

# Paleogene Nummulitid biostratigraphy of the Kohat and Potwar Basins in north-western Pakistan with implications for the timing of the closure of eastern Tethys and uplift of the western Himalayas

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**ABSTRACT:** The Paleogene larger benthic foraminifera (LBF) of the Kohat and Potwar basins, Pakistan are very useful for dating shallow marine sediments and documenting cessation of marine sedimentation that provides constraint on the initial age of India-Asia collision. We record important Paleogene LBF species in multiple sections of the two basins. We performed biometric analysis of nummulitid species useful for taxonomic purposes. We recognize six Larger Benthic Foraminiferal Zones (BFZ Zones 1-6) in the Kohat Basin. The first three (BFZ Zones 1-3) also occur in the Potwar Basin and the adjoining Trans Indus Ranges (TIR). The correlation of BFZ 1-6 Zones with previous local and regional LBF biostratigraphic schemes in the Eastern Tethys (Pakistan-India) and Western Tethys (European Basins) resulted in recognition of useful index taxa for developing a regional stratigraphic framework during Paleogene. The last occurrence (LO) of *Miscellanea miscella* in the BFZ 1 Zone, and the first occurrence (FO) of *Assilina dandotica* in the BFZ 2 Zone mark the late Paleocene (Late Thanetian) - early Eocene (Lower Illeridian 1) boundary. The co-occurrence of *A. pustulosa*, *Al. vredenburghi*, *Al. globula* and *Al. pasticillata* in the BFZ 2 Zone characterizes lower Eocene (Lower Illeridian 1-Middle Illeridian 1) sediments. The synchronous FO of *N. atacicus* and *N. globulus* is an excellent global biostratigraphic marker of the early Eocene (Middle Illeridian 1- Middle Illeridian 2) boundary and the FO of *O. complanatus* is a useful biostratigraphic marker of Lower Cuisian 2-Middle Cuisian boundary in the BFZ 3 Zone. Mammalian bones found at the base of Koldana Formation in the Kohat Basin represent early Eocene (Upper Cuisian), which is in agreement with the LBF biostratigraphy of the underlying Middle Cuisian strata. The FO of *A. exponens* in the BFZ 4 Zone record middle Eocene (Middle Lutetian 1) sediments while the FO of *N. beaumonti* in the BFZ 5 Zone marks the middle Lutetian 1-middle Lutetian 2 boundary. The FO of *A. cancellata* in the BFZ 6 Zone marks Middle Lutetian 2-Upper Lutetian boundary.

The implications of our LBF study are that cessation of marine sedimentation in both Pakistani basins occurred in early Eocene (Middle Cuisian ~BFZ 3) around 50-49.5 Ma. Notably, marine conditions returned in the Kohat Basin in middle Eocene (Middle Lutetian 1 ~ BFZ 4) due to an eustatic sea level rise. The final cessation of marine sedimentation, causing closure of the Eastern Tethys seaway in the Kohat Basin occurred in middle Eocene (Upper Lutetian ~BFZ 6) around 41.2 Ma, probably as a result of India-Asia post-collisional stresses.

## INTRODUCTION

The Kohat and Potwar Basins form a plateau in a structurally defined foreland fold and thrust belt, which is known as the Kohat and Potwar fold and thrust belt. The Kohat Plateau, an approximately 10,000 square km area of rugged anticlinal hills, is bounded to the north by the Main Boundary Thrust fault system (MBT) and to the south by the Trans-Indus Ranges (Pivnik and Wells 1996). The Kurram Fault and the Indus River form the western and the eastern boundaries of the Plateau, respectively (text-fig. 1). The Kohat Plateau contains highly deformed Precambrian-Cenozoic sedimentary rocks.

The Potwar Plateau has a width of 150 km in the north-south direction (Kazmi and Rana 1982). It is bounded to the south by the Salt Range Thrust (SRT) and to the north by the Kalachitta-Margalla Hill Ranges. The Indus and the Jehlum rivers mark the western and the eastern boundaries, respectively (text-fig. 1). The deformed rocks in the northern part of the Potwar Plateau were designated as the Northern Potwar Deformed Zone (NPDZ) (Abbasi and McElroy 1991).

The Paleogene rocks of the Kohat Basin include clastic-carbonate mixed lithofacies of the Patala Formation, pelagic clays of the Panoba Formation, Bahadur Khel Salt Facies, Jatta Gypsum Facies, carbonate-clastic mixed facies of the Sheikhan Formation, red continental clays of the Koldana Formation and the carbonate dominated sequence of the Kohat Formation (Table 1). The Paleogene rocks of the Potwar Basin and adjacent Trans Indus Ranges (TIR) include carbonates of the Lockhart Formation, clastic-carbonate mixed lithofacies of the Patala Formation and carbonates of the Nammal, Sakessar and Chorgali formations (Table 1).

The usage of Ranikot for Paleocene, Laki for early Eocene (Noetling 1903), and Kirthar for middle Eocene (Blanford 1878) in the Lower Indus Basin has been extended by previous workers (Vredenburg 1906; Davies 1940; Eames 1950, 1952; Nagappa 1959) to subdivide the Paleogene strata of the Kohat and Potwar Basins. Vredenburg (1906) established local biozones and described *N. millecaput* at the base of the upper Kirthar beds and *N. beaumonti* near the top of the upper Kirthar (upper middle

TABLE 1

Cretaceous-Paleogene Lithostratigraphic framework of the Kohat Basin, Potwar Basin, Trans Indus Ranges, and adjoining Kala Chitta and Hazara area, NW Pakistan.

AGE	KOHAT	KALA CHITTA	HAZARA	POTWAR & TIR
MIOCENE	MUREE FORMATION			
OLIGOCENE	FATEHJANG MEMBER			
Eocene	UPPER (PRIBONIAN)	UNCONFORMITY		
	MIDDLE (LUTETIAN)			
	LOWER (YPRESSIAN)	JATTA GYPSUM / SHEIKHAN FM BAHADUR KHEL SALT / PANORA FM	CHORGALI FORMATION MARGALA HILL LIMESTONE	SAKESSAR FM NAMMAL FM
PALEOCENE	UPPER	PATALLA FORMATION LOCKHART LIMESTONE		
	LOWER	FERRUGINOUS PILSITE		
	DANIAN	HANGU FORMATION	UNCONFORMITY	
CRETACEOUS	UPPER	MAAST	UNCONFORMITY	
	CAMP			
	SANT			
	CON	KAWAGARH FORMATION		

Eocene) beds in the Kohat Basin. According to Vredenburg (1906) the lowest zone of upper Kirthar contains *A. spira*, and *N. perforatus* which continue into the overlying zone, while his third zone contains *N. complanatus*. Nuttall (1925, 1926) re-recorded age diagnostic foraminifera from the Laki Series of the Kohat Basin and classified them according to their septal filament types. Davies (1930, 1940) synonymises the species in Vredenburg (1906) Zone 1, *A. spira* with *A. papillata* and its larger derivative *A. irregularis*, *N. perforatus* with *N. obtusus* / *N. uroniensis* in Zone 2, and *N. complanatus* with *N. millicaput* in Zone 3.

Davies (1940) claimed that there is no paleontological evidence to define an upper / middle Kirthar boundary in the Kohat Basin. Eames (1950) presented the local paleontological subdivisions and correlated the Eocene rocks of the Kohat Basin with the Rakhi Nala and Zinda Pir area in the Lower Indus Basin. He concluded that more work is needed to be done on collections from different facies of the Laki and Kirthar Series before any regional subdivision on paleontological grounds could be attempted. Gill (1953) described various Laki age *Assilina* species from the Kohat Basin. Nagappa (1959) and Pascoe (1963) reported early Eocene *Alveolina oblonga*, *A. daviesi*, *A. laminosa*, *N. atacicus* and *Orbitolites complanatus* from the Kohat Basin. Kureshy (1975) provides an overview of the taxonomy and a range distribution of the larger benthic foraminiferal species recorded from different parts of Pakistan including a few representatives of the Laki and the Kirthar age from the Kohat Basin. Meissner et al. (1974), in a comprehensive study of the Kohat Plateau, also confirmed LBF of Eocene age. Roohi and Baqri (2004) reported middle-upper Eocene foraminiferal species from the Kohat Formation in the Kohat Basin. Different views exist about the development of upper Kirthar (upper middle Eocene) beds in the Kohat Basin. Davies (1940), Vredenburg (1906), Eames (1950, 1952) and Roohi and Baqri (2004) support the existence of the upper Kirthar (upper middle Eocene) strata while Gill (1953) and Meissner (1974) did not find any bed younger than the middle Kirthar (lower middle Eocene) in the Kohat Basin. The previous paleonto-

TABLE 2

The table shows the number of samples and sample spacing from studied sections.

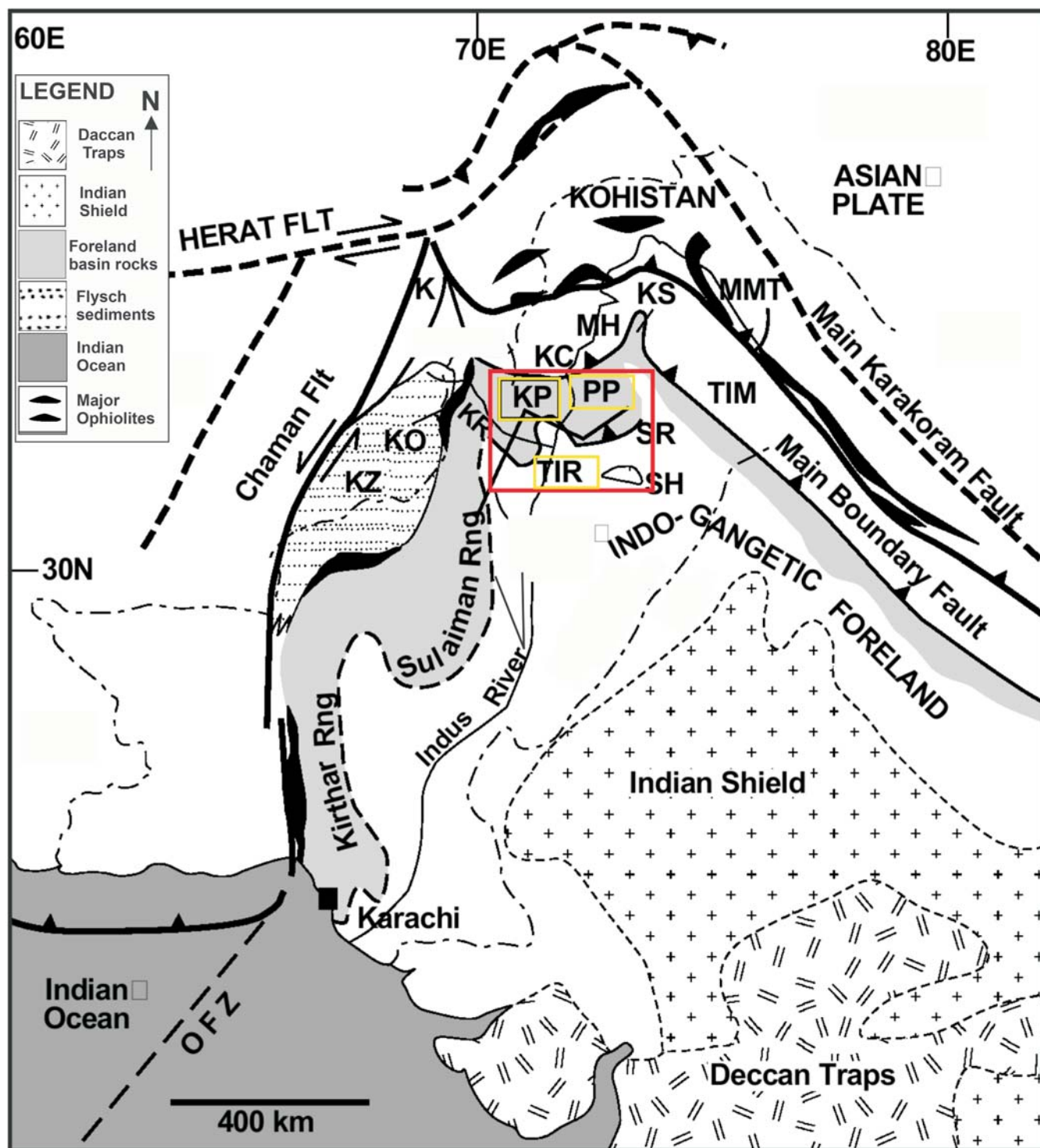
	Stratigraphic Sections	Sampling rate	Biostratigraphic samples
KOHAT BASIN	Panoba Nala Section	Variable (from 1-15 m)	98
	Tarkhobi Nala Section	Variable (from 1-12 m)	53
	Sheikhan Nala Section	Variable (from 1-13 m)	131
	Bahadur Khel Salt Tunnel Section	Variable (from 2-13 m)	23
			Total= 305
POTWAR BASIN	Gharibwal Cement Factory Sectin	Variable (from 1-2 m)	32
	Sikki Village Sectin	Variable (from 1-1.2 m)	34
	Nammal Gorge Section	Variable (from 10cm-26 m)	112
	Ziarat Thatti Sharif Section	Variable (from 5-10 m)	33
TIR	Kalabagh Hills Section	Variable (from 5m-10 m)	37
	Chichali Nala Section	Variable (from 10cm-23 m)	88
			Total=336

logical investigations related to the biostratigraphy of the Potwar Basin (Weiss 1988, 1993; Köthe et al. 1988; Afzal and Daniels 1991; Butt 1991; Weiss 1993; Afzal 1996; Afzal and Butt 2000; Akhtar and Butt 2000; Sameeni and Butt 2004; Afzal et al. 2005; Sameeni 2009; Gahzi et al. 2010) and Kohat Basin are well summarized in the work of Afzal et al (2009, 2011). They have integrated, collated, and reinterpreted the dinoflagellate, nannofossil, planktonic foraminiferal and shallow benthonic foraminiferal biostratigraphical data for the Greater Indus Basin in Pakistan. In their work, age-diagnostic LBF are illustrated only from the late Paleocene Lockhart Formation. Therefore, in order to establish a more reliable and comprehensive LBF biostratigraphic scheme for the Kohat and Potwar Basins, we aim to investigate the LBF in more detail for a reliable biostratigraphic framework for the Paleogene strata in the two basins. A regional comparison of the LBF biostratigraphy of the study area including the Indian Basins (Govindon 2003; Matsumaru and Sarma, 2010) and European Basins (Sierra-Kiel et al 1998) has also been attempted to test the LBF chronostratigraphic significance and implications for documenting the timing of the closure of eastern Tethys seaway in Pakistan.

