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Revised Late Paleocene-Early Eocene planktonic foraminiferal biostratigraphