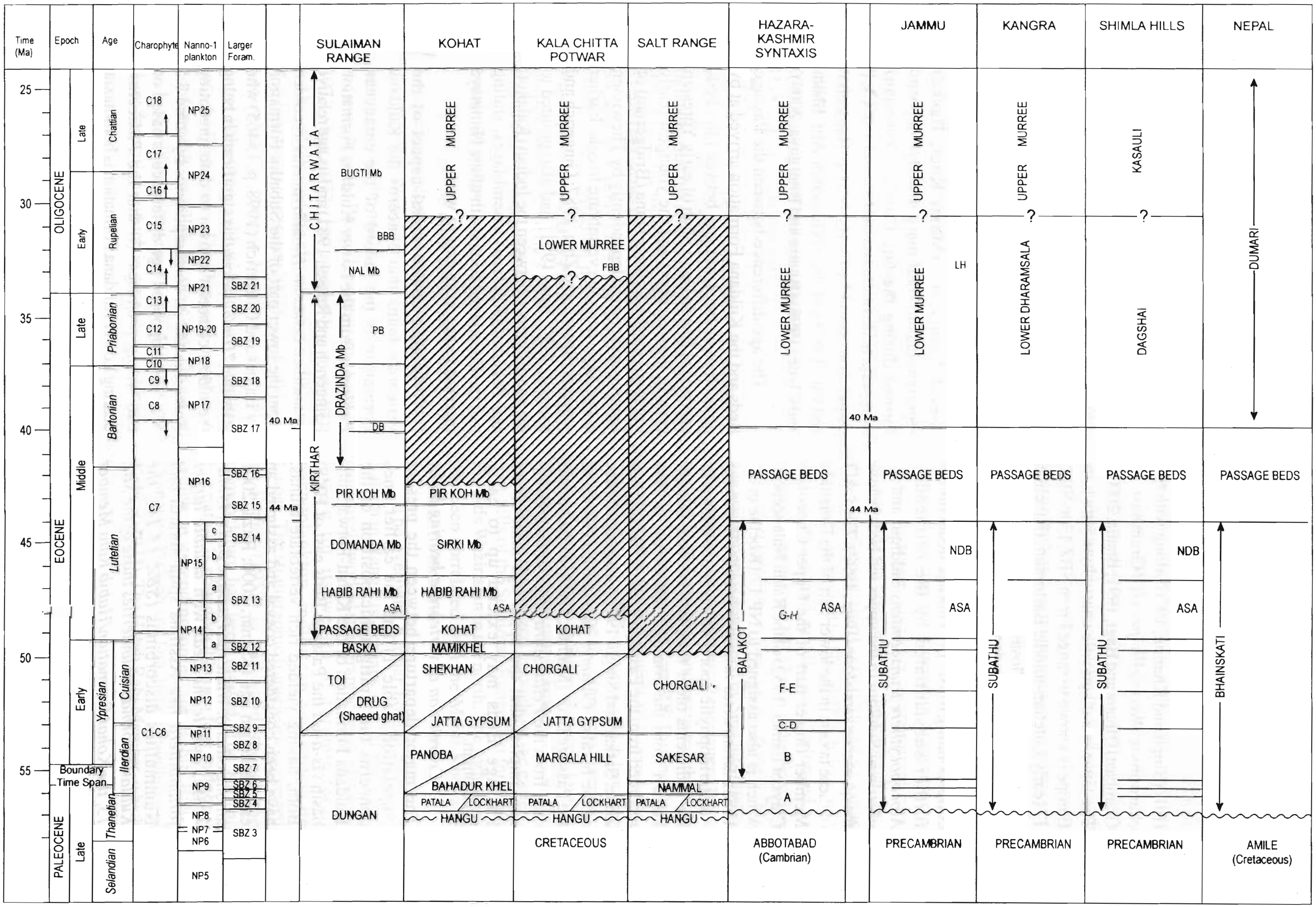
A similar chronostratigraphic gap between the Eocene Kirthar Formation and the Oligocene Chitrawata Formation of the Bugti area in southern Sulaiman Range, has been recorded by Welcomme, Benammi, Crochet, Marivaux, Antoine and Baloch (2001), indicating an erosional unconformity corresponding to an intra-early Oligocene orogenic phase.

Correlation of the Passage Beds and the Kuldana Formation

Before dealing with the biostratigraphic set-up of the third tectonostratigraphic domain-the Sulaiman Range of the Indus Basin, we propose to discuss the age and correlation of the Passage Beds (*sensu* Bhatia and Mathur, 1965; Bhatia, 2000; Bhatia and Bhargava, 2002; Red Subathus *sensu* Najman and Garzanti, 2000; Kalakot Zone *sensu* Ranga, Rao, 1971, 1986). In tectonically undisturbed sections, the Subathu and equivalent formations are succeeded by a sequence of red and green beds with intercalated oyster bands overlying the foraminiferal bands containing *Assilina spira abrardi* Schaub (SBZ 13) and *Nummulites discorbinus* (Schlotheim) (SBZ 14) and underlie the massive white-greenish quartzose sandstone constituting the base of the Dagshai/ Dumri/ Dharamsala/ Murree formations. The Passage Beds contain a rich and diverse fresh and brackish water fauna and flora besides vertebrates and palynomorphs, but are devoid of larger foraminifera indicating cessation of marine condition in the Himalayan Foreland Basin around 44 Ma (Bhatia and Bhargava, 2002). For a comprehensive review of the entire fossil fauna and flora including the vertebrates, a reference may be made to the works of Bhatia (2000) and Kumar (2000). According to Bhatia and Bhargava (2002, 2003, 2005), the Passage Beds span the period ca 44 Ma to 40Ma and represent a stratigraphically condensed sequence correlatable with the Domanda-Pir Koh-Drazinda members (partim) of the Kirthar Formation of the Sulaiman Range.

The following fossils aid in correlating the Passage Beds with homotaxial beds in the Sulaiman Range in Pakistan and in case of charophytes with European Charophyte Zonation. The gastropods *Aplexa kohatica* Eames and *Pseudoceratodes kohaticus* Eames reported in the Passage Beds (Batra, 1987, 1989) are confined to the Lower Chharat Beds of Kohat area (Eames, 1952), correlatable with the Domanda Member (=Lower Chocolate Clays of Eames, 1952) of the Rakhi Nala section, assigned to NP 15 (Koethe *et al.*, 1998). At this stratigraphic level there was an influx of fresh water in the basin which brought the alga *Pediastrum* in bloom in the Rakhi Nala section (Koethe *et al.*, 1998) as well as in the Shimla

Table 1- Showing correlation of the Palaeogene sediments of the Himalayan Foreland Basin in the three tectonostratigraphic domains. (Time scale after Berggren *et al.*, 1995; Charophyte zonation C1 to C18 after Riveline *et al.* (1996) Charophyte zones beginning *Pekichara llobrigatensis* (C1) up to *Chara notata* (C18); Nannoplankton Zonation after Martini (1971); Larger Foraminiferal Shallow Benthic Zonation after Serra-Kiel *et al.* (1998). Bed numbering from A-H in Hazara-Kashmir Syntaxis after Bossart and Ottiger (1989). Unless otherwise stated, all stratigraphic names imply formtion. ASA - *Assilina spira abrardi* Bed, BBB - Bugti Bone Bed, DB - *Discocyclina* Bed, FBB - Fatehajung Bone Bed, HIM - *Himalayacetus* Horizon, LH - *Leptomeryx* Horizon, Mb - Member, NDB - *Nummulites discorbinus* Bed, PAK - *Pakicetus* Horizon, PB - *Pellatispira* Bed.



Time (Ma)
Epoch
Age
Charophyte
Nanno-1 plankton
Larger Foram.
SULAIMAN RANGE
KOHAT
KALA CHITTA POTWAR
SALT RANGE
HAZARA-KASHMIR SYNTAXIS
JAMMU
KANGRA
SHIMLA HILLS
NEPAL
25
30
35
40
45
50
55
OLIGOCENE
EOCENE
PALEOCENE
Late
Early
Middle
Boundary Time Span
Chattian
Rupelian
Priabonian
Bartonian
Lutetian
Ypresian
Cuisian
Ilerdian
Thanetian
Selandian
C18
C17
C16
C15
C14
C13
C12
C11
C10
C9
C8
C7
C1-C6
NP25
NP24
NP23
NP22
NP21
NP19-20
NP18
NP17
NP16
NP15
NP14
NP13
NP12
NP11
NP10
NP9
NP8
NP7
NP6
NP5
SBZ 21
SBZ 20
SBZ 19
SBZ 18
SBZ 17
SBZ 16
SBZ 15
SBZ 14
SBZ 13
SBZ 12
SBZ 11
SBZ 10
SBZ 9
SBZ 8
SBZ 7
SBZ 6
SBZ 5
SBZ 4
SBZ 3
40 Ma
44 Ma
CHITARWATA
KIRTHAR
BUGTI Mb
BBB
NAL Mb
PB
DRAZINDA Mb
DB
PIR KOH Mb
DOMANDA Mb
HABIB RAHI Mb
ASA
PASSAGE BEDS
BASKA
TOI
DRUG (Shaeed ghat)
DUNGAN
UPPER MURREE
SIRKI Mb
KOHAT
MAMIKHEL
SHEKHAN
JATTA GYPSUM
PANOBA
BAHADUR KHEL
PATALA
LOCKHART
HANGU
LOWER MURREE
FBB
CHORGALI
MARGALA HILL
CRETACEOUS
SAKESAR
NAMMAL
BALAKOT
G-H
F-E
C-D
B
A
ABBOTABAD (Cambrian)
LH
SUBATHU
NDB
PRECAMBRIAN
LOWER DHARAMSALA
KASAULI
DAGSHAI
DUMARI
BHAINSKATI
AMILE (Cretaceous)

Hills (Singh and Khanna, 1976) along with the charophyte *Raskyella peckii* (Grambast & Grambast) (Bhatia and Bagi, 1991; Bhatia, 2000). The latter is a diagnostic charophyte which in Europe is known to range From SBZ 13 to SBZ 17 (early Lutetian-middle Bartonian) (Riveline *et al.* 1996; Martin-Closas, Serra-Kiel, Busquets and Ramos-Guerrero, 1999). This taxon fixes the upper age limit of the Passage Beds at ca 40Ma corresponding to NP 17. This age deduction is further substantiated by the ostracodes *Alocopocythere transcendens* Siddiqui and *A. abstracta* Siddiqui in the upper red beds below the quartzose sandstone (Bagi, 1992). The LAD of these taxa is in the lower part of the Drazinda Member (lower part of the Upper Chocolate Clays of Eames, 1952) of the Rakhi Nala section, which is also assigned to NP 17 (Koethe *et al.* 1988). *Striatriletes susannae* (van der Hammen) - a pteridophytic spore which is not known in the sediments older than late Eocene, though known from the younger sediments, is also recorded from the Passage Beds (=*Todisporites* Zone, Sarkar and Singh, 1998). The occurrence of the bivalve *Chlamys pakistanica* Eames in the Passage Beds (Mathur, 1969), so far known only from the *Pellatispira* Beds of Priabonian age, implies that the upper age limit of the Passage Beds may extend up to early Priabonian.

Correlation of vertebrate-bearing beds: The major departure between the present correlation (table 1) and the earlier ones concerns the stratigraphic position of the Kuldana Formation of the Kohat-Potwar sub-basin *vis-a-vis* the Passage Beds east of HKS. Both, having yielded rich vertebrate faunas, have been considered coeval and assigned an early Lutetian age (Kumar, 2000; Raza, 2001 among others). *While the Passage Beds (44Ma-40Ma) overlie the beds with datable larger foraminifera like* Assilina spira abrardi *and* Nummulites discorbinus *(SBZ 13-14), the Kuldana Formation underlies those of the SBZ 13, the Kohat Formation/Habib Rahi Member and hence stratigraphically older. Thus, notwithstanding their lithologic and vertebrate faunal similarities, there is an age difference of the order of 5.5 Ma between the two.*

While the Passage Beds were deposited during low-sea stand following the early Lutetian high-sea stand correlative with cycles TA3.2 and TA3.3, the beds of the Kuldana and coeval formations (Mami Khel, Baska) represent clastic shelf margin wedge deposits formed during the late Cuisian (Ypresian) regression correlative with cycle TA3.1 (between 49 Ma and 49.5 Ma) of Haq, Hardenbol and Vail (1987) and also of Gingerich, Arif, Bhatti and Clyde (1998) (Bhatia and Bhargava, 2003).

The age difference between the Passage Beds and the Kuldana Formation arrived at by us is close to the 4 Ma gap between the beds exposed at Banda Daud Shah of early Ypresian (=early Waasatchian) and the youngest (early Lutetian) for the Kalkaot fauna (Bridgerian) of Jammu arrived at independently by Thewissen *et al.*(2001) from the vertebrate fossils. Earlier workers (Russell and Zhai, 1987; Gingerich and Russell, 1990; Roe, 1991) had also pointed to the age difference between the Indian (Kalakot) and Pakistan (Kuldana) assemblages, stating that the Eocene red beds south of the Himalaya increase in age from east to west.

Another controversial aspect of the vertebrate fauna that concerns the Kuldana Formation is the record of the cetaecean *Pakicetus* from the Lower Kuldana Formation (Gingerich and Russel, 1981) and its age relative to another cetacean *Himalayacetus* recorded from the lower part of the Subathu Formation by Bajpai and Gingerich (1998, p. 15465) who state that "*Himalayacetus* is significant in being the oldest cetacean known to date, predating *Pakicetus* and its contemporaries by some 3.5 Ma. This supposed age difference is based on two wrong premises: (i) that the *Pakicetus*-bearing Lower Kuldana Formation is homotaxial with the Passage Beds (level of Kalakot fauna) and (ii) that *Himalayacetus*-bearing bed (Subathu Sub Zone III c, Mathur, 1978) is assignable to SBZ 8, based on the identification of *Nummulites atacicus* Leymerie (Mathur, 1978).

As discussed above, the Kuldana Formation is not coeval with the Passage Beds and ranges in age from 49.5 Ma to 49 Ma (also see Gingerich *et al.,* 1998). Insofar as the stratigraphic position of the *Himalayacetus*-bearing horizon is concerned, Bajpai and Gingerich (1998) state that it comes from the Sub Zone III c of Mathur (1978). This zone now redesiganted as Zone IV (Mathur and Juyal, 2000), is underlain by beds containing *Nummulites burdigalensis burdigalensis* de la Harpe (also see Bhatia and Bagi, 1993)--a fossil characteristic of SBZ 10 (early Cuisian) and overlian by Zone V containing *N. rotularis,* Deshayes also assignable to SBZ 10. This indicates that the *Himalayacetus*-bearing level lies towards the top of the SBZ 10, calibrated at 51.5-51Ma on the time-scale of Berggren, Kent, Swisher and Aubry (1995) by Serra-Kiel *et al.* (1998). Thus, based on the ages cited above *Himalayacetus* predates *Pakicetus* by *only* two million years and not by 3.5Ma as estimated by Bajpai and Gingerich (1998).

Sulaiman Range

Perhaps the most complete Palaeocene-Eocene sequence in the entire foreland basin is developed in Waziristan and Sulaiman ranges which formed the northern and eastern parts of the middle Indus Basin (Hemphill and Kidwai, 1973, Shah, 1977). For the sake of convenience we have followed the classifications of Kazmi and Jan (1977) and Raza (2001). The basal unit known as the Dungan Formation spans the entire Palaeocene with its base even extending into the Cretaceous. The Dungan Formation is conformably overlian by the Gazij Group of early to middle Eocene age and is divisible into three formations which in ascending order are: Shaheed Ghat, Drug and Toi. The Shaheed Ghat Formation mainly comprises olive green shales with intercalated marl beds, while the Drug Formation consists of orange to cream coloured limestone, which locally is nodular and argillaceous. The rocks of the Toi Formation overlie the Shaheed Ghat Formation where ever the Drug Formation is missing and is constituted of interbedded sandstone, mudstone, conglomerate with coal seams. This unit, rich in fresh water gastropods and plant remains, evidenlty represents a regressive phase. Although no larger foraminiferal data exist to indicate precise age of these formations, the samples of the Gazij (Shaheed Ghat Formation) examined by Haq (1972a, b) indicated that the lower and middle parts belonged to nannoplankton zone NP 12 of middle Ypresian age (*Marthasterites tribrachiatus* Zone). This age assignment is confirmed by Samanta (1972) who studied the planktonic foraminifera from the Rakhi Nala section and assigned them to planktonic foraminiferal zone P 8. This indicates that the entire Gajiz Group is of Cuisian age. The overlying Baska Formation which has long been considered to be the uppermost member of the Gazij Group includes the well known shales with alabaster unit of Eames (1952). The formation is recognized throughout the eastern foot-hills of the Sulaiman Range, but thins out towards Waziristan in the north. The formation has been correlated with the Mami Khel and Kuldana formations.

The overlying Kirthar Formation in the Sulaiman Range is perhaps one of the most extensively worked stratigraphic unit and is well known for its wealth of foraminiferal, nannoplankton, molluscan and vertebrate faunas. The stratigraphic framework suggested by Eames (1952) is still valid, though the nomenclature has been revised. The Kirthar Formation is now divisible into four members which in ascending order are Habib Rahi, Domanda, Pir Koh and Drazinda (Hemphill and Kidwai, 1973). The Habib Rahi Member, which corresponds to the Platy Limestone with *Assilina* Bed of Eames (1952), contains early Lutetian *Assilina spira abrardi* Schaub and other taxa assignable to SBZ 13. Koethe *et al.* (1988) assigned this member to NP 14 to NP 15, correlatable with high-sea stand TA 3.2 (Gingerich *et al.* 1998; Bhatia and Bhargava, 2003). This member can be confidently correlated with the *Assilina spira abrardi* Bed in several sections east of Hazara-Kashmir Syntaxis. The Habib Rahi Member gradually passes into the red shales of the Domanda Member (= Lower Chocolate Clays of Eames, 1952). Koethe *et al.* (1988) assign this member to NP 15 (*Chiphragmalithus quadratus* Zone). According to Gingerich *et al.* (1998) the Domanda Formation with characteristic lithology indicates deposition during middle Lutetian as shelf margin wedge during regression following the Habib Rahi high-sea Stand. The overlying Pir Koh Member marks a sudden change in lithology from red beds to white marl. Koethe *et al.* (1988) assign this member to NP 15-16. The overlying Drazinda Member is made up of olive green shale grading to brown gypseous shale interbedded with the *Discocyclina*-bearing limestone. The base of the *Discocyclina* limestone corresponds to NP 16 with its major part falling in NP 17 (Bartonian) (Koethe *et al.,* 1988). The upper most part of the Drazinda Member is assigned to NP 18-NP 19/20 (Priabonian) by Koethe *et al.* (1988). These age assignments are also corroborated by the ştudies of Samanta (1972) on plaktonic foraminifera, who assigned the Lower Drazinda, *Discocyclina* Bed and *Pellatispira* Bed to planktonic foraminiferal zones P 12-13, P 14, and P 15-17 respectively.

The middle to late Lutetian age assigned to the *Discocyclina* Bed and the overlying Drazinda Member (including the *Pellatispira* Bed) by Gingerich *et al.* (1998) is untenable in the light of the works of Samanta (1978) and Koethe *et al.* (1988).

CORRELATION OF THE MOLASSIC SEDIMENTS

The red shale and clastic Palaeogene molassic sediments constituting the foredeep-fill of the Himalayan foreland basin have a broad distribution and strike continuity in the fold-thrust belt on the either side of the HKS. The sediments which have been variously designated as Dumri, Dagshai/Kasauli, Dharamsala and Muree formations rest conformably over the Passage Beds in sections east of HKS including the Syntaxis and areas south of Hazara (Bhatia and Bhargava, 2002, 2005). As stated earlier, west of HKS there is an intra-late Eocene chronostragraphic gap between the Murree Formation and the underlying marine Eocene formations. Bossart and Ottiger (1989, fig. 3) attributed this chronostratigraphic gap to diachronity of the Murree sediments, the oldest being in the syntaxial region in the north and the youngest in the southwest in the Kohat region. The chronostratigraphic gap and the unconformity which is more pronounced in the Salt Range as compared to Kohat resulted in the erosion of the greater part of the Eocene sediments and their redeposition as reworked nummulitics in the lower most Murree sediments. The period of erosion (non-deposition) in the areas west of HKS corresponds to the period, during which the Lower Murree/Lower Dharamsala/Dagshai, spanning almost the middle to late Eocene, were being deposited in areas east of HKS and in the Sulaiman Range.

There is a general paucity of fossils in these formations and those that are present are poorly preserved and point to contradictory ages. The only fossils which till recently were considered to be age indicators are terrestrial vertebrate remains in the Fatehjang Bone Bed at the base of the Murree. This bone bed occurs in a conglomerate with reworked *Nummulites* derived from the underlying Eocene sequence. The vertebrate assemblage was earlier assigned an early Miocene age and compared with the fauna from the Chinji Formation. Similar vertebrate assemblage was later described in the coeval Bugti Bone Beds, Bugti Member (Chitrawata Formation) in the southern Sulaiman Range (Pilgrim, 1908, 1912) and also in Jammu (Ranga Rao, 1986). The early Miocene age assignment to the Fatehjang and Bugti Bone Beds led many workers to suggest a major hiatus involving late Eocene-Oligocene in the Himalayan Foreland Basin. With the exception of sections west of HKS (the Salt Range, Kohat, Potwar and Kala Chitta), where there is a chronostratigraphic gap between the marine Eocene formations and the overlying Murree Formation, discussed above, a biochronological continuity from the Subathu through the Passage Bed to the Dagshai has already been demonstrated (Bhatia and Bhargava, 2002, 2005) and also in the Sulaiman Range from the Kirthar Formation through the Nal Member to the Bugti Member (Welcome *et al.* 2001). Bhatia and Bhargava (2002, 2005) pointed to the occurrence of diagnostic late Eocene foraminifer *Linderina* in the basal Dagshai and also of a chara - *Harrischara vasiformis* (Reid & Groes) - diagnostic of late Eocene age (middle Bartonian-middle Priabonian) recorded from the Lower Dharamsala (Mathur, Mishra and Mehra, 1996). From the Upper Dharamsala of the same locality, Feist and Tewari (1999) reported three species of chara viz. *Chara microcera* Grambast & Paul, *Stephanochara ungeri* Fiest Castel and *Chara notata* Grambast & Paul. The first appearance datum of these taxa indicate that the basal part of the Upper Dharamsala may be of Chattian age. The palynological studies in the Changartalai well drilled in the Punjab Basin also indicate a late Eocene-Oligocene age for the Lower Dhramsala (Berry, Misra and Chopra, 1996).

The occurrence of artiodactyl *Leptomeryx* reported by Mehta and Jolly (1989) about 540m above the Subathu-Murree contact in the Kalakot area (Jammu) and other vertebrates (Ranga Rao, 1986) confirm that the upper part of the Lower Murree Formation is of Oligocene age. These vertebrate-bearing horizons, though not precisely dated within the Oligocene, are correlatable with the Fatehjang and Bugti Bone Beds. The controversial aspect of *Primus microps* de Bruijn *et al.* recorded by Kumar and Kad (2002) from the vicinity of the locality of *Leptomeryx* and their age assignment to early Miocene has been questioned by Bhatia and Bhargava (2005).

Marivaux, Vianey and Welcomme (1999) and Welcomme *et al.* (2001) have reviewed and re-evaluated the Bugti vertebrate fauna and assigned it a definite Oligocene age. Welcomme *et al.* (2001) reject the exisistence of the supposed Oligocene hiatus in the Sulaiman Range as traditionally accepted. Since the Bugti fauna is now assigned a definite Oligocene age, by analogy its equivalent Fatehjang fauna with which it has long been correlated should also be re-examined and assigned an Oligocene age.

On faunal and floral evidences cited above and discussed in detail by Bhatia and Bhargava (2002, 2005) and Welcomme *et al.* (2001), it is obvious that the basal Dagshai and Lower Dhramsala/Lower Murree can be assigned a late Eocene-Oligocene age, while the Bugti Member and Fatehjang Bone Bed should be assigned a definite Oligocene age (late Rupelian). The paucity of fossils and their sporadic occurrence in discontinuous sections, however, preclude a precise correlation of the fluviatile sequences of the Himalayan Foreland Basin.

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