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Biochronological continuity of the Paleogene sediments of the Himalayan Foreland Basin: paleontological and other evidences

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Abstract

The paleontological and field evidences presented in the paper demonstrate a biochronological continuity from the marine Subathu (Late Thanetian to Middle Lutetian) through the Passage Beds (Late Lutetian to Middle Bartonian) to the Dagshai and equivalent formations (Late Bartonian to Rupelian) of the Himalayan Foreland Basin, east of Hazara–Kashmir syntaxis. A similar continuity has also been demonstrated in the Sulaiman Range based on an assignment of Oligocene age to the Bugti vertebrate fauna, hitherto considered to be of Early Miocene age. Thus, the concept of a >10 Ma hiatus in the foreland basin based on $^{40}Ar/^{39}Ar$ dates of single detrital muscovite grains from the supposed basal Dagshai arenite is no longer tenable. While the occurrence of Cr-spinel and K–T boundary nannoplanktons in the Subathu Formation and Passage Beds indicate a westerly–northwesterly provenance, that of the radiolarian chert in the Dagshai and coeval formations indicates a northerly provenance from the Indus Suture Zone, coinciding with the first influx of the Himalayan detritus around 40 Ma.

Keywords: Himalaya; Foreland; Paleogene; Biochronological continuity; Paleontological evidences

1. Introduction

The Paleogene sequence of the Himalayan Foreland Basin east of Hazara–Kashmir Syntaxis comprising the Subathu, Dagshai and Kasauli formations was initially considered to constitute a continuous and conformable succession (Medlicott, 1864). Later discoveries of vertebrate assemblages (Pilgrim, 1908, 1910, 1912) from two horizons—Fatehjung Bone Bed (Murree Formation, Shah, 1977) and the Bugti Bone Bed (Bugti Member, Chitrawata Formation, Hemphill and Kidwai, 1973; Raza and Meyer, 1984) were assigned a Lower Miocene age. Subsequent correlation of the fossiliferous horizons with the Dagshai which overlies the Subathu Formation (Paleocene–Middle Eocene) implied that a major hiatus involving Late Eocene and whole of Oligocene existed in the Paleogene Foreland succession. This view found support from several workers and still finds a mention in Text Books in India.

This concept of a hiatus, however, was first questioned by Bhatia and Mathur (1965) who recorded ‘Passage Beds’ (lithologically akin to the Dagshai Formation) between the Subathu and Dagshai formations, containing fresh water molluscs. Subsequently, on field evidences, several workers (Bhandari and Agarwal, 1967; Ranga Rao, 1971; Batra, 1989; Najman et al., 1993) among others confirmed the passage from the Subathu Formation to the Dagshai Formation. This stratigraphic continuity was further confirmed by the discovery of a rich assemblage of invertebrates, vertebrates and palynomorphs in the Passage Beds and the Dagshai and equivalent formations.

Najman et al. (1997), however, on the basis of $^{40}Ar/^{39}Ar$ dates of single detrital muscovite (25–28 Ma) from the supposed Dagshai arenite samples, suggested a >10 Ma hiatus between the Subathu and Dagshai formations. This concept has been utilized by several workers for modeling of Himalayan tectonic evolution and the development of

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the Foreland Basin (DeCelles et al., 1998; Najman and Garzanti, 2000; Najman et al., 2001; White et al., 2001). All these workers overlooked the field setup and paleontological evidences of age diagnostic taxa (even though meager) from the Passage Beds and the Dagshai/Murree and equivalent formations. Besides, a perusal of these publications reveals that the radiometric dates are not only at variance among themselves and with the paleomagnetic and fission track dates, but also with the paleontologic evidences.

The present paper which addresses all these contradictions at length is a corollary to our communication presented at the 17th HKT Workshop at Gangtok, India (Bhatia and Bhargava, 2002). Our findings demonstrate a biochronological continuity from the Subathu Formation through the Passage Beds to the Dagshai and equivalent formations and negates a >10 Ma gap in the Himalayan Foreland succession.

2. Stratigraphic setup and provenance of the sediments

2.1. Stratigraphic setup

The Paleogene Foreland Basin sediments are subdivisible into the Subathu (=Bhainskati=Balakot), Dagshai (=Dumri=Lower Dharamsala=Lower Murree) and Kasauli (=Upper Dharamsala=Upper Murree) formations. These formations were regarded by Medlicott (1864) to have formed one continuous and conformable sequence. The Paleogene sediments are prominently exposed in the parautochthonous belt between Kashmir and Dadhau (Himachal Pradesh), east of Dadhau the belt attenuates and is tectonically concealed. Farther east, the Paleogene sediments intermittently reappear in Uttranchal, Nepal, Bhutan and Arunachal. In this paper we confine to the area between Hazara–Kashmir Syntaxis (HKS) and Nepal (Fig. 1).

2.2. Subathu Formation s.s.

The Subathu Formation initially was assigned an Early to Middle Eocene age. Later, definite Paleocene fossils were discovered in the basal part designated as the Kakra Series (Srikantia and Bhargava, 1967). In our opinion it should be referred to as the Kakra Member as lithologically this sequence is indistinct from the main Subathu, hence not mappable.

The basal part of the Subathu Formation comprises local chert breccia, poor quality coal, carbonaceous shale, green shale and limestone. The overlying sequence is made up of olive green splintery shale, lenticular limestone beds and

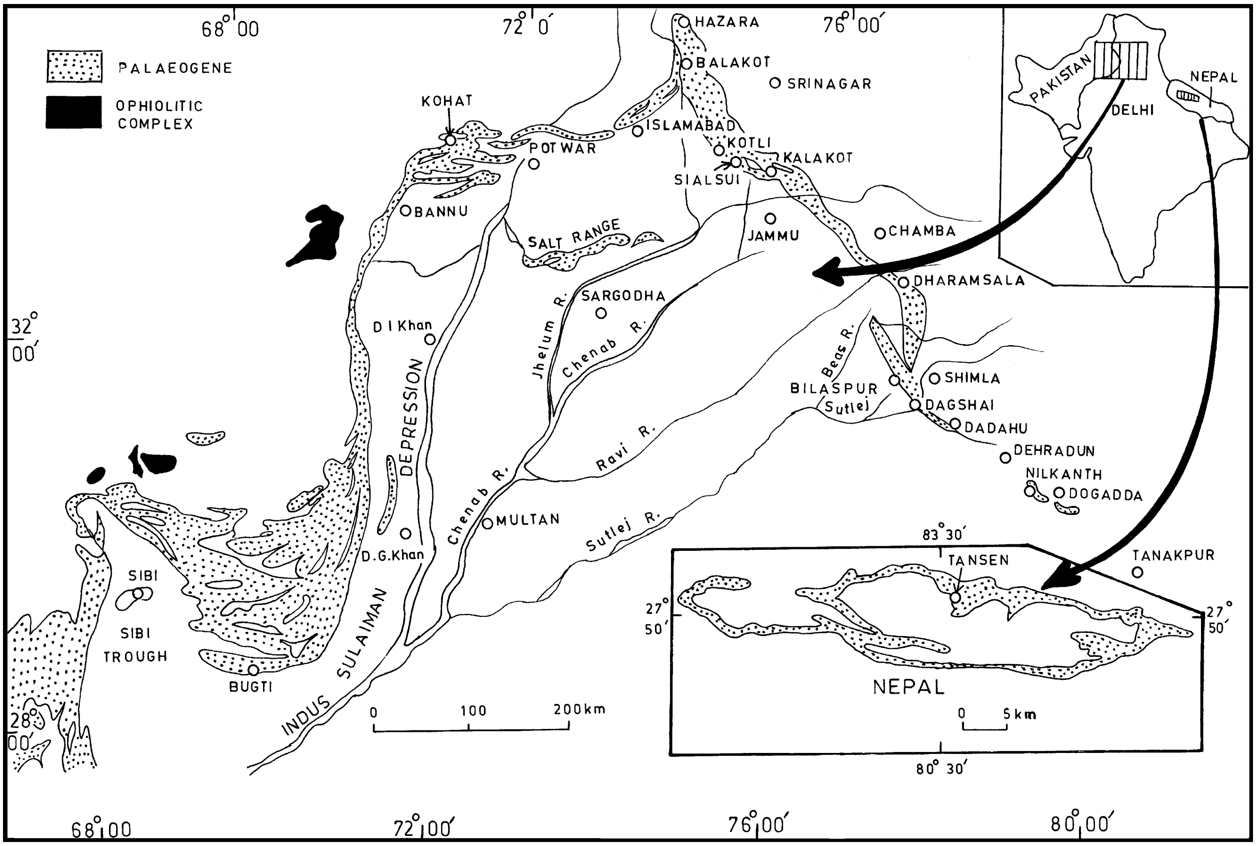

Fig. 1. Distribution of the Paleogene sediments of the Himalayan Foreland Basin.

rare green sandstone. In Nepal, its equivalent, the Bhainskati Formation consists of carbonaceous shale with several intercalated limestone and marl bands rich in bivalves and larger foraminifera in the basal 130 m of the sequence (Sakai, 1983). In the Hazara–Kashmir Syntaxis, the equivalent Balakot Formation with several foraminifera-bearing marl beds (Bossart and Ottiger, 1989; Najman et al., 2001) is structurally intercalated with the red beds of the Murree Formation.

The lower part of the Subathu Formation represents sedimentation in euxinic and evaporitic environments in protected lagoons of an embayment. Most of the sediments were deposited in a shallow sea with some tidal attributes in an embayment having well developed mud zones and tidal flats (Singh, 1978).

Chrome spinel, ophiolitic detritus and reworked nannoplanktons constitute important detrital components of the Subathu as well as the Passage Beds (Bossart and Ottiger, 1989; Critelli and Garzanti, 1994; Najman and Garzanti, 2000; Jafar and Kapoor, 1988; Jafar and Singh, 1992). The significance of these components is discussed under provenance.

2.3. Passage Beds

In all the tectonically undisturbed sections, the Subathu Formation is succeeded by a variegated sequence comprising alternation of green and red shales. This sequence forms a transition from predominantly green facies of the Subathu to the red facies of the Dagshai. Depending upon the bias, this sequence has been variously grouped by different workers as the upper most part of the Subathu or basal part of the Dagshai.

As envisaged initially by Bhatia and Mathur (1965) and later re-interpreted by Bhatia (2000) the Passage Beds in the Fold-thrust Belt comprise the green and red bed sequence between the last appearance of larger foraminifera and the first appearance of massive white to greenish quartzose sandstone constituting the base of the Dagshai/Dharamsala/Murree formations. Their distinctive lithology facilitates easy recognition in the field (Ranga Rao, 1986; Bhatia, 2000).

The Passage Beds correspond to the units H, I, and J of the Kotli area in Pakistan occupied Kashmir (Wells and Gingerich, 1987), Beds 3d, 3e, 3f, and 3 h, measuring approximately 35 m (Bossart and Ottiger, 1989, Fig. 7) of the Hazara–Kashmir syntaxis, 'transitional zone' between the Kala Chitta Group (Eocene) and the Murree Formation (Oligocene) of Hazara area (Calkin et al., 1975). In the Jammu area, they are designated as the Kalakot Zone (Ranga Rao, 1986), corresponding to Zones viii and ix (Mathur, 1978), Zone iii (Batra, 1989), and Zone vii (Mathur and Juyal, 2000a). In Nepal, the 30 m thick sequence forming the upper most part of the Bhainskati Formation comprising red and green shales, bioturbated mudstone, oolitic silty sandstone, lamellar haematitic sandstone capped by a 5 m oxysol zone (DeCelles et al., 1998) is correlatable with the Passage Beds (Bhatia, 2000).

The environment of deposition of the Passage Bed varied from one area to another. In Nepal, the oolitic ironstones in the Passage Beds, indicate shallow agitated marine water with low rate of sediment influx and abundant source of ferric oxide from a highly weathered landmass (DeCelles et al., 1998). Flooding during high wind/tide under prolonged exposure resulted in the deposition of purple shales in supratidal zone (Singh and Andotra, 2000). Wells and Gingerich (1987) regarded the vertebrate and pulmonate gastropod bearing red bed sequence in the Kotli area as on-shore pedogenised clays representing slow sedimentation. Srivastava and Kumar (1996) interpreted the sequence in the Kalakot area to represent fluvio-deltaic environment.

Perhaps the most congenial environment for fossilization prevailed in the area now part of the Shimla Hills where the absence of haematite rich beds, presence of several oyster rich beds, red mudstone rich in bivalves, brackish water ostracodes and arenaceous foraminifera and presence of even two species of nautiloids (in Garkhal locality, Juyal and Mathur, 1994) indicate occasional open-sea connections.

2.4. Dagshai and equivalent formations

Mapping by the Oil and Natural Gas Commission has shown that the Lower Dharamsala of the Dharamsala–Palampur region (Kangra) is in strike continuation with the Dagshai Formation of the Bilaspur tectonic unit in the Shimla Hills (Karunakaran and Ranga Rao, 1979). Similarly, the continuity of the Murrees of the Jammu area across the border and around Hazara–Kashmir syntaxis with the type area in Potwar has been demonstrated by Calkin et al. (1975) and Ranga Rao (1986).

The base of the Dagshai, Dharamsala and Murree formations, as also of the Dumri Formation in Nepal, invariably commences with a medium to coarse grained white to greenish quartzose sandstone which everywhere rests on the variegated red, purple and green shales of the Passage Beds (Bhatia, 2000, Plate, 1A, B). It thus forms a marker bed in almost all the sections from Hazara–Kashmir syntaxis to Nepal. Elsewhere, as in Pakistan (e.g. Kohat, Kala Chitta and Salt Range) where an erosional unconformity separates the Murree from the underlying marine Eocene sequence, reworked nummulitics, alveolines and other foraminifera have been recorded. The magnitude of this unconformity is attributed to the time transgressive nature of the Murree Formation (Bhatia and Bhargava, 2003). The sequence above the marker sandstone comprises alternation of fine, medium-coarse grained sandstone with red mottled shale, local conglomerate lenses and calcrete horizons with argillite dominating the arenite. The calcrete horizons commonly yield terrestrial vertebrate fossils and charophytes (Mehta and Jolly, 1989). Eleven calcrete horizons have been recorded in the Jammu area in the Lower Murree Formation (Singh, 2000) each of which is supposed to represent a time span of 10 Ka (Ranga Rao, 1986).

The sandstones in the basal part of the Dagshai contain reworked fragments of radiolarian chert (Dutta and Singh, 1975; Najman and Garzanti, 2000; Critelli and Garzanti, 1994). Singh and Singh (1995), DeCelles et al. (1998), Singh (2000), and Najman and Garzanti (2000) have described the detailed petrography, sediment dispersal pattern and paleocurrents of the Dagshai and equivalent formations.

While most of the earlier workers regarded the sediments of the Dagshai and equivalent formations to be of fluviatile origin, Singh (1978) interpreted the Dagshai sediments to represent estuarine complex in an oxidising environment, where main sedimentation took place in extensive flats. Singh and Singh (1995) have cited evidences of tidal influence. In Nepal, thick sandstone bodies showing fining upward lenticular unit with erosional base are regarded to be fluvial channel deposits (DeCelles et al., 1998).

2.5. Provenance of sediments

A significant feature of detrital component of the Paleogene sediments is the occurrence of Cr-spinel and ophiolitic detritus and reworked K–T boundary nannoplanktons in the Subathu and equivalent formations and in the Passage Beds (Red Subathu) and of reworked radiolarian chert fragments in the Dagshai and equivalent formations.

The input of Cr-spinel and ophiolitic detritus reached a maximum in the Lutetian times pointing to increase in supply from arc-trench system source (Critelli and Garzanti, 1994). Similar increase in the percentage of Cr-spinel was also noticed by Najman and Garzanti (2000) from the Passage Bed. We do not concur with the view that the Cr-spinel was derived from the ophiolites of the Indus Suture Zone (ISZ) as suggested by Najman and Garzanti (2000). The validity of using Cr-spinel chemistry as an indicator of the provenance has been questioned by Power et al. (2000). The existence of a marine basin in the Zanskar region until Late Cuisian (SBZ12, Kong Formation) followed by a piggy-back molassic basin (Chulung La Formation) in the Middle and Late Lutetian times (Mathur and Juyal, 2000b) must have acted as a barrier for transport of sediments from ISZ to the Foreland Basin. In our opinion the Zhob–Waziristan–Khost ophiolitic Complex (Pakistan) which is known to have contributed mafic and volcanic detritus to the Toi, Kuldana and other formations (Warwick et al., 1998; Raza, 2001) in all probability provided the source for the Cr-spinel and ophiolite detritus recorded in the Subathu and equivalent formations.

Further clues to the westerly and northwesterly provenance of the Subathu sediments are provided by the occurrence of reworked K–T boundary nannoplanktons which have been reported from different stratigraphic levels in the Eocene Gazij Group and Panoba Shales in Pakistan (Koethe et al., 1988) and also in the Subathu s.s. and the Passage Beds in the Shimla Hills (Jafar and Kapoor, 1988; Jafar and Singh, 1992). The same species as those recorded from Pakistan and Shimla Hills are found in the Late Cretaceous Parh Group sediments in northern Baluchistan and in the Darsamand Formation of the Kohat area. In order to explain the occurrence of reworked nannoplanktons, Jafar and Kapoor (1988) suggested that an arm of the Late Maastrichtian sea extended from the Assam–Arakan region into the Lesser Himalaya. This view is untenable. These authors were apparently unaware of the earlier work of Koethe et al. (1988) and also about the occurrence of geographically much closer Late Maastrichtian outcrops of the Kawagarh Limestone in the Hazara area, considered equivalent to the Parh Group and Darsamand Formation (Calkin et al., 1975), which are more likely to be the source of the reworked nannoplanktons.

In so far as the provenance of the reworked radiolarian chert fragments in the Dagshai and Lower Murree arenites are concerned, we ascribe them to the first large scale appearance of the Himalayan detritus around 40 Ma from the volcano-sedimentary sequences associated with the Spontang and Nidar ophiolite which must have been exposed to erosion concurrently with the un-roofing of the proto-Himalayan thrust stacks.

3. Conflicting radiometric and other dates of the Dagshai and equivalent formations

The radiometric, paleomagnetic and fission track dates of the Dagshai and equivalent formations, listed below, give contradictory ages. These dates are evaluated in the sequel to find out the causes of contradictions.

3.1. Radiometric dates

Najman et al. (1997) based on ^{40}Ar/^{39}Ar dates of single detrital muscovite from two samples of supposed Dagshai sandstone (Sample No. 90-29F at Locality 1 and 91-12G at Locality 2) gave <25 and <28 Ma ages indicating a break between the Subathu and Dagshai formations exceeding 10 Ma, covering Late Eocene–Oligocene. Detailed field work and also critical perusal of earlier geological maps (Auden, 1934; Karunakaran and Ranga Rao, 1979, Sheet B) reveal that no Dagshai outcrop exists at Locality 1 of Najman et al. (1997) (Fig. 1), or even in its vicinity. The red coloured rocks exposed at this locality, apparently simulating Dagshai, belong to the Nahan Formation (=Lower Siwalik) instead. The location of the second sample is ambiguous. It falls close to the MBF (sensu stricto) along which the Nahan rocks are juxtaposed against the Subathu. Since this sample too has yielded comparable dates, there is but little doubt that it also came from the Nahan rocks. Thus, the <25 and <28 Ma ages are of the Nahan rocks and not of the Dagshai Formation. The anomaly between the radiometric dates and fossil and field evidences is, therefore, due to sampling of wrong horizon and has no relevance to the Subathu–Dagshai relationship. It is interesting to note that Najman et al. (2000) obtained 36–40 Ma $^{40}Ar/^{39}Ar$ date of single detrital muscovite from the homotaxial Murree Formation of Hazara–Kashmir Syntaxis area—a date more in conformity with paleontological findings presented in our paper.

3.2. Paleomagnetic dates

Paleomagnetic dates provided by Klootwijk et al. (1986) for Lower Murree of the Kalakot area, Jammu, by Najman et al. (1994) for the Dagshai Formation from several localities in Himachal Pradesh and by Gautam (1989) for its equivalent Dumri Formation in Nepal, are Middle Eocene, 35.5 ± 6.7 and 40 Ma, respectively. These dates are more or less in conformity with the ages indicated by fossil evidences.

White et al. (2001), however, assigned an age of 20 Ma for the base of the Lower Dharamsala from the Birdhar–Chimnun section. From this very section, Mathur (1984) recorded Middle to Late Eocene palynological assemblage from the Lower Dharamsala Formation. The magnetic polarity data, totally divorced from corroborative fossil evidence carry little conviction.

3.3. Fission track dates

Fission track (FT) dating of zircon from the Dagshai suggests 23–33 Ma (Lal et al., 1998) and also 30.9 ± 1.6 Ma (Najman et al., 1999). The precise stratigraphic levels of these samples are not known, if from the upper part of the sequence, these dates more or less corroborate the fossil evidence discussed in the sequel. However, between fossil evidence and FT dates, the former a time tested criterion, is always preferable.

4. Paleontological evidences

Paleogene sequences of the Himalayan foreland basin comprise a series of interbedded marine and non-marine strata. Except for certain sections in the Sulaiman and Salt Ranges, the marine strata in other sections (particularly in the Fold-thrust Belt south of MBT) lack important biostratigraphic markers such as planktonic foraminifera. The age determination and chronostratigraphic correlation of such marine sequences is based mainly on larger foraminifera, ostracodes and nannoplanktons and those of non-marine and terrestrial sequences on ostracodes, charophytes, palynomorphs and mammals. We do not concur with the view of Thewissen et al. (2001) that the larger foraminifera and the pattern of transgression and regression do not yield reliable means of chronologic correlation of the Eocene sediments south of the Himalaya. We ascribe the problem in identification and correlation referred to by Thewissen et al. (2001) more to incorrect identifications and lack of taxonomic revision of Nummulitidae following Schaub (1981) monographic work and the non-recognition of shallow benthic zones of Serra-Kiel et al. (1998) rather than to non-reliability of the larger foraminifera as tools of age determination and correlation. Correlation based on the biostratigraphy of the archeocete Cetacea and their relation to sequence stratigraphy has been attempted by Bajpai and Gingerich (1998) and Gingerich et al. (1998) and the palynological zonation by Singh et al. (1978) and Sarkar and Singh (1998) among others. Fossils crucial for age fixation are discussed in the sequel and tabulated in Fig. 2.

4.1. Subathu Formation s.s.

The foreland basin was initiated in late Thanetian times (56 Ma) as is evident from the occurrence of *Daviesina garumnensis* in the basal Subathu (= Kakra Member) in the Jammu and Kurla areas (Bhatia and Syed, 1988; Mathur and Juyal, 2000a). This foraminifer is characteristic of the Tethyan Shallow Benthic Zone SBZ 4 (Serra-Kiel et al., 1998). Diagnostic foraminifera of Shallow Benthic Zones SBZ 5–SBZ 12, spanning the entire Ilerdian and Cuisian have also been recognized (Batra, 1987, 1989; Bhatia and Bagi, 1993; Mathur and Juyal, 2000a).

The early Lutetian sequence SBZ 13 with its diagnostic taxa *Assilina spira abrardi*, *N. lehneri* and *N. obesus* is recognized in almost all the sections in the Shimla Hills and Jammu (Bhatia and Bagi, 1993; Mathur and Juyal, 2000a; Bhatia, unpublished data) and also in the Hazara–Kashmir Syntaxis (Bed 3C, Bossart and Ottiger, 1989). The *A. spira abrardi* bed (2–3 m thick whitish-brown packstone with large sized assilines, nummulitics and oysters) is a very distinctive lithological marker of the Subathu Formation and is correlatable with the Habib Rahi Member (Kirthar Formation) of the Sulaiman Range, Waziristan and Kohat (Hemphill and Kidwai, 1973) which includes the Platy Limestone and *Assilina* bed of Eames (1952). This member (15–150 m thick) also forms a persistent ridge which is an excellent marker in the field (Hemphill and Kidwai, 1973). Based on nannoplanktons, Koethe et al. (1988) assign the Habib Rahi Member to the nannoplankton zone NP 14–NP 15. It is also correlative with high sea stand in sea-level cycle TA 3.2 (Early Lutetian) of Haq et al. (1987) and Gingerich et al. (1998).

The *A. spira abrardi* bed in the Shimla Hills and Jammu area is overlain by a marl bed containing *N. discorbinus*, *A. exponens* (form A), *A. papillata* (Bhatia and Bagi, 1993; Bhatia, 2000; Mathur and Juyal, 2000a; Bhatia, unpublished data). This bed marks the last appearance of larger foraminifera assignable to SBZ 14 (Middle Lutetian) constraining the upper age limit of the marine Subathu s.s. at Ca 44 Ma. The upper age limit in other sections of the Subathu and also in Nepal (of Bhainskati Formation) is not

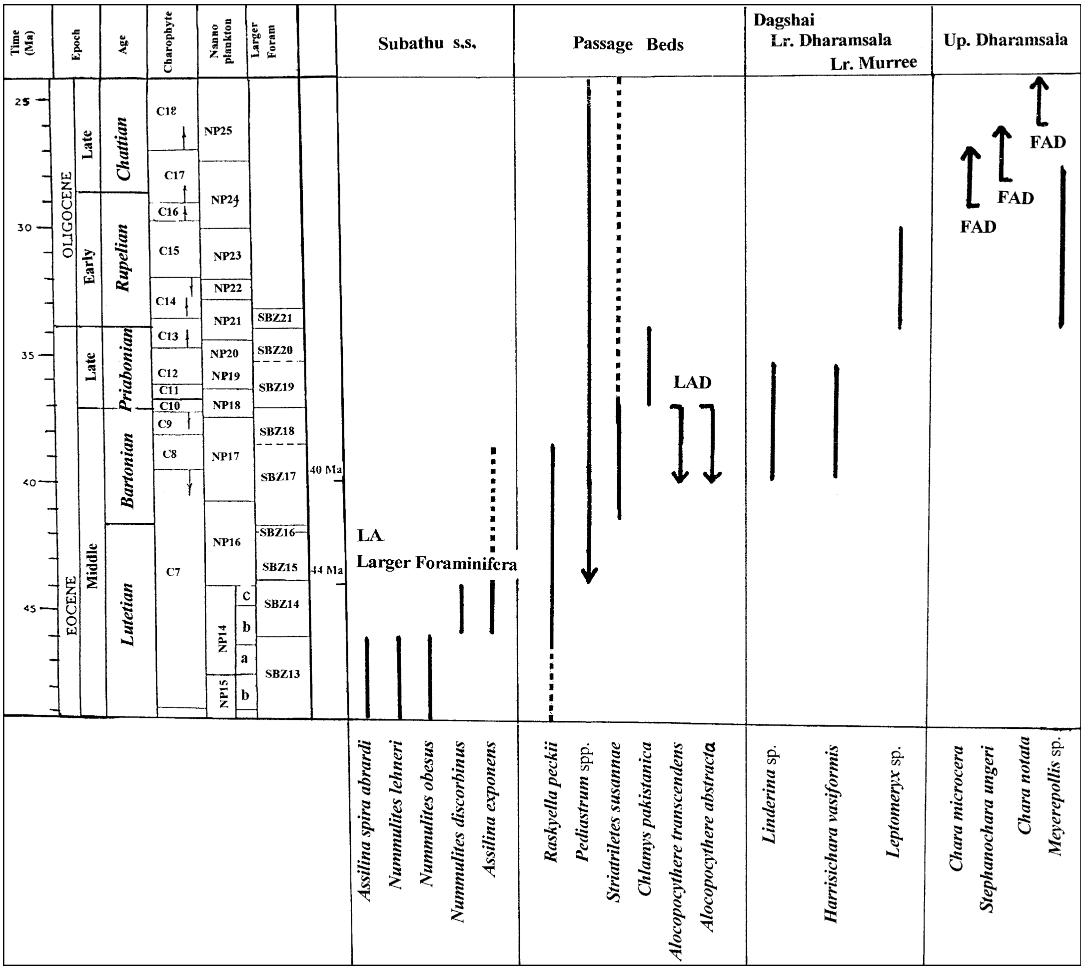

Fig. 2. Known stratigraphic ranges of age diagnostic fossil taxa of the Subathu Formation s.s., the Passage Beds and the Dagshai and equivalent formations east of Hazara–Kashmir Syntaxis (solid line indicates ranges in the Himalayan Foreland Basin; dashed line indicates ranges elsewhere; LA, last appearance; LAD, last appearance datum; FAD, first appearance datum). Time scale after Berggren et al. (1995), Charophyte zonation C1 to C18 after Riveline et al. (1996), Charophyte zones beginning *Pekichara llobrigatensis* (C1) upto *Chara notata* (C18); Nannoplankton zonation after Martini (1971); larger foraminifera shallow benthic zonation (SBZ) after Serra-Kiel et al. (1998).

precisely constrained. Sakai (1983) and Matsumaru and Sakai (1989) record only two species, *N. beaumonti* and *A. papillata*, from two levels—30 and 50 m—from the base of the Bhainskati Formation. Both these species are known to range from SBZ 15 to 17, though they have also been recorded from lower stratigraphic levels (Bhatia, unpublished data). Tewari and Gupta (1976) recorded seven taxa of larger foraminifera from the Surkhet Valley in western Nepal. All these taxa are of Early Eocene age, except *N. dojkdjakartae* which is of Late Eocene age.

The absence of larger foraminifera in the overlying Passage Beds indicates commencement of regression in the foreland basin ca. 44 Ma. A similar conclusion based on other criteria was also arrived at by Pande (1986).

4.2. Passage Beds

The rich fossil fauna and flora of the Passage Beds have been reviewed by Bhatia (2000) and the vertebrate fauna by Kumar (2000). Here we highlight only those fossils which have a bearing on the upper age limit (minimum) of the Passage Beds.

The marl bed with *N. discorbinus* SBZ 14 gradually passes from green shales through brownish to reddish brown shales indicating shallowing upward cycle of marine regression. These red beds are correlatable with the Domanda Member (Hemphill and Kidwai, 1973) (=Lower Chocolate Clays of Eames, 1952). Koethe et al. (1988) and Haq (1972a,b) assigned this member to nannoplankton zone NP15 (*Ciphragmalithus quadratus* Zone). It is at this stratigraphic level that the fresh water alga *Pediastrum* appears in large numbers in the Rakhi Nala section of the Sulaiman Range (Koethe et al., 1988) and also in the Passage Beds in the Shimla Hills (Singh et al., 1978; Singh and Khanna, 1976). In certain sections, this alga occurs in bloom constituting 90% of the palynological assemblage. This denotes an event of rapid influx of fresh water in the foreland basin. The influx of fresh water also brought a diagnostic charophyte—*Raskyella peckii*—recorded from the Koshalia river section. This taxon was originally identified as a new species *R. feisti* by Bhatia and Bagi (1991), but later considered a junior synonym of *R. peckii* Grambast and Grambast (Bhatia, 2000). This species in Europe ranges from SBZ13 to middle of SBZ17 and NP17 (Early Lutetian to Middle Bartonian) (Riveline et al., 1996; Martin-Closas et al., 1999). Two ostracode taxa—*Alocopocythere transcendens* and *A. abstracta*—also occur in abundance in the upper red beds below the quartzose sandstone (Bagi, 1992; Mathur and Juyal, 2000a). Although these two species also occur at lower stratigraphic levels, they reached their LAD in the Passage Beds. In the type area in the Rakhi Nala section also, the LAD of these two taxa is in the Drazinda Member (= lower part of Upper Chocolate Clays of Eames, 1952) (Siddiqui, 1971, 1983) also assigned to NP17 (Bartonian) (Koethe et al., 1988). A broad regional correlation of the Paleogene sequences in the entire foreland basin has been attempted by Bhatia and Bhargava (2003).

A Late Eocene taxon—*Striatriletes susannae*—an aquatic pteridophytic spore of the family Parkeriaceae, has been recorded from the *Todisporites* spp. Zone (= Passage Beds) of the Banethi—Bagthan area in Himachal Pradesh. The species is distributed in Late Eocene and younger sediments in India and elsewhere and has so far not been recorded from strata older than Late Eocene (Sarkar and Singh, 1998, p. 92). Yet another significant Late Eocene species—*Chlamys pakistanica* Eames—a bivalve, has been recorded from the Garkhal section (Mathur, 1969; Mathur and Juyal, 2000a). This species has been recorded only from the upper part of the Drazinda Member (the *Pellatispira* Bed of Eames, 1952), implying that the upper age limit of the Passage Bed may even extend to Early Priabonian. The record of two species of *Nautilus*, also from the Garkhal section (Juyal and Mathur, 1994) appears to be ecologically significant as it indicates the persistence of normal marine conditions during the deposition of the Passage Beds or an open sea connection, probably resulting from a short lived high-sea stand.