## MATERIAL AND METHODS

This study uses taxonomy of the selected LBF species based on morphological differences and on quantitative measurements of the rate of growth of each whorl, which is species specific (Racey 1995). We also compare the newly proposed LBF biostratigraphy of the Paleogene rocks of Pakistan with those from other areas Indo-Pacific (Govindon 2003; Mukhopadhyay 2003, 2005; Renema 2002; Matsumaru and Sarma 2010), Middle East (Bellen et al. 1959; Rahaghi 1980; Kalantari 1981; White 1994; Racey 1994, 1995; Karim and Baziany 2007) and Europe (Schaub 1981; Serra-Kiel et al. 1998). We use the proposed LBF biostratigraphy of the two basins to investigate the timing of the disappearance of Tethys seaway in the Pakistan area as a result of India-Asia collision.

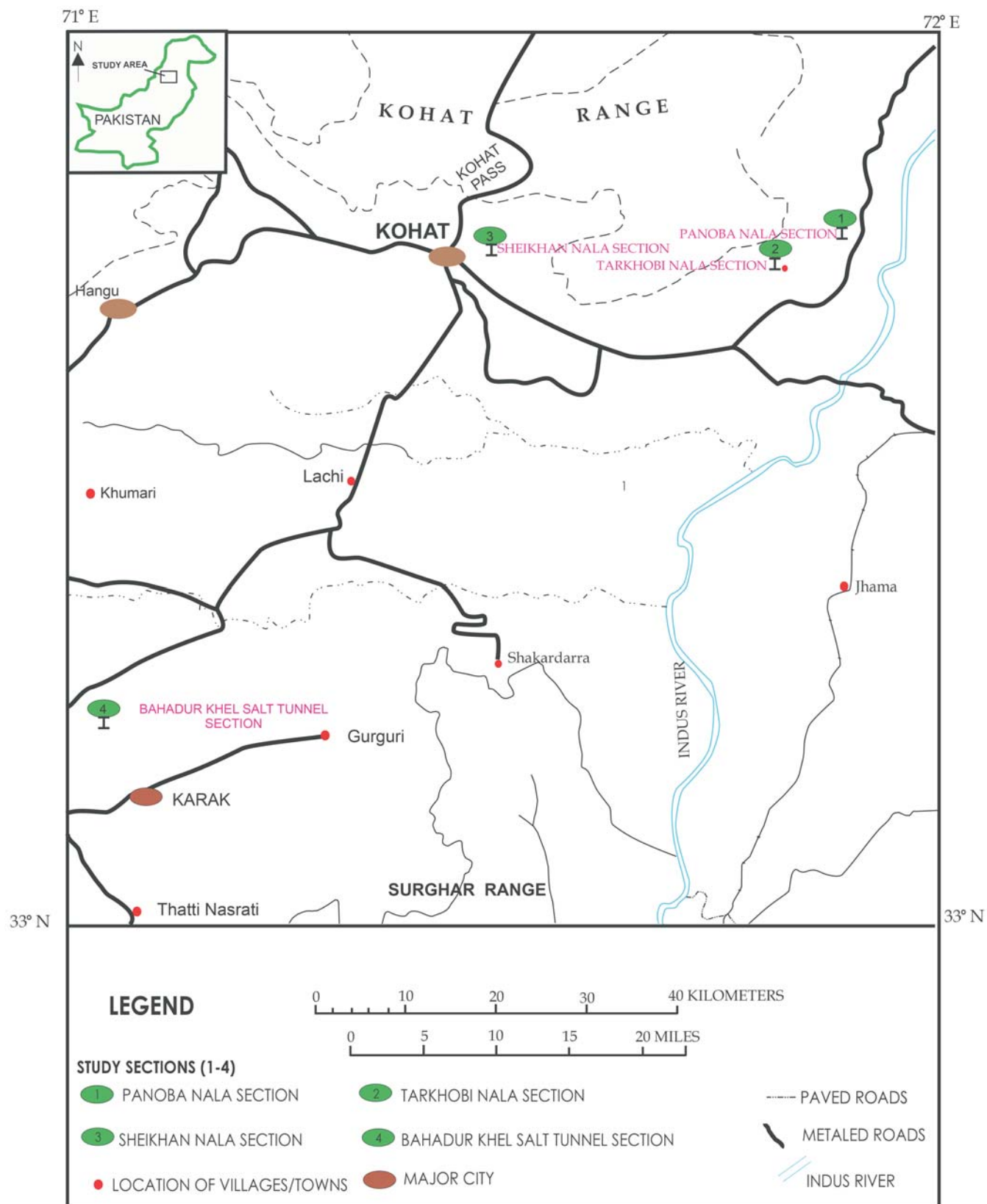
The present study is based on a detailed stratigraphic logging and a high-resolution LBF analysis of the Paleogene rock units exposed in several key stratigraphic sections (text-fig. 2a-b).



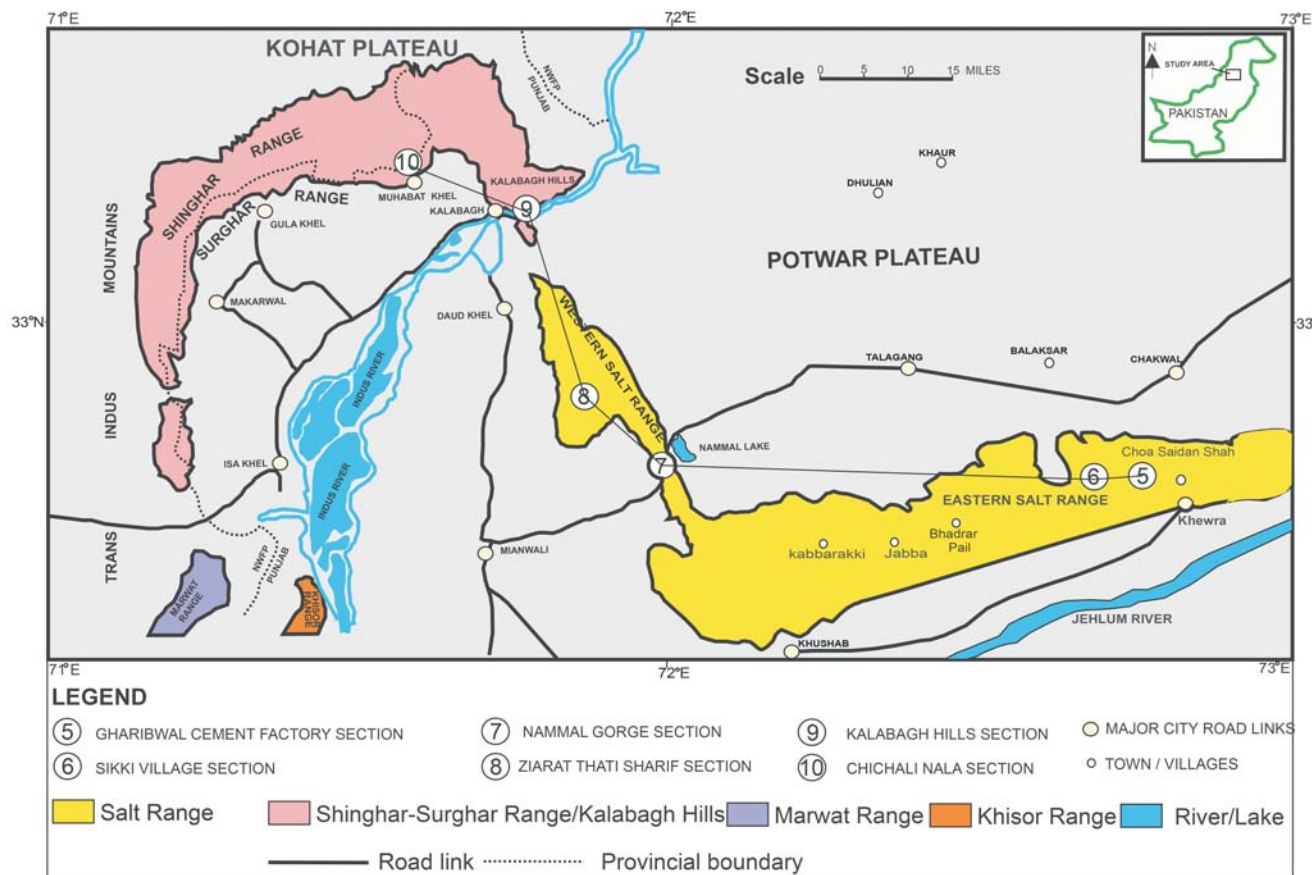
TEXT-FIGURE 1

Tectonic map of northern Pakistan, inset showing location of study area: the Asian Plate, the Kohistan Island Arc, the northern Indian continental margin (TIM), the undeformed Indo-Gangetic foreland and the Indian Shield. Abbreviations are: K-Kabul Block; KC-Kala Chatta Range; KO-Khost Block; KP-Kohat Plateau; KR-Kurram River; KS-Kashmir Syntaxis; KZ-Katawaz Flysch Basin; MH-Margalla Hills; MMT-Main Mantle Thrust; OFZ-Owen Fracture Zone; PP-Potwar Plateau; SH-Sargodhah Hills; SR-Salt Range; TIR-Trans Indus Ranges modified after Treloar and Izzat (1993) and Pivnik and Wells (1996).





TEXT-FIGURE 2a  
Location map of the studied sections in the Kohat Basin, northwest Pakistan.



TEXT-FIGURE 2b

Location map of the studied sections in the Potwar Basin and the Trans Indus Ranges, northwest Pakistan.

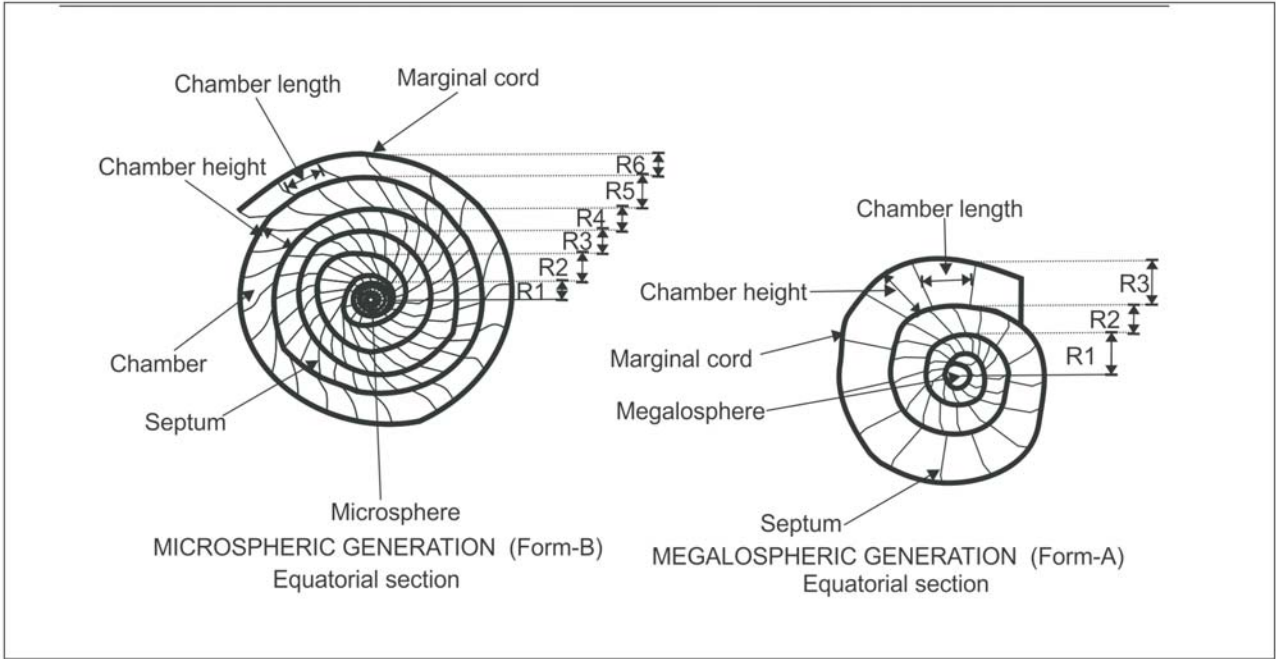
Systematic sampling has been carried out by collecting rock samples with variable intervals (ranges from 10 cm to 26 m in key stratigraphic sections) in the two basins (Table 2). In the Kohat Basin, we collected samples from the Patala, Panoba, Sheikhan and Kohat formations, which form part of the north-eastern Sheikhan Nala, Panoba Nala and Tarkhobi Nala Sections and the south-western Bahadur Khel Salt Tunnel Section (text-fig. 2a). In the Potwar Basin, we collected samples from the Lockhart, Patala, Nammal, Sakessar and Chorgali formations, which form part of the Gharibwal Cement Factory and Sikki Village Sections in the Eastern Salt Range, Ziarat Thatti Sharif Section in the Western Salt Range, Nammal Gorge Section in the Central Salt Range, Kalabagh Hills and Chichali Nala Section in the Trans Indus Ranges (text-fig. 2b). About 500 thin sections of rock samples were prepared in order to study the LBF. In addition, oriented thin sections of individual foraminiferal tests of nummulitids (*Nummulites*/*Assilina*) were also used for further identification. The taxonomy of recorded species is based on a review of the available literature with a focus on faunas from the Indian subcontinent (Nuttall 1926; Davies and Pinfold 1937; Gill 1953; Nagappa 1959; Pascoe 1963; Sarkar 1968; Raju et al. 1970; Singh et al. 1970; Sahni and Kumar 1974; Samanta 1965, 1968, 1981; Murty 1983; Jauhari 2006; Jauhari and Agarwal 2001; Mukhopadhyay 2003, 2005; Sameeni et al. 1998, 2009; Afzal 2009, 2011, and Ahmad et al. 2014), the Indo-Pacific region (Verbeek and Fennema

1896; Doornink 1932; Crotty and Engelhardt 1993; Wilson 1995; Renema 2002), the Mediterranean region (Schaub 1981; Serra-Kiel et al. 1998) and Tertiary rocks of the Middle East (Bellen et al. 1959; Rahaghi 1980; Kalantari 1981; White 1994; Racey 1994, 1995; Karim and Baziany 2007).

In this study, biometric features including alar prolongation, coarseness of the marginal cord, overlap of spiral sheets, type of coiling (evolute/involute), opening of the spire, number of whorls, chambers (height, shape and numbers) and septal filaments (as shown in text-fig. 3) are taken into consideration for the identification of species of *Nummulites* and *Assilina*, following Racey (1995).

#### BIOMETRIC ANALYSIS OF NUMMULITID FAUNA

It is difficult to define the generic limits in *Nummulites* because of parallel development along several lines (Nagappa 1959; Blondeau 1972). Cole (1964) takes the extreme position in the Treatise and lumps together most of the previously recognized genera into *Nummulites*, including *Assilina*, *Operculina*, *Operculinella*, *Operculinoides* and *Ranikothalia*. Höttinger (1977) bases a generic determination on the stolon and canal system and claims that the traditional description of the *Nummulites*, which emphasizes the nature of coiling and presence or absence of secondary septa, should be abandoned. However, Haynes (1981) suggests that a composite approach combining the tradi-



TEXT-FIGURE 3  
The figure shows Morphological features (septum, chambers, marginal cord, micro- and macrospheres) and measurement procedure of the whorl radius in microspheric (Form-B) and megalospheric tests (Form-A) in *Nummulites* and *Assilina*.

tional criteria and evidence of fine structures can help in discrimination of *Nummulites* genera. The usefulness of species of *Nummulites* in the stratigraphic analysis and correlation of the lower Tertiary of the Indo-Pacific region is widely known, but in many of these species identifications are difficult and intra-specific variations have not been investigated (Sen Gupta 1965).

During this study we have found that different *Nummulites* and *Assilina* species show variability in the opening of the spire and the number and radius of successive whorls. We used the procedure for measurement of the radius in each whorl (text-fig. 3) as described by Racey (1995) and Renema (2002). For selected index species, the number and radius of each whorl and the number of septa are recorded. Coiling graphs have been drawn to show the rate of opening of spire in all recorded nummulitid species (text-fig. 4A-F). These coiling graphs provide an additional basis for species level differentiation, and are particularly helpful in cases where taxa of *Nummulites* and *Assilina* are morphologically similar (text-fig. 4A-F).

**Taxonomy of Nummulitids**

The diagnostic morphology of selected index species and reference to the illustrations are given (Plates 1-4). Under the heading, “Diagnosis” diagnostic morphology is elaborated, “Equatorial Section” describes three characters “Whorl”, “Radius” and “Chambers” where found are noted. Whorl refers to the whorl number; radius measures the distance (in mm) between the whorl periphery and initial chamber and chambers denotes the number of chambers per whorl. In remarks, we differentiate morphologically similar species and discuss the variation in the coiling graphs of selected species (text-fig. 4A-F). All studied rock samples/LBF and their representative thin sec-

tions are available in the repository at the Museum of Department of Geology, University of Peshawar, Pakistan.

*Nummulites atacicus* Leymerie 1846  
Text-figure 4A-B; Plate 1, figure 7; Plate 3, figures 11-14

*Material:* (Marls sample 300 grams, 34 specimens, both Form-B and A).

**Form-B**

*Diagnosis:* The test shape is lenticular. In equatorial section, a regularly opening spire is present. The initial five whorls are tightly coiled and later ones are loosely coiled (text-fig. 4A), numerous chambers are present which are rectangular and higher than long but in the later whorls chambers are longer than high. Septa are straight to gently inclining towards the periphery (Plate 3, fig. 12). A thin marginal cord is present. In axial section, a polar pustule is common in young specimens, which are sometimes buried in adults (Plate 1, fig. 7; Plate 3, fig. 11).

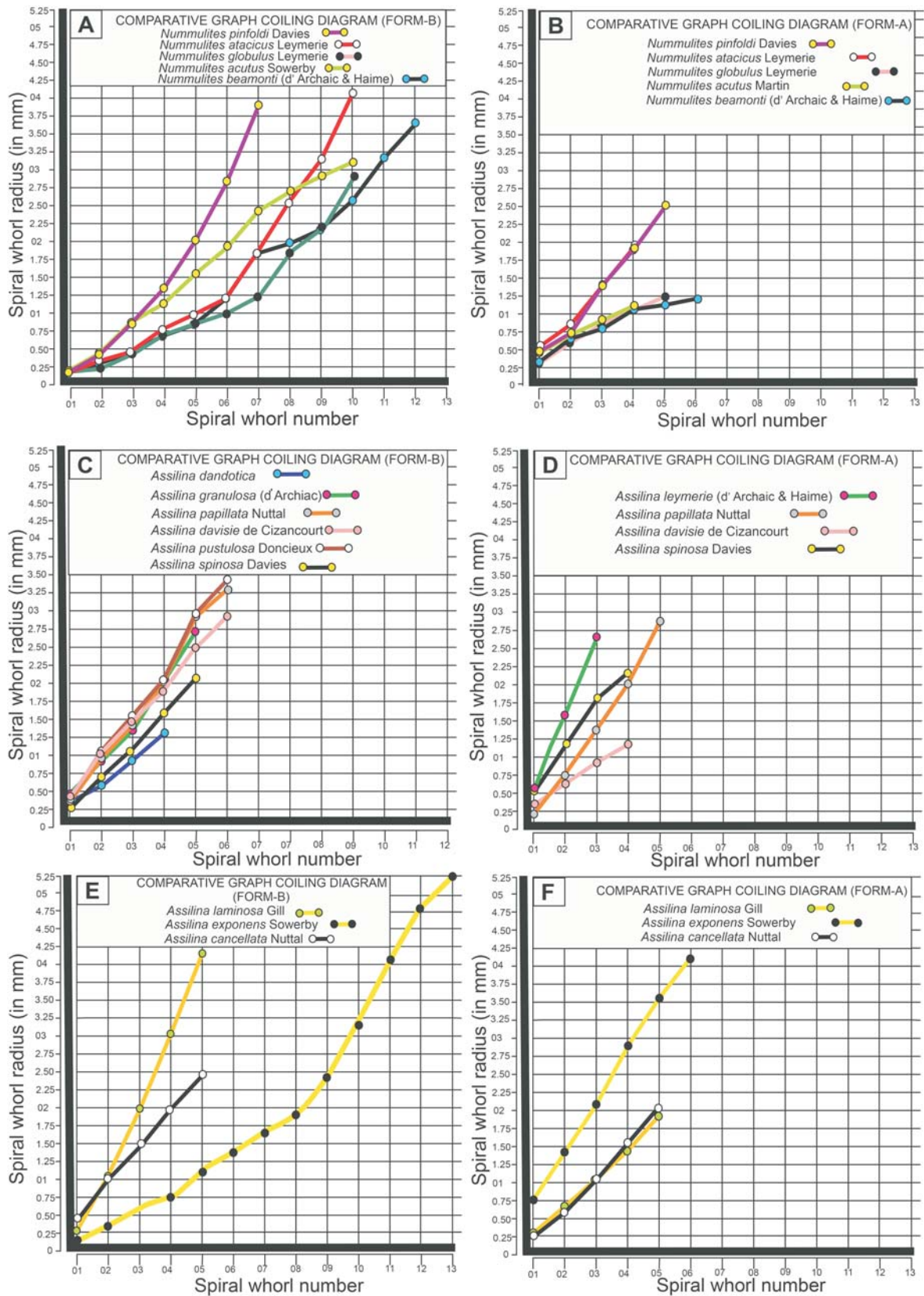
Equatorial Section (Plate 3, figure 12)

Whorl	1	2	3	4	5	6	7	8
Radius	0.08	0.18	0.44	0.72	1.20	1.56	2.40	3.68
Chambers	6	14	18	2	24	30	38	48

**Form-A**

*Diagnosis:* The spire is regularly opening with straight to inclined septa (text-fig. 4B). Chambers are rectangular and are longer than high. The marginal cord is thin and uniform. Proloculus size of the figured specimen is 0.38 mm (Plate 3, fig. 13). In axial section, a polar pustule is common (Plate 3, fig. 14).





TEXT-FIGURE 4

Coiling graph plots (Form B & A) of different species of *Nummulites* (A-B) and *Assilina* (C-F) recorded in different Paleogene rock units in the study area.

Equatorial Section (Plate 3, figure 13)

Whorl	1	2	3	4	5
Radius (mm)	0.58	0.92	1.44	2.10	2.30
Chambers	8	16	18	22	30

Proloculus size 0.40-0.76mm in diameter

**Remarks:** In specimens from Pakistan, *N. atacicus* (both Forms B and A) has early whorls that are tight in the spire and later ones are loosely coiled (text-fig. 4A-B). When the illustrations of *N. atacicus* (Schaub 1981, pl. figs. 15-30) are compared with specimens from this study, similar morphological features are noted. These features are the non-uniform marginal cord thickness, rapidly opening spire having early whorls tightly coiled and the dominance of higher than long chambers. Straight to slightly twisted septa are also common in this comparison. The comparison of Form-A with Schaub (1981, pl. 25, figs. 10-12 and 41-50) revealed the common presence of 4 whorls, non-uniform marginal cord and straight to slightly curved back septa.

*Nummulites globulus* Leymerie 1846

Text-figure 4A-B; Plate 1, figures 7-8; Plate 3, figures 15-18

**Material:** (Marls sample 400 grams, 44 specimens, both Form-B and A)

Form-B

**Diagnosis:** The test is small and biconical. The spire is tight and compact in the early five whorls, then regularly opening in later whorls (text-fig. 4A). Septa are straight in early whorls and in later whorls become inclined and sometimes curved back towards the periphery. Chambers are higher than long (Plate 3, fig. 15). In axial section, scattered pillars are seen (Plate 3, fig. 16).

Equatorial Section (Plate 3, figure 15)

Whorl	1	2	3	4	5	6
Radius (mm)	0.08	0.14	0.26	0.43	0.62	0.91
Chambers	12	16	22	24	26	28

Whorl	7	8	9
Radius (mm)	1.15	1.46	1.67
Chambers	35	48	53

Form-A

**Diagnosis:** A rapidly opening spire characterizes this species (text-fig. 4B). The septa are straight to inclined and higher than long (Plate 1, fig. 8). The marginal cord is non uniform. In axial section, a thick polar pillar and a large proloculus is present (Plate 3, fig. 18).

Equatorial Section (Plate 3, figure 17)

Whorl	1	2	3	4	5
Radius (mm)	0.42	0.63	0.86	1.04	1.24
Chambers	10	18	20	29	37

Proloculus size 0.60-1.10 mm in diameter

**Remarks:** *N. globulus* Leymerie is the Form-B of *N. mamilla* Fichtel and Moll. The comparison of figured topotype material of *N. globulus* (Schaub 1981, pl. 40, figs. 1-60) revealed commonly found morphological features, such as the presence of 7-8 whorls with initial whorls tightly coiled and later whorls loosely coiled and isometric chambers with straight to curved

back septa (Schaub 1981, pl. 40, figs 42-45). Central pillars within the axial section are also common (Schaub 1981, pl. 40, figs. 50-51). The European specimens of Form-A (Schaub 1981, pl. 40, figs. 26-29) are similar to specimens in this study, having up to 4 whorls in a regularly opening spire, central pillars and curved back septa.

*Nummulites beaumonti* d' Archiac and Haime 1853

Text-figure 4A-B; Plate 2, figure 6; Plate 3, figures 25-28

**Material:** (400 grams Nummulitic shales; 60 specimens, both Form-B and A)

Form-B

**Diagnosis:** In equatorial section, the spire is regularly opening (text-fig. 4A). Septa are mostly inclined, numerous chambers (4-66) are present which are mostly higher than long. The marginal cord is uniform (Plate 3, fig. 25). In axial section, the pillars are commonly scattered (Plate 2, fig. 6; Plate 3, fig. 26). The diameter of figured specimen is 6.36 mm. The average thicknesses of 5 studied specimens is 3.8 mm, maximum observed thickness is 4.5 mm and the average ratio of the diameter to thickness is 1.8 to 1.

Equatorial Section (Plate 3, figure 25)

Whorl	1	2	3	4	5	6
Radius (mm)	0.12	0.24	0.40	0.69	0.80	0.85
Chambers	04	20	27	29	33	38

Whorl	7	8	9	10	11	12
Radius (mm)	1.20	1.79	2.18	2.54	2.88	3.18
Chambers	20	48	53	55	60	66

Form-A

In the equatorial section, the spire displays regular opening, having six whorls (text-fig. 4B; Plate 3, fig. 27). Chambers are higher than long, but longer than high chambers are also found in later whorls. The septa are mostly straight, but inclined in early and last whorls. The marginal cord thickness is not uniform. In axial section, pillars are commonly scattered (Plate 3, fig. 28). The diameter of the proloculus in the figured specimen is 0.24 mm.