From the foregoing discussion of the age diagnostic taxa of the Passage Beds and the general environment of deposition as revealed by the rich and varied fossil fauna and flora it is obvious that the Passage Beds were deposited following the high-sea stand during Early Lutetian (Cycle TA 3.2) during which *A. spira abrardi* Bed/Habib Rahi Member were deposited. Unlike the Sulaiman Range where several global sea level changes are identified during the deposition of the Kirthar Formation and have helped in working out the sequence stratigraphy (Gingerich et al., 1998), similar sea-level changes cannot be identified in the Passage Beds which span the same time frame as the Domanda-Pir Koh-Drazinda Members (partim) viz. Middle Lutetian to Bartonian, perhaps even Early Priabonian. The global changes in small depositional basins, like those which had obviously come into existence during the deposition of the Passage Beds during the withdrawal of sea are dependant on local factors like tectonism, subsidence and climate (Miall, 1977). It is, however, more likely, that the Early Tertiary record of transgressions and regressions in northern Pakistan and India was controlled by Himalayan tectonism rather than by global eustasy (cf. Pivnik and Wells, 1996). This led Thewissen et al. (2001) to question the use of sea-level changes for determining the chronology of the depositional sequences.

4.3. Dagshai–Kasauli/Dharamsala/Murree formations

Although there are several sporadic records of palynomorphs, leaf impressions, molluscs, ostrocodes and vertebrates from these formations, only those having age connotation are discussed here. Notwithstanding the paucity of fossils, the few that are age diagnostic occur in a proper chronological order and at the same stratigraphic level at which they occur in other regions.

In thin sections of the coarse grained gray to purple arenites of the Dagshai Formation, exposed between Kumarhatti and Dagshai, one of us (SBB, unpublished data) has recorded frequent specimens of *Linderina*, besides fragments of *Araucaria* wood and radioloarian chert. The occurrence of this marine foraminifer, which ranges from Late Bartonian to Priabonian (Loeblich and Tappan, 1988) in a fluviatile estuarine sequence indicates an ephemeral marine transgression during Late Eocene times. This surmise is in harmony with the views of Singh (1978) who had suggested, on sedimentological evidences, the existence of marine influence during the deposition of the Dagshai Formation.

Other records of *Linderina* from this basin are from the Drazinda Member (= Upper Chocolate Clays, Fossil Zone 12, Eames, 1952) between the *Discocyclina* Bed and *Pellatispira* Beds of the Sulaiman Range in Pakistan. This sequence in Pakistan is assigned to nannoplankton zone NP17. The basal Dagshai may also be assigned to Late Bartonian and Early Priabonian, the known stratigraphic range of *Linderina*.

Further convincing evidence about similar time-frame for the deposition of the homotaxial Lower Dharamsala sediments is provided by the occurrence of the charophyte assemblage—*Harrischara* cf. *vasiformis, Nitellopsis* (*Tectochara*) *latispira*, *Rhabdochara* sp., and *Chara* sp., from the Dharamsala area (Mathur et al., 1996). Of these, only *H.* cf. *vasiformis* is well preserved. Although Mathur et al. (1996) were tentative about this identification, comparison with topotype material available with us confirms this identification. This species in Europe ranges from Middle Bartonian to Middle Priabonian (the same time range as *Linderina*) (base of *Chara fritelli* Zone to base of *H. vasiformis tuberculata* Zone) corresponding to the base of NP17 to the base of NP19 (Riveline et al., 1996; Soulié-Märsche, personal communication SBB).

Palynological evidence, though not precise, corroborates the age indicated by *H. vasiformis* and *Linderina*. From the samples of the Lower Dharamsala, collected from the Birdhar-Chimnun and other areas in the Kangra district, Mathur (1984) assigned a late Middle Eocene to early Late Eocene to the upper part of the Lower Dharamsala. These age assignments, however, are based on identifications, in most cases, up to generic level.

From the palynological studies of the Changartalai well (105–4968 m) drilled in the Punjab Basin, Berry et al. (1996) have identified five palynozones (Oppel Zones) of which the lower two are assigned to the Lower Dharamsala. The lower most zone is called the *Psilodiporites hammenii–Proxaperites operculatus* Zone on the LAD (first down hole occurrence of these two taxa) and assigned a late Early Eocene–Middle Eocene age. The second zone is called the *Spinizonocolpites echinatus–Morgocolporites sahnii* Zone (LAD of these taxa) and assigned a Late Eocene–Oligocene age. Incidentally, the Upper Dharamsala in the well section is assigned an Early Miocene age.

In so far as the age of the Upper Dharamsala is concerned, the palynological and the charophyte evidences point to an Oligo-Miocene age for its upper part. Mathur (1984) assigned a late Late Eocene–Oligocene age to the lower and an Oligocene age to the middle parts of the Upper Dharamsala based on abundance of the characteristic Oligocene taxon *Meyerepollis*. The evidence of the charophyte flora (Fiest and Tewari, 1999) from the Upper Dharamsala is also indicative of an Oligo-Miocene age. Of the various taxa recorded by them, three taxa viz. *Chara microcera*, *Stephanochara ungeri* and *Chara notata* first appeared at 29.5, 28.5 and 26.5 Ma, respectively, suggesting a late Rupelian–Middle Chattian age (Riveline et al., 1996). These taxa continue until Early Miocene. *S. ungeri* has also been recorded from the Kasauli Formation (Arya, 1997) suggesting a similar age for this formation.

Based on the aforementioned palynological and charophyte evidences, we surmise that the Lower Dharamsala (=Dagshai) is of Late Eocene–Oligocene age and the Upper Dharamsala (=Kasauli) of Oligo-Miocene age. It is difficult to precisely place the Eocene–Oligocene boundary as the fossils come from discontinuous and widely separated sections. Similarly, the upper age limit of the Upper Dharamsala cannot be precisely defined from the available paleontological data.