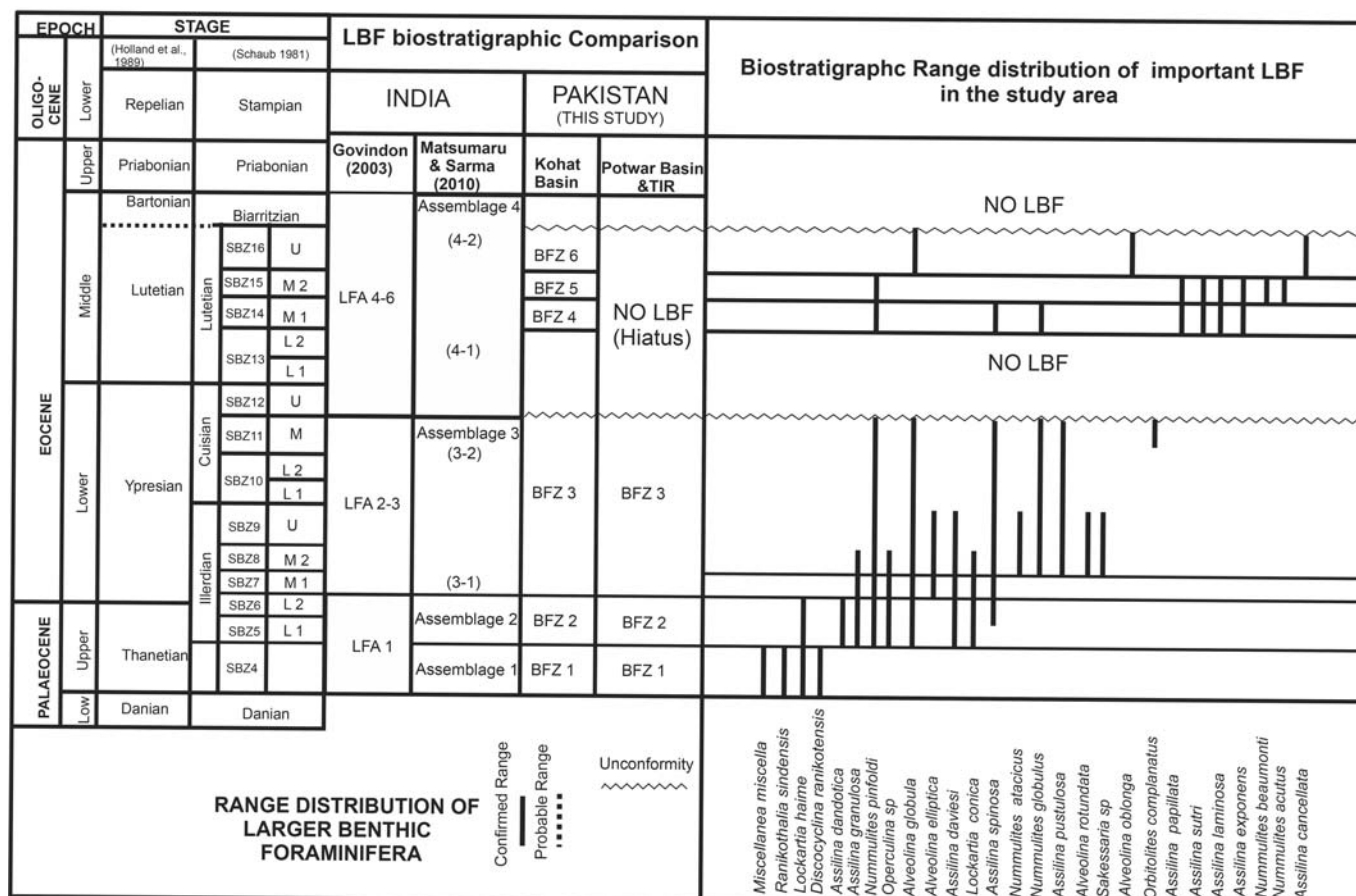
Equatorial Section (Plate 3, figure 27)

Whorl	1	2	3	4	5	6
Radius (mm)	0.30	0.57	0.78	1.03	1.13	1.24
Chambers	13	16	21	24	33	40

Proloculus size 0.12-0.24mm in diameter

**Remarks:** The specimens of *N. beaumonti* from the Cambay Basin, India are characterized by an inflated lenticular test, acute peripheral margin, radial septal filaments slightly curving at the polar part, tight spire, chambers of mature whorls having length nearly equal to height, uniform whorl wall containing a few spiral canals including a thick proximal canal, fairly wide alar prolongations, thin marginal cord, buried polar pillars, moderately high foramina and moderately large bilocular proloculus (diameter 0.275 mm - 0.475 mm) having protoconch larger than the deutoconch (Mukhopadhyay 2005, Plate 2, figs. 1-14). Some of the forms from Kutch (pl. 2, fig. 7, and pl. 5, fig. 10) have characteristics of both *N. discorbinus* and *N. beaumonti*. In the study area, *N. beaumonti* has a regularly opening spire, but the eighth whorl shows tightness of the spire and a partial tripartite nature, as the later whorls again show regular opening of the





TEXT-FIGURE 5

Comparison of larger benthic foraminiferal biostratigraphic zonation (BFZ 1-6 Zones) of the Paleogene rocks of study area with the regional biozonation in the Indian Basins (Govindon 2003, Matsumaru & Sarma 2010) and the Western Tethys SBZ Biozone of Serra Kiel et al. (1998).

spire (text-fig. 4A-B). The commonly noted features between the Indian specimens and this study are the presence of radial septal filaments, fairly wide alar prolongations, thin marginal cord and buried polar pillars, while dissimilar chambers in the last few whorls are seen (Mukhopadhyay 2005).

*Nummulites acutus* Sowerby, 1840

Text-figure 4A-B; Plate 4, figures 29-32

Material: Nummulitic shales sample 600 grams, 19 specimens, both Form-B and A)

Form-B

**Diagnosis:** In equatorial section, the spire is gradually opening (text-fig. 4A; Plate 4, fig. 29). Granules are commonly present along the meandrine septal filaments and generally throughout the spire. Chambers are rectangular, occasionally isometric and are longer than high. The septa are gently curved in early whorls and curved back in later whorls. The marginal cord is not uniform, while scattered pillars are commonly present (Plate 4, fig. 30). The average thickness to diameter ratio of the 10 measured specimens varies from 2.5 mm to 1.2 mm.

Equatorial Section (Plate 4, figure 29)

Whorl	1	2	3	4	5	6
Radius (mm)	0.24	0.40	0.80	1.14	1.55	1.85
Chambers	17	22	24	26	34	38

Whorl	7	8	9	10
Radius (mm)	2.16	2.49	2.64	2.82
Chambers	44	48	50	56

Form-A

**Diagnosis:** In equatorial section, the spire is gradually opening (text-fig. 4B). The septa are inclined. Chambers are rectangular and longer than high (Plate 4, fig. 31). A non-uniform marginal cord is seen that equals 2/4th - 3/4th of the chamber height. In axial section a large proloculus and scattered pillars are present (Plate 4, fig. 32).

Equatorial Section (Plate 4, figure 31)

Whorl	1	2	3	4
Radius (mm)	0.47	0.68	0.86	1.01
Chambers	10	20	30	36

Proloculus size 0.44-0.64mm in diameter

Genus *Assilina* d' Orbigny

Type species: *Nummulites spira* Roissy

The genus *Assilina* embraces all those forms which are morphologically like *Nummulites* but characterized by evolute coiling, whereas in *Nummulites* the coiling is involute. Cole (1960) stated that individual species may grade from involute to evolute, and thus he identified *Paleocamerinoides* Cole (genotype *Nummulites exponens* Sowerby) as a junior synonym of *Nummulites*. In the past, the megalospheric and microspheric forms of *Assilina* were designated by two different names. As these names are in common use, therefore, they are retained here with A and B forms being identified in the diagnosis. The stratigraphic range of *Assilina* is Paleocene to Eocene.

*Assilina dandotica* Davies and Pinfold, 1937

Text-figure 4C; Plate 1, figure 5; Plate 3, figures 2-3

**Material:** (300 grams argillaceous limestone, 09 specimens only Form B)

Form-B

**Diagnosis:** The test is discoidal with a sharp periphery; in equatorial section the spire is tight, regularly opening (text-fig. 1C), granules are common, septa straight to slightly curved in later whorls, chambers are rectangular, twice higher than long (Plate 3, fig. 2). In axial section, the spiral sheet completely embraces the succeeding whorls (Plate 3, fig. 3).

Equatorial Section (Plate 3, figure 2)

Whorl	1	2	3	4
Radius	0.27	0.56	0.94	1.39
Chambers	7	14	20	25

**Remarks:** The comparison of *A. dandotica* from Pakistan with the Schaub specimens (1981, pl. 84, figs 5, 7, 16) demonstrates common features that include four whorls in a regularly opening spire and straight to slightly twisted septa in later whorls. However the difference in chamber shape is noted. The Schaub (1981) specimens characterize dominance of the isometric chambers, but in the present study rectangular chambers are dominant in the Pakistani specimens. The axial sections of *A. dandotica* in both areas are quite similar.

*Assilina exponens* Sowerby 1840

Text-figure 4E-F; Plate 2, figure 5; Plate 3, figures 29-32

**Material:** (600 grams Nummulitic shales; 30 specimens both Form-B and A)

Form-B

**Diagnosis:** The spire is regular, but compact with some irregularities due to doubling in the middle to outer whorls (text-fig. 4E). Chambers are higher than long and slightly inclined (Plate 3, Fig 29). In axial section polar pillars are prominent (Plate 3, fig. 30).

Equatorial Section (Plate 3, figure 29)

Whorl	1	2	3	4	5	6
Radius (mm)	0.1	0.8	0.47	0.66	1.08	1.33
Chambers	4	12	17	20	22	24

Whorl	7	8	9	10	11	12
Radius (mm)	1.63	1.83	2.47	3.39	4.36	5.07
Chambers	29	31	36	48	52	62

Form-A

**Diagnosis:** The test is evolute, lenticular to flattened-lenticular in shape. It has a slightly swollen polar region and often shows a small polar depression. Ornaments are similar to those found in Form-B (Plate 3, fig. 31). The spire is regular (text-fig. 4F). In axial section, the granules are distributed throughout the test and scattered, buried pillars are commonly present (Plate 3; fig. 32).

Equatorial Section (Plate 3, figure 31)

Whorl	1	2	3	4	5	6
Radius	0.96	1.60	2.14	2.94	3.90	4.30
Chambers	9	20	26	35	32	43

Proloculus size 0.54-0.80mm in diameter

**Remarks:** The morphological comparison of the Pakistani specimens with the European specimens of *A. exponens* (Schaub 1981, pl. 92 figs. 1-20) shows that Form-B in both regions has a regularly opening spire with tight early and loose later whorls, straight to slightly curved forward septa, and an external central depression with heavy granulation. However, the European specimens are larger in size.

*Assilina cancellata* Nuttall 1926

Text-figure 4E-F; Plate 2, figure 8; Plate 3, figures 33-35

**Material:** (600 grams Nummulitic shale, 18 specimens, both Form-B and A)

Form-B

**Diagnosis:** The test is flat, lenticular, with a sharp periphery and a non-ornamented smooth exterior surface. The septa are straight in shape. Chambers are higher than long (Plate 3, fig. 33). The spire is gradually opening (text-fig. 4E; Plate 3, fig. 33). The marginal cord is uniformly thick and granules are present in the center.

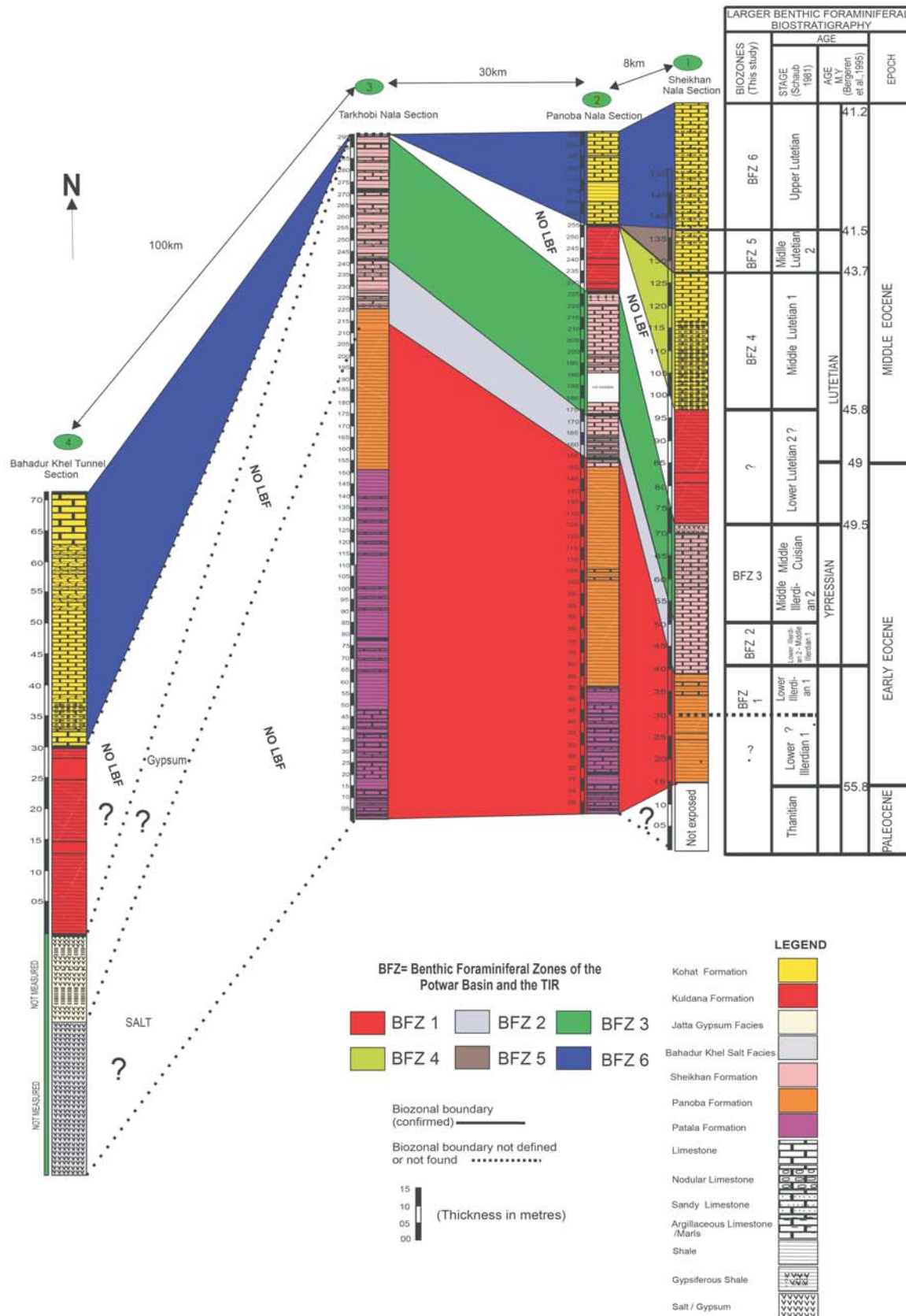
Equatorial Section (Plate 3, figure 33)

Whorl	1	2	3	4	5
Radius (mm)	0.43	0.99	1.42	1.89	2.4
Chambers	5	19	25	32	38

**Remarks:** It is the microspheric Form-B of the *A. subcancellata* Nuttall

Form-A

**Diagnosis:** The spire is tight, but in later whorls becomes loosely coiled (text-fig. 4F). Chambers are rectangular, higher than long, and separated by straight to gently inclined in later whorls (Plate 3, fig. 35). The axial section shows the same morphological features as that of Form-B, but it is smaller in size (Plate 3, fig. 36).



TEXT-FIGURE 6  
 Biostratigraphic correlation of the Paleogene rocks in studied sections of the Kohat Basin.



# Equatorial Section (Plate 3, figure 35)

Whorl	1	2	3	4	5
Radius (mm)	0.24	0.51	1.05	1.52	2.1
Chambers	5	8	16	24	30

## BIOSTRATIGRAPHY

The biostratigraphic range distribution of selected index nummulitid species and associated larger foraminifera (Plates 1-4) are used to establish biozonal boundaries in the Paleogene successions of the study area (text-fig. 5). These zonal boundaries divide the Paleogene succession of the Kohat and Potwar basins into six and three larger Benthic Foraminiferal Zones (BFZ 1-6 Zones), respectively. The BFZ Zones of local nature are correlated with earlier local biozonation in the Kohat Basin (Vredenburg 1909; Gee 1944; Nagappa 1959), Potwar Basin (Weiss 1988, 1993; Afzal 1997; Sameeni 2009; Afzal 200, 2011), regional biozonation and species in Indian Basins (Govindon, 2003; Matsumaru and Sarma 2010), and the Western Tethys LBF standard Zones (Höttinger 1960; Schaub 1981; and Serra-Kiel et al. 1998) (text-fig. 5). The absolute chronologic calibration of the BFZ 1-6 Zones are based on the magnetostratigraphy as presented in the geological time scale of Berggren et al. (1995). The descriptions of the BFZs are as follows.

### BFZ 1 Zone

The FO of *Miscellanea miscella*, *Lockhartia haimei* and *Ranikothalia sindensis* defines this Zone (text-fig 5). The associated LBF include, *L. conica*, *L. huntii*, *L. newboldi*, *Operculina salsa*, *O. subsalsa*, *Discocyclina ranikotensis*, and *N. pinfoldi*.

BFZ 1 Zone is correlated with the Ranikot Stage of the Sind area (Vredenburg 1909) and the Khairabad Limestone of the Punjab Salt Range (Gee 1944). In the Jaintia Hills, Meghalaya, NE India Assemblage 2 of LBF (*M. miscella*, *M. primitiva*, *Ranikothalia nuttalli* and *Lockhartia haimei*) within the Lakadong Limestone (Matsumaru and Sarma 2010) is well correlated with the BFZ 1 Zone. *M. miscella* was also documented in the LFA 1 Zone as Tertiary a1 Zone of Indian Basins by Govindon 2003, representing the late Paleocene (Thanetian). Based on the FO of *M. miscella* it can tentatively be correlated with the Shallow Benthic Zone (SBZ 4) of Serra-Kiel et al. (1998) (text-fig. 5).

The thickness of the BFZ 1 Zone ranges from 11-212 m in the Sheikhhan and Tarkhobi Nala Sections (text-fig. 6) of the Kohat Basin while its thickness ranges between 21-143 m in the Sikki Village and Kalabagh Hills Section (text-fig. 7) of the Potwar Basin.

*Geological age:* Late Paleocene (Thanetian).

### BFZ 2 Zone

The stratigraphic ranges of *Assilina dandotica*, *A. pustulosa*, *Alveolina globula* and *Al. pasticillata* define this Zone (text-fig. 5). The associated LBF include *A. spinosa*, *N. pinfoldi*, *Operculina* sp., *Al. vredenburghi* (*cucumiformis*), and *L. conica*. The BFZ 2 Zone is partially correlated with the lower Laki Limestone of the Laki Stage in the Sind area in Pakistan (Vredenburg 1909; Nagappa 1959). It partially correlates with LBF Assemblage 2 recorded in the Jaintia Hills, Meghalaya, NE India (Matsumaru and Sarma, 2010) and partially with the LFA 1-2 Zone of the Indian Basins (Govindon 2003). Based on the biostratigraphic occurrence of *A. dandotica*, *A. pustulosa*,

*Al. vredenburghi* (*cucumiformis*) and *Al. globula*, the BFZ 2 Zone is partially correlated with the SBZ 5-7 Zone (Serra-Kiel et al. 1998), representing early Eocene (Lower Illeridian 1-Middle Illeridian 1) (text-fig. 5). In the Kohat Basin, the thickness of BFZ 2 Zone ranges from 9-30 m in the Sheikhhan and Tarkhobi Nala Sections (text-fig. 6), while it is 10-180 m thick in the Potwar Basin and adjacent TIR in the Nammal Gorge and Kalabagh Hills Sections, respectively (text-fig. 7).

### BFZ 3 Zone

The FO of *Nummulites ataticus*, *Nummulites globulus* and the FO of *Orbitolites complanatus* defines this Zone (text-fig. 5). The associated LBF include *R. sahini*, *N. pinfoldi*, *A. spinosa*, *A. laminosa*, *Al. elliptica*, *L. conica* and *Operculina* sp. The BFZ 3 Zone is correlated with the fauna of the Laki Stage in the Punjab Salt Range, Pakistan (Gee 1944; Nagappa 1959). The BFZ 3 Zone can also be correlated with LBF Assemblages 3-1 and 3-2 recorded in the upper part of the Umlatdoh Limestone in the Jaintia Hills, Meghalaya, NE India (Matsumaru and Sarma 2010). Govindon (2003) also reported *N. ataticus* in his LFA 2 and 3 Zones as Tertiary a2, representing the early Eocene (Ypresian) in the Indian Basins (text-fig. 5). Based on the FO of *N. ataticus* (after Schaub, 1981) and *Orbitolites complanatus*, the BFZ 3 Zone can be correlated with SBZ 8 to 11 (Serra-Kiel et al. 1998).

In the Kohat Basin, the thickness of BFZ 3 Zone ranges from 22-55 m in the Sheikhhan and Panoba Nala Sections, respectively (text-fig. 6). The BFZ 3 Zone is 12-315 m thick in the Potwar Basin and TIR, in the Kalabagh and Chahali Nala Sections (text-fig. 7).

*Geological age:* early Eocene (Middle Illeridian 2-Middle Cuisian)

### BFZ 4 Zone

The FO of *Assilina exponens* (in Schaub 1981) defines the base while the FO of *N. beaumonti* marks the top of this Zone. The associated LBF include *N. pinfoldi*, *A. papillata*, *A. laminosa*, *A. spinosa*, and *A. sutri*. The BFZ 4 Zone is correlated with the fauna of the Kirthar Stage in the Punjab Salt Range, Pakistan (Nagappa 1959). The BFZ 4 Zone partially correlates with Assemblage 4 (1) in the Jaintia Hills, Meghalaya, NE India (Matsumaru and Sarma 2010), LFA 4 to 6 (Tertiary a3) in the Indian Basins (Govindon 2003) and SBZ Zone 14 (Serra-Kiel et al. 1998) (text-fig. 5).

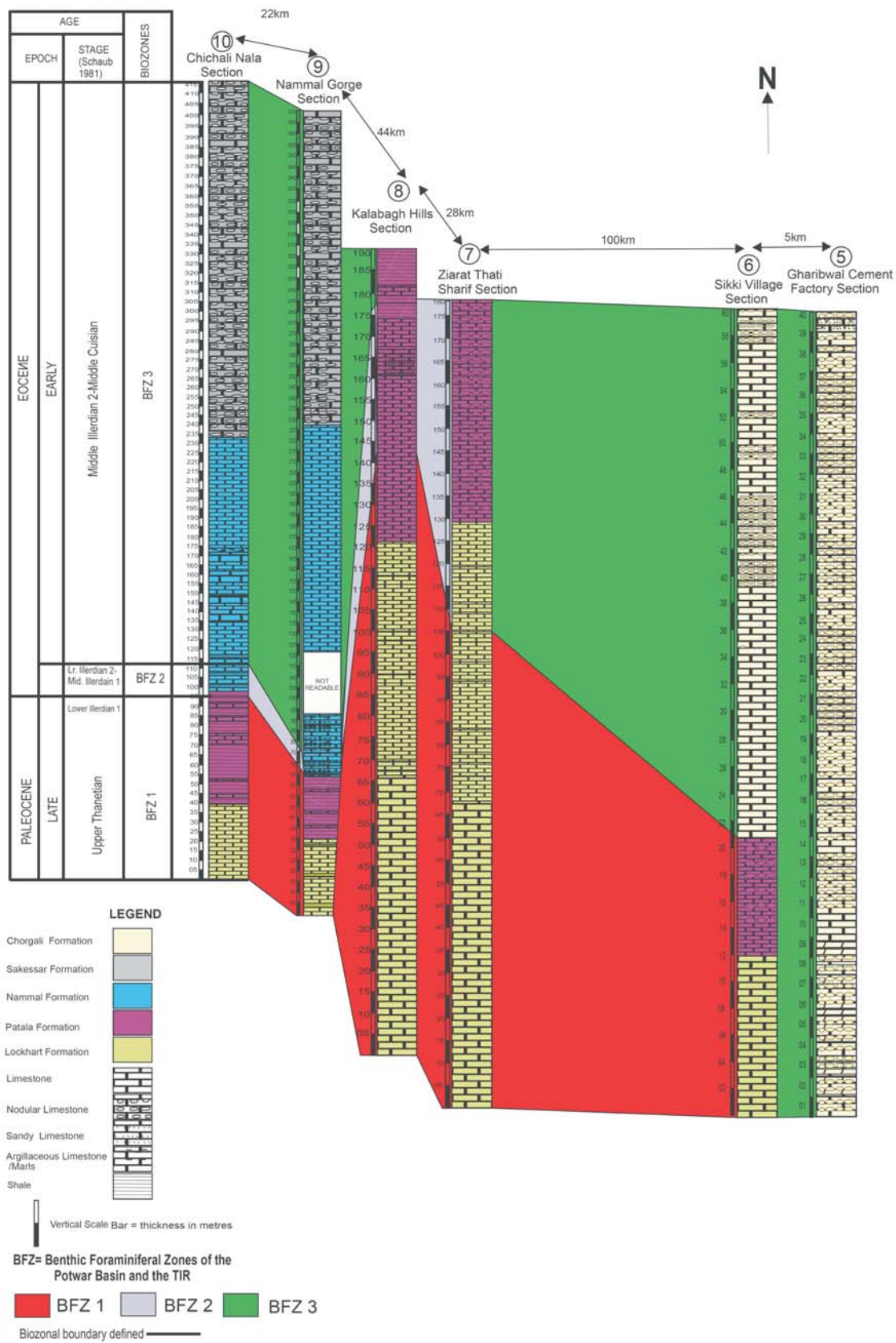
In the Kohat Basin, the BFZ 4 Zone is 32 m thick, recorded in the Kohat Formation in the Sheikhhan Nala Section (text fig. 6). It is not recorded in the Potwar Basin and TIR (text figs. 5, 7).

*Geological age:* middle Eocene (Middle Lutetian 1).

### BFZ 5 Zone

The FO of *Nummulites beaumonti* defines the base while FO of *A. cancellata* marks the top of this Zone. Other associated LBF include *Al. elliptica*, and *N. acutus*. The BFZ 5 Zone is correlated with the fauna of the Kirthar Stage in the Punjab Salt Range, Pakistan (Nagappa 1959). The BFZ 5 Zone can be correlated with Assemblages 4-1 and 4-2, recorded from the middle Prang Limestone, exposed in the Jaintia Hills, Meghalaya, NE India (Matsumaru and Sarma, 2010) (text-fig. 5).