The only records of age diagnostic vertebrate faunas are from the Lower Murree sediments exposed near Jigni and Sial Sui, near Kalakot, Jammu. The vertebrate fossils which occur mainly in the calcrete horizons were first recorded by Ranga Rao (1986) from the Sial Sui locality. Although the fauna is poorly documented, it is comparable with the Bugti Fauna, now assigned to Oligocene (see discussions below). The taxa listed by Ranga Rao (1986) include *Teleoceras* sp. cf. *T. fatehjungensi* (Perissodactyla), *Paleochoerus* sp., *Gonotelma* sp. and *Microbunodon* (Artiodactyla). From the Upper Murree *Dinotherium pentapotamiae* is reported.

Mehta and Jolly (1989) described well-preserved left upper molars of an artiodactyle—*Leptomeryx*—from the Lower Murree section exposed NE of Sial Sui at Jigni (Loc. 1). The fossils were recovered from a calcrete horizon 575 m above the Subathu/Murree contact. Although diverse leptomericids are known from the Late Eocene–Miocene of Africa, Asia, Europe and N. America, the genus *Leptomeryx*, prior to its record from Jammu, was known only from N. America. Although the identification is only up to generic level, the species, according to Mehta and Jolly (1989), shows affinities with N. American *L. mammifer* (Late Eocene to Middle Oligocene) in size and with *L evansi* (Middle to Late Oligocene) in morphology.

Besides the *Leptomeryx* from Locality I, Mehta and Jolly (1989) also mentioned the occurrence of rodents, bivalves and charophyte gyrogonites in the adjacent locality near Sial Sui (Locality II), possibly the same as the one mentioned by Ranga Rao (1986). The base of this section is disturbed and its relation with the Subathu/Murree contact is uncertain. From this second locality at Sial Sui, Kumar and Kad (2002) have reported a solitary left upper molar of a cricetid rodent *Primus microps* De Bruijn et al. (1981). This species was first described from the basal ‘Murree’ near Banda Daud Shah, Kohat district, Pakistan and assigned an Early Miocene age. This fossil record is from a small isolated outcrop of the Lower Murree, whose precise stratigraphic level is uncertain. Their section II at Sial Sui is located about 2 km downdip from where *Leptomeryx* was reported (Locality 1) at which the Subathu/Murree contact is exposed. It is, thus, obvious that the *Leptomeryx* and *Primus* bearing calcrete horizons cannot belong to the same stratigraphic level—the latter being definitely younger (?Upper Murree) and hence not in conflict with the Oligocene age of the *Leptomeryx* bearing Lower Murree at Jigni. Incidentally, the diverse rodent assemblage comprising *Primus microps* described by De Bruijn et al. (1981) includes all new species and genera and a few inderminate taxa. Their claim of the fauna having affinity with the Chinji fauna of Early Miocene age is not well founded.

In a recent publication, Kumar and Kad (2003) describe and illustrate additional vertebrate fossils from the same locality and horizon as *Primus microps*. Besides the long-ranging taxa, the assemblage also includes two characteristic Oligocene taxa—*Menoceras* (Rhinoceratid) and *Microbunodon* (earlier also recorded by Ranga Rao, 1986). In Europe, both these taxa are restricted to Middle–Late Oligocene. Accordingly, these authors did not rule out the possibility of the Murree Formation extending into Oligocene.

From the foregoing discussions regarding the records of definite Oligocene taxa like *Leptomeryx*, *Menoceras* and *Microbunodon* from the Lower Murree, Oligocene palynomorph *Meyerepollis* and of Oligo-Miocene charophytes from the Upper Dharamsala besides several late Middle Eocene to Late Eocene taxa discussed earlier under the Passage Beds and the Lower Dharamsala demonstrate that the supposed Late Eocene–Oligocene hiatus does not exist in the Fold-thrust Belt of the Himalayan Foreland

Basin. Our surmise is corroborated by the recent work of Marivaux et al. (1999) and Welcomme et al. (2001) who have described and re-evaluated the vertebrate faunas known from the Bugti Bone Bed (Bugti Member, Chitrawata Formation) of the Sulaiman Range. The newly described cricetid rodent fauna from the Bugti Member not only represents the first, but also the oldest Paleogene record of the family in the Indian subcontinent. The record of primitive species of *Pseudocricetodon* from the Bugti Member is of great significance since this genus was known only from the Early Oligocene (MP23) of Europe. According to Welcomme et al. (2001, p. 403), "These results demonstrate that the continental Oligocene hiatus does not occur in the Sulaiman geological province as traditionally accepted." These authors also reject the views about endemism of any rodent fauna and of the existence of any hetrochronus elements and conclude (p. 401) that, "…the hypothesis of faunal isolation of the Indian subcontinent from Late Eocene until Early Miocene times (Flynn et al., 1990) can now be refuted and so called 'Bugti Hills endemism' must be definitely rejected". Since the Bugti Fauna is now definitely assigned to Oligocene, by analogy that of the Fatehjung from the Murree Formation with which it has long been correlated should also be assigned the same age. The Fatehjung fauna needs to be re-examined and re-interpreted in the light of recent discoveries from the Bugti area.

5. Conclusions

The paleontological evidences cited above demonstrate that despite the sporadic occurrences of fossils only in a few bands and lack of continuous sections, there is a distinct biochronological continuity from the Subathu Formation through the Passage Beds to the Dagshai and equivalent formations negating a >10 Ma hiatus advocated by Najman et al. (1997) and others. However, the occurrence of ferricrete, oxysol and calcrete at several stratigraphic levels does indicate the existence of minor hiatuses within the red bed sequences.

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