In the Kohat Basin, the BFZ 5 Zone is 9 m thick and is recorded only in the Kohat Formation, exposed in the Sheikhhan Nala Sec-



TEXT-FIGURE 7

Paleogene biostratigraphic correlation chart of the studied sections in the Potwar Basin and Trans Indus Ranges.

tion (text-fig. 6). It is not recorded in the Potwar Basin and TIR (text-figs. 5 and 7).

*Geological age:* middle Eocene (Middle Lutetian 2)

#### BFZ 6 Zone

The stratigraphic range of *Assilina cancellata* (in Schaub 1981) defines this Zone. The associated LBF include *N. beaumonti*, *N. acutus*, *A. papillata*, *Operculina* sp and *Al. elliptica*. The BFZ 6 Zone is correlated with the fauna of the Kirthar Stage in the Punjab Salt Range, Pakistan (Nagappa 1959).

This Zone can be correlated with Assemblages 4-1 and 4-2 recorded in the middle Prang Limestone, in NE India (Matsumaru and Sarma 2010) and LFA 4 to 6 (Tertiary a3) in other Indian Basins (Govindon, 2003) (text-fig. 5). Based on the stratigraphic range of *A. cancellata* in Schaub (1981), the BFZ 6 Zone is equivalent to the *A. gigantea* Zone of Schaub (1981), and it can partially be correlated with SBZ Zone 16 (Serra-Kiel et al. 1998).

In the Kohat Basin, the BFZ 6 Zone is 28 m thick in the Sheikan Nala and 40 m thick in the Panoba Nala Section (text-fig. 6). The BFZ 6 Zone is not recorded in the Potwar Basin and TIR (text-figs. 5 and 7).

*Geological age:* middle Eocene (Upper Lutetian).

## DISCUSSION

### Inter-regional biostratigraphic correlation

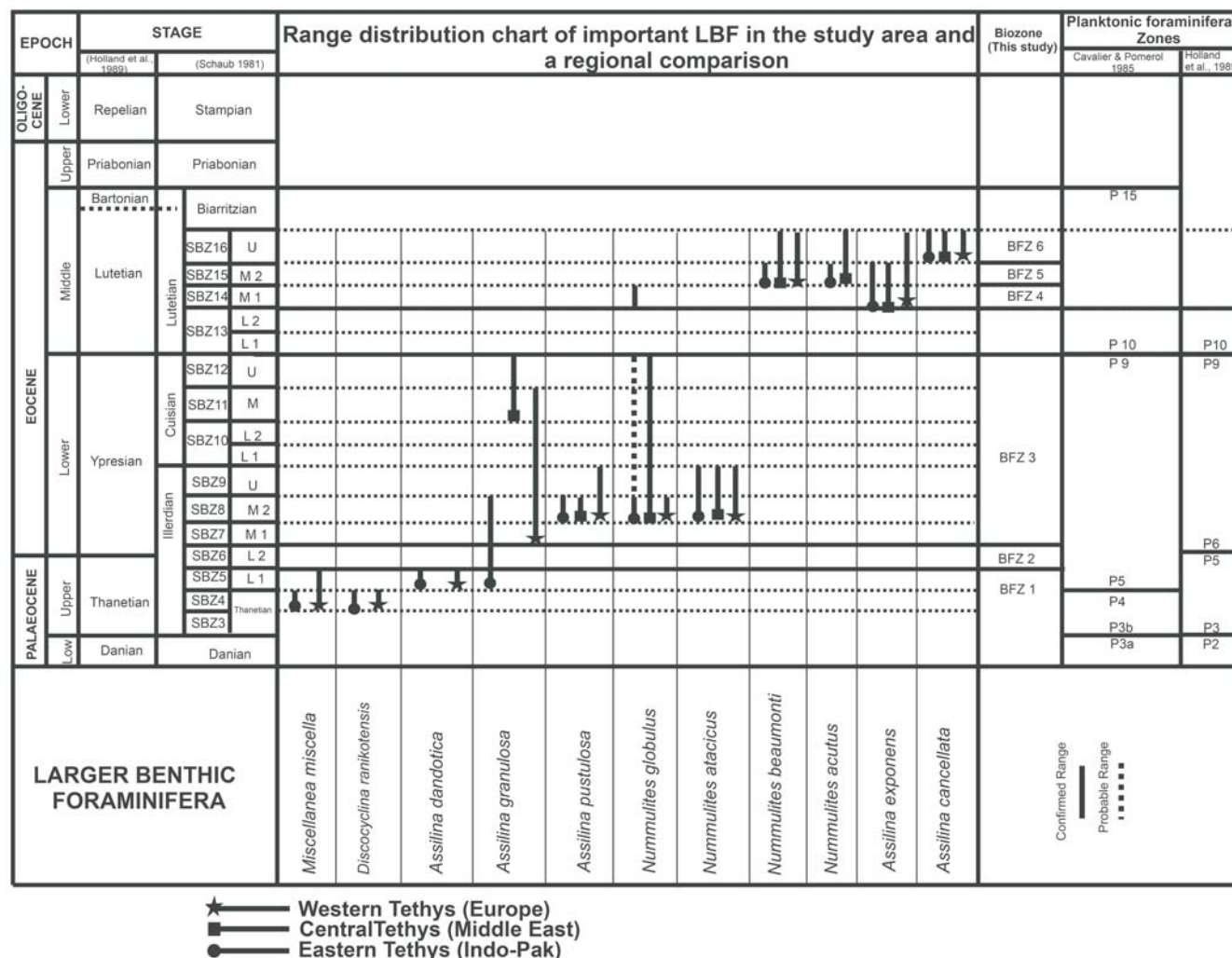
The LBF are important stratigraphic indicators of Paleogene rocks throughout the Tethys. Carbonate sequences are correlated based on the occurrences of *Nummulites*, *Assilina* and *Alveolina* in the Indo-Pacific (Vredenburg 1909, Gee 1944, Nagappa 1959, Weiss 1988, 1993, Afzal 1997, Sameeni et al. 1998, 2009; Afzal 2009, 2011, Ahmad et al. 2014), the Middle East (Kalantari 1981; Racey 1994, 1995; Rahaghi 1980; White 1994 and Karim and Baziany 2007) and Europe (Höttinger 1960, 1971; Schaub 1966, 1981; Serra-Kiel et al. 1998). Various authors have identified biozonations that have a global significance based on the LBF (Höttinger 1960; Schaub 1981; and Serra-Kiel 1998). These zones are very useful in dating carbonate strata of late Paleocene to Oligocene age. The LBF Zones have been correlated with planktonic foraminiferal and coccolithophorid zones (Cavalier and Pomerol 1986; Harland et al. 1989).

The LBF of the Paleogene sequences of the Kohat and Potwar Basins have not been studied in great detail or have not been illustrated as yet (Davies 1940; Vredenburg 1906; Eames 1950, 1952; Afzal 1997; Roohi and Baqri 2004; Sameeni et al. 1998, 2004, 2009; Gahzi et al. 2010; Afzal 2008, 2010; Ahmad et al. 2014). In this paper, we describe the stratigraphic occurrences of selected age diagnostic nummulitid and associated species (text fig. 8). We define the boundaries of the local zones as much as possible based on FO of species which are known to have chronostratigraphic significance in carbonate sequences from the Indo-Pacific, Middle East, and European areas. We discuss here in detail the usefulness of the LBF to subdivide the Kohat and Potwar Paleogene sequences, correlation of the boundaries to other areas such Indo-Pacific, Middle East, and Europe, and the implications for dating of these boundaries.

Late Paleocene (Thanetian) sediments are dominated by the co-occurrence of *M. miscella*, *Ranikothalia sindensis* and *D. ranikotensis* in several sections of both the Kohat and Potwar Basins within BFZ 1 Zone (text-fig. 8). In the Tethyan Himalayas of Tibet, the Paleocene has been recorded in SBZ5, slightly later than in the Western Tethys (Qinghai et al, 2013). In Europe (France), *Miscellanea* sp. was found associated with *R. bermudezi* and *D. seunesi* indicating a late Paleocene (Thanetian~SBZ4) age (Tambareau and Villate 1977; Höttinger 1960; Tambareau 1972). These species occurred throughout the Tethys in the Late Thanetian (~SBZ4-5) (Racey 1995; Serra-Kiel et al. 1998, ). The disappearance of *M. miscella* and *R. sindensis* coincide with the upper boundary of the late Paleocene (Thanetian~SBZ4)(text-fig. 8). This boundary is further defined by the FO of *A. dandotica* in the Kohat and Potwar Basins. The FO of *A. dandotica* is synchronous in sections from the Indo-Pacific, Middle East (Oman) and Europe (text-fig. 8). The FO of *A. dandotica* has been recorded from the Eastern Tethys (Pakistan), representing the early Eocene (Lower Illeridian 1~SBZ5). In the Middle East and Europe, *A. dandotica* represents the early Eocene (Lower Illeridian 1-lower Illeridian 2~SBZ5-6) (Schaub 1981; White 1994; Racey 1995). Based on this, it appears that *A. dandotica* synchronously evolved throughout the Neo-Tethys and we conclude that FO of *A. dandotica* can be used as a global marker for the late Paleocene (Thanetian ~SBZ4)-early Eocene (lower Illeridian 1~SBZ5) boundary. Furthermore, the co-occurrence of *A. pustulosa*, *Al. vredenburgi* (*cucumiformis*), *Al. globula* and *Al. pasticillata* characterizes the early Eocene (Lower Illeridian 1-Middle Illeridian 1~SBZ5-SBZ7) LBF assemblage within the BFZ 2 Zone. The BFZ 2 Zone can be compared with the SRX 2 and SRX 3 Zones of Afzal (1997) and the upper part of the *Lockhartia haime-Dictyokathina simplex* Zone of Weiss (1988, 1993) in the Potwar Basin.

In the study area, the BFZ 3 Zone is characterized by the simultaneous FO of *N. globulus* and *N. aticus* and FO of *Orbitolites complanatus* (text-fig. 8). The BFZ 3 Zone can be compared with the *Assilina leymerie/Nummulites globulus* Zone of Schaub (1981), the SRX 5-7 Zone of Afzal (1997), and the lower part of the *Assilina leymerie-Nummulites fossulata-Discocyclina ranikotensis* Zone -*Assilina spinosa-Flosculina globosa-Dictyokathina cooki* Zone of Weiss (1988, 1993). Previous studies suggest that *N. globulus* was found in the early Eocene shoal facies of Kurdistan in northeast Iraq (Bellen et al. 1959; Karim and Bazainy, 2007). In northern Spain and southern France, it represents the early Eocene (Middle Illeridian 2) (Höttinger 1960; Tambareau and Villate 1977; Robador et al. 1991; Schaub 1981). In India, it represents the early Eocene (Middle Illeridian 2~SBZ8) and middle Eocene (Middle Lutetian 2~SBZ15) (Jauhri 1997, 2006; Jauhri and Agarwal 2001). It appears synchronously with *N. aticus* in Europe (Schaub 1981). In the Kohat Basin, however, it has an extended range compared to Europe, because we also found it in the middle Lutetian 1 (~SBZ14) (text-fig. 8). Therefore, only the synchronous FO of *N. aticus* and *N. globulus* are considered to be excellent global biostratigraphic markers of the early Eocene (Middle Illeridian 1-Middle Illeridian 2~SBZ7-SBZ8) boundary (text-fig. 8). The FO of *Orbitolites complanatus* (Serra-Kiel et al 1998) is useful for constraining the age of the sediments (BFZ 3) below the terrestrial Koldana beds (Gingerich 1977, 2003). The co-occurrence of these species in this interval of only a few meters indicates an early Eocene (Upper Illeridian-Middle Cuisian~SBZ9-SBZ11) age (text-fig. 8). *O. complanatus* has





TEXT-FIGURE 8

Global first and last occurrences of the *Nummulitids* in the Eastern Tethys (Nuttall 1926; Davies and Pinfold 1937; Eames 1950, 1952; Gill 1953; Nagappa 1959; Pascoe 1963; Kureshy 1968; Sarkar 1968; Raju et al. 1970; Sing et al. 1970; Sahni and Kumar 1974; Samanta 1981; Murty 1983; Weiss et al. 1988, 1993; Jauhri and Agarwal 2001; Jauhri 2006; Govindon 2003; Sameeni et al. 1998, 2009; Mukhapadayay 2003, 2005; Afzal 2009, 2011; Ahmad et al., 2014), Central Tethys (Bellen et al. 1959; Rahaghi 1980; Kalantari 1981; White 1994; Racey 1994, 1995; Karim and Bazainy 2007), and Western Tethys (Schaub 1981; Serra-Kiel et al. 1998).

been reported in Assemblage 3-1 and 4-1, representing early-middle Eocene (Middle Cuisian-middle Lutetian 1~SBZ 11-SBZ15) from the Umladoh Limestone and Prang Limestone, exposed in the Jaintia Hills, Meghalaya, NE India (Matsumaru and Sarma, 2010). It seems that *O. complanatus* has appeared simultaneously in the study area (Middle Cuisian~SBZ11) and Indian Basins (Govindon 2003, Matsumaru and Sarma 2010). In Tibet (Willems and Zhang 1993) also found *O. complanatus* in association with *Nummulites* and *Alveolina* in the Upper Zhepure Shale Formation representing the early Eocene (Cuisian~SBZ 11-12). Based on the FO of *O. complanatus* in SBZ 11 (Serra-Kiel et al. 1998) and its regional distribution, it is concluded that the FO of *O. complanatus* is a useful biostratigraphic marker for the early Eocene (Lower Cuisian 2-Middle Cuisian~SBZ10-SBZ11) boundary (text-fig. 8). Mammalian bones found at the base of the Koldana Formation in the Kohat Basin (Gingerich, 2003) are early Eocene in age

(upper Cuisian~SBZ 12), which is in agreement with the LBF biostratigraphy of this study. There are no marine sediments found in the Potwar Basin after the early Eocene (Middle Cuisian~SBZ 11). In the Kohat Basin, however, marine sediment accumulation occurred on top of the Koldana red beds following a new phase of marine transgression in the middle Eocene (Middle Lutetian 1~SBZ 14). This is indicated by the FO of the following nummulitid species: *A. exponens*, *A. spinosa*, and *A. papillata*. The FO of *A. exponens* (Schaub 1981; Serra-Kiel et al. 1998) in BFZ4 Zone constrains the age of the first marine beds to the middle Eocene (Middle Lutetian 1~SBZ 14).

Based on the common presence of *N. beaumonti*, *Al. elliptica* and *N. acutus*, the BFZ 5 Zone partially correlates to LFA 4 to 6 (Tertiary a3) in the Indian Basins (Govindon 2003; Matsumaru and Sarma 2010) and to SBZ Zone 15 (Serra-Kiel et al. 1998). The FO of *N. beaumonti* marks the middle Eocene (Middle

Lutetian1-Middle Lutetian 2~SBZ14-SBZ15) boundary (text-fig. 8). Other LBF species show a diachronous appearance within this zone and can be used only as local biostratigraphic markers (text-fig. 8). The BFZ 6 Zone is characterized by the FO of *A. cancellata*. Based on the stratigraphic range of *A. cancellata* in Schaub (1981), the BFZ 6 Zone represents a middle Eocene (Upper Lutetian~SBZ16) age (text-fig. 8).

#### IMPLICATIONS FOR THE TIMING OF CLOSURE OF EASTERN TETHYS

Cessation of marine sedimentation is one of the important methods used to date the timing of the India-Asia collision, which resulted in the uplift of the Himalayas (for overviews see Najman et al. 2010). We follow this approach, and we use the new LBF biostratigraphy to provide evidence for the timing of the disappearance of the Tethys seaway in the Pakistan area as a result of Himalayan uplift.

The disappearance of *A. davisie*, *A. pustulosa*, *N. atacicus*, and *O. complanatus* in the study area is similarly documented in ramp carbonates in the South-eastern Pyrenean Foreland Basin (NE Spain), Western Tethys (Serra-Kiel et al. 2003). Although regression in the Kohat and Potwar Basin started earlier, our biostratigraphic data suggest that complete subaerial exposure of the basin took place around 50-49.5 Ma. This is a time of a global sea level fall as documented by Haq et al (1987). Collisional tectonics played an important role in the restriction of the sea, but we suggest that the regression was most likely triggered by global sea level fall around 50-49.5 Ma. The record of a rich LBF assemblage in BFZ 4 Zone shows that a renewed phase of marine sedimentation in the Kohat Basin began in the middle Eocene (Middle Lutetian 1~SBZ 14). Naggapa (1959) described the distribution of foraminiferal fauna and facies in Pakistan / India / Burma and concluded that the Kirthar Transgression (Kirthart was used as an equivalent to Middle Lutetian) was a major transgression covering India (Western Narbada Valley, South of Combay, Cutch, Aasam), Pakistan (Sind, Baluchistan, Kohat and Potwar), Burma (Anarkan, Andamans) and the whole of Indonesia. The Lutetian transgression, where a dozen identical species of *Nummulites* have been found in the Alps and in the Himalayas during the Lutetian, indicates that the transgression was not only continuous but

isochronous intercontinentally (Sarkar 1967). The deposition of Middle Lutetian 1 carbonates in the Kohat Basin (~BFZ 4 Zone) can be correlated with eustatic sea level rise in the TEJAS A TA 3 stratigraphic cycle of Haq et al. (1987). We can only speculate why renewed flooding occurred in the Kohat Basin, possibly caused by a combination of flexural loading of the Indian plate (Pivnick and Wells 1996) and/or eustatic sea-level rise (e.g. Haq et al. 1987).

The biostratigraphic range of *A. cancellata* (Schaub 1981) along with associated nummulitid species in the Kohat Basin constrains the age of the final retreat of the eastern Tethys seaway in Pakistan, to the middle Eocene (Upper Lutetian ~BFZ 6 Zone), around 41.2 Ma.

#### SUMMARY AND CONCLUSIONS

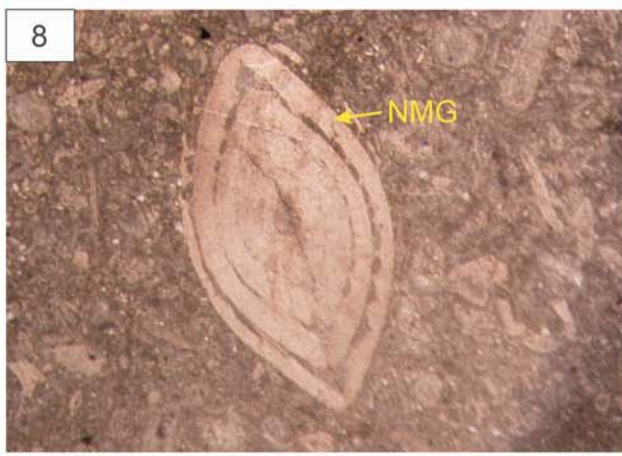
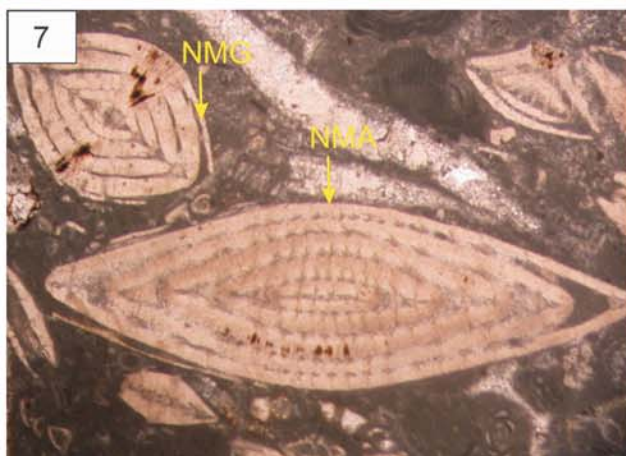
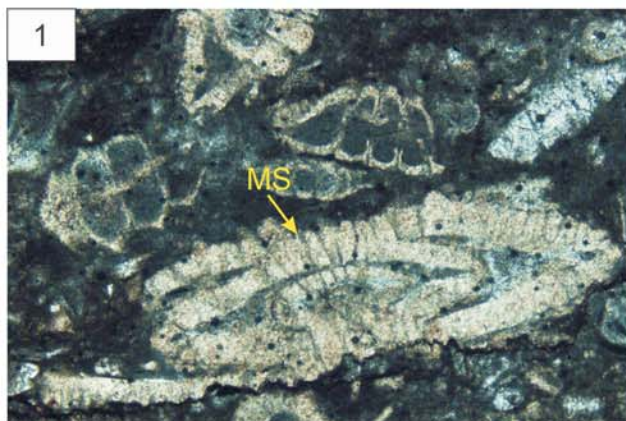
The Paleogene LBF study of the Kohat and Potwar Basins of northwestern Pakistan, representing the Eastern Tethys, is documented. The recorded LBF include *M. miscella*, *R. sindensis*, *D. ranikotensis*, *L. haimie*, *L. conica*, *A. dandotica*, *Al. globula*, *N. globulus*, *N. atacicus*, *N. pinfoldi*, *A. spinosa*, *Al. pasticillata*, *O. complanatus*, *A. exponens*, *A. laminosa*, *N. beaumont*, *A. papillata*, *A. cancellata*, *A. granulosa*, *A. pustulosa*, *Al. cucumiformis*, *Al. elliptica*, *Operculina* sp, *R. sahani*, *A. daviesi*, *A. sutri*, and *N. acutus*.

The biometric features and coiling graphs of the nummulitids are presented and compared with specimens, mostly from the Eastern (Mukhopadhyay 2003) and Western Tethys (Schaub 1981) and was used for selection of species for local and regional biostratigraphic correlation. Six local Zones (BFZ 1-6) representing late Paleocene (Thanetian)-middle Eocene (Upper Lutetian) are established in the Kohat Basin. The first three Zones (BFZ 1-3) representing the late Paleocene (Thanetian)-early Eocene (Middle Cuisian) are found in the Potwar Basin and TIR. All zones are compared with previously established local and regional LBF biostratigraphic schemes. We conclude that the disappearance of *M. miscella* and *R. sindensis* and the FO of *A. dandotica* coincides with the late Paleocene (Thanetian~SBZ4) and early Eocene (Lower Ilterdian 1) boundary. In the BFZ 2 Zone, *A. pustulosa*, *Al. vredenburgi* (*cucumiformis*), *Al. globula* and *Al. pasticillata* represent the

#### PLATE 1

- 1 Axial view of *Miscellanea miscella* (MS) recorded from the Lockhart Formation in the Potwar Basin.
- 2 Axial view of *Ranikothalia sindensis* (RA) recorded from the Patala Formation in the Potwar Basin.
- 3 Axial view of *Discocyclus ranikotensis* (DSR) recorded from the Lockhart Formation in the Potwar Basin.
- 4 Axial view of *Lockhartia haimeii* (LOH) recorded from the Lockhart Formation in the Potwar Basin.
- 5 Axial view of *Assilina dandotica* Davies (ASD) recorded from the Lockhart Formation in the Potwar Basin.
- 6 Equatorial view of *Alveolina globula* (ALG) from the Sheikhan Formation in the Kohat Basin.
- 7 Axial view of *Nummulites globulus* Leymerie (NMG) and *Nummulites atacicus* Leymerie in the Sakessar Formation in the Trans Indus Ranges.
- 8 Axial view of *Nummulites globulus* Leymerie (NMG) in the Chorgali Formation in the eastern Salt Range area of the Potwar Basin.







early Eocene (Lower Illerian 1-Middle Illerian 1~SBZ5-SBZ7). The FO of *N. atcicus/N. globulus* and *O. complanatus* (Serra-Kiel et al 1998) in the BFZ 3 Zone is useful for constraining the early Eocene (Lower Illerian 1-Middle Cuisian ~SBZ8-11) age of sediments below the terrestrial Koldana beds. The record of BFZ 3 Zone indicates that cessation of marine sedimentation in the Kohat Basin and the Potwar Basin occurred around 50-49.5 Ma (BFZ 3 Zone~SBZ11). This age provides constraint to the minimum age of the India-Asia collision. The FO of *A. exponens* and associated LBF species in BFZ 4 marks the middle Lutetian 1 (BFZ 4 Zone~SBZ11). Renewed flooding occurred only in the Kohat Basin in BFZ 4 (Middle Lutetian 1). The FO of *N. beaumonti* in BFZ 5 Zone marks the Middle Lutetian 1-Middle Lutetian 2 Boundary (BFZ 5 Zone~SBZ15). The final closure of the Kohat Basin, which marks the final retreat of the Tethyan seaway, occurred around 41.2 Ma in the Pakistan area (BFZ 6 Zone~SBZ16). The cause of renewed local flooding remains speculative, probably caused by some form of local post collisional stress (after BFZ 3 Zone) and/or eustatic sea level rise (during BFZ 4 Zone). Based on the occurrence of LBF it is also concluded that the youngest marine sediments in the Kohat Basin belong to the middle Eocene (Upper Lutetian) supporting the upper Kirthar (late middle Eocene) view of Davies (1940), Vredenburg (1906), Eames (1950, 1952) and Roohi and Baqri (2004).

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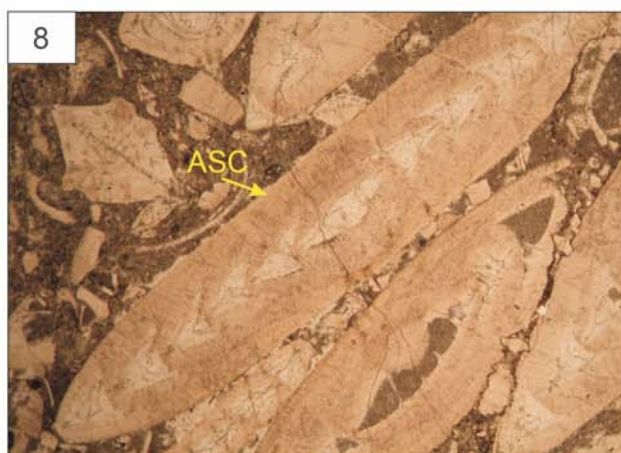
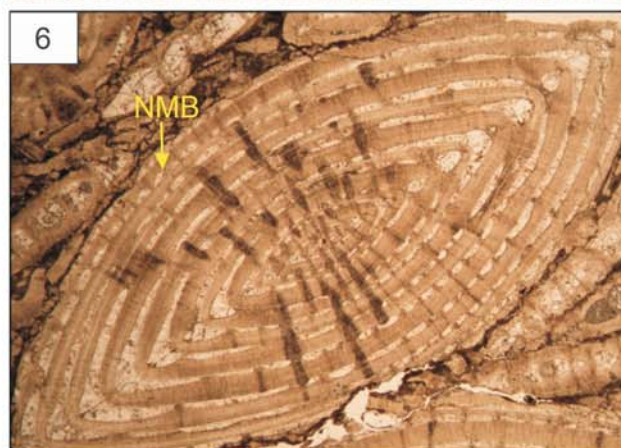
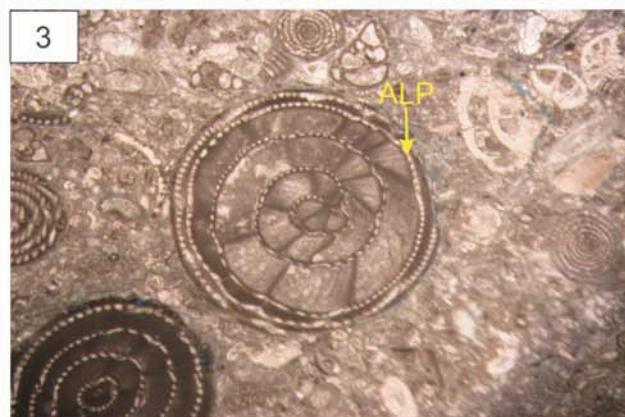
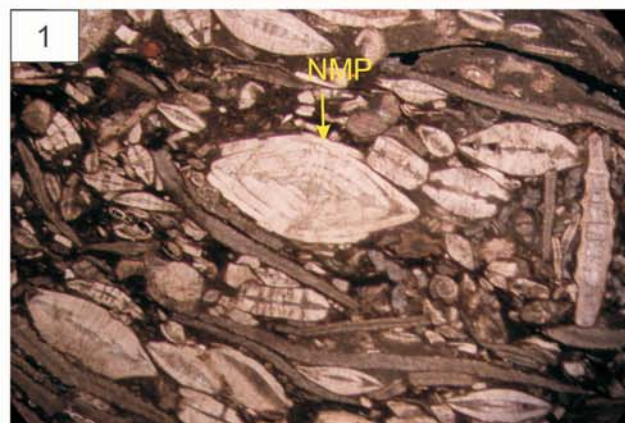
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#### PLATE 2

- 1 Axial view of *Nummulites pinfoldi* Davies (NMP) in the Nammal Formation in the Trans Indus Ranges.
- 2 Axial view of *Assilina spinosa* Davies (ASP) and *Discocyclina ranikotensis* (DSR) in the Nammal Formation in the Trans Indus Ranges.
- 3 Flosculinized *Alveolina pasticillata* (ALP) in the Sheikhan Formation, Kohat Basin.
- 4 *Orbitulites complanatus* (ORC) in the Sheikhan Formation, Kohat Basin.
- 5 Axial view of *Assilina exponens* Nuttal (ASE) and *Assilina laminosa* Gill (ASL) in the Kohat Formation, Kohat Basin.
- 6 Axial view of *Nummulites beaumonti* d'Archiac and Haime (NMB) in the Kohat Formation, Kohat Basin.
- 7 Axial view of *Assilina papillata* Nuttal (ASP) in the Kohat Formation, Kohat Basin.
- 8 Axial view of *Assilina cancellata* Nuttal (ASC) in the Kohat Formation, Kohat Basin.







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### PLATE 3

List of age diagnostic LBF recorded in BFZ Zones in the study area.

#### *Miscellanea miscella*

- 1 *Miscellanea miscella* Davies and Pinfold (Axial section)

#### *Assilina dandotica*

- 2 Axial section partially exposing the equatorial section
- 3 Form B, axial section

#### *Assilina granulosa* d' Archiac and Haime

- 4 Form B, equatorial section
- 5 Form B, axial section
- 6 Form A, equatorial section
- 7 Form A, axial section

#### *Assilina pustulosa* Doncieux

- 8 Form B, equatorial section
- 9 Form B, axial section
- 10 Form A, axial section

#### *Nummulites atacicus* Leymerie

- 11 Form B, axial section
- 12 Form B, equatorial section
- 13 Form A, equatorial section
- 14 Form A, axial section

#### *Nummulites globulus* Leymerie

- 15 Form B, equatorial section
- 16 Form B, axial section
- 17 Form A, equatorial section
- 18 Form A, axial section

#### *Alveolina cucumiformis*

- 19 Unflosculinized specimen

- 20 Axial section

#### *Alveolina globula*

- 21 Equatorial section

#### *Alveolina pasticilata*

- 22 Equatorial section

#### *Alveolina elliptica*

- 23 Axial section
- 24 Oval shaped, double protoconch

#### *Nummulites beaumonti* d' Archiac and Haime

- 25 Form B, equatorial section
- 26 Form B, axial section
- 27 Form A, equatorial section
- 28 Form A, axial section

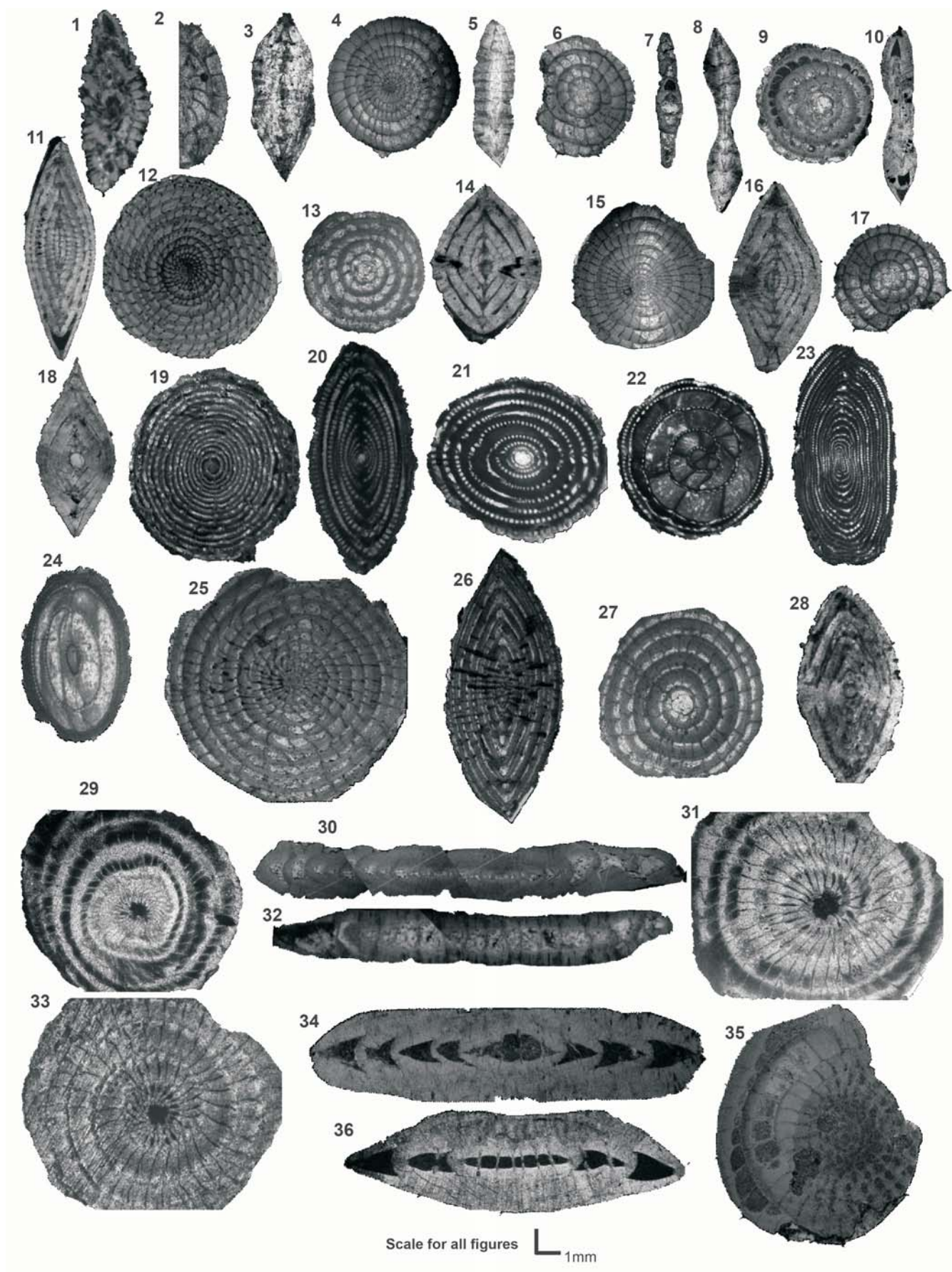
#### *Assilina exponens* Sowerby

- 29 Form B, equatorial section
- 30 Form B, axial section
- 31 Form A, equatorial section
- 32 Form A, axial section

#### *Assilina cancellata* Nuttall

- 33 Form B, equatorial section
- 34 Form B, axial section
- 35 Form A, equatorial section
- 36 Form A, axial section





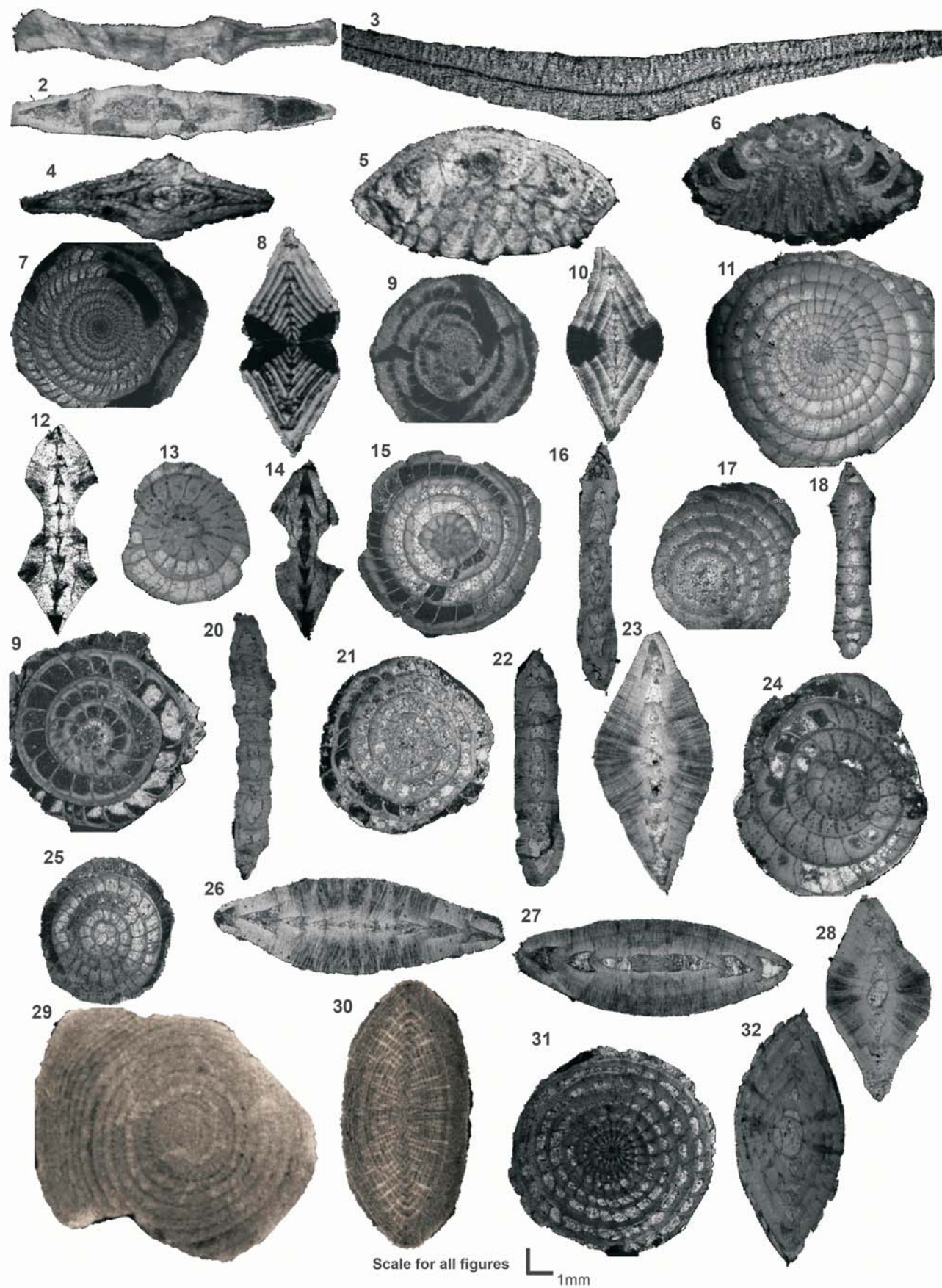
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#### PLATE 4

The list of associated LBF in the BFZ Zones of the study area.

- |  |                                  |
|--|----------------------------------|
| 1 <i>Ranikothalia sindensis</i> (axial section)      | 18 Form A, axial section         |
| 2 <i>Operculina</i> sp. (off centered axial section) | <i>Assilina papillata</i> Nuttal |
| 3 <i>Discocyclina ranikotensis</i> (axial section)   | 19 Form B, equatorial section    |
| 4 <i>Ranikothalia sahni</i> (axial section)          | 20 Form B, axial section         |
| 5 <i>Lockhartia haimei</i> (axial section)           | 21 Form A, equatorial section    |
| 6 <i>Lockhartia conica</i> (axial section)           | 22 Form A, axial section         |
| <i>Nummulites pinfoldi</i> Davies                    | <i>Assilina laminosa</i> Gill    |
| 7 Form B, equatorial section                         | 23 Form B, equatorial section    |
| 8 Form B, axial section                              | 24 Form B, axial section         |
| 9 Form A, equatorial section                         | 25 Form A, equatorial section    |
| 10 Form A, axial section                             | 26 Form A, axial section         |
| <i>Assilina davisie</i> de Cizancourt                | <i>Assilina sutri</i> Schaub     |
| 11 Form B, equatorial section                        | 27 Form B, axial section         |
| 12 Form B, axial section                             | 28 Form B, axial section         |
| 13 Form A, equatorial section                        | <i>Nummulites acutus</i> Sowerby |
| 14 Form A, axial section                             | 29 Form B, equatorial section    |
| <i>Assilina spinosa</i> Davies                       | 30 Form B, axial section         |
| 15 Form B, equatorial section                        | 31 Form A, equatorial section    |
| 16 Form B, axial section                             | 32 Form A, axial section         |
| 17 Form A, equatorial section                        |                                  |







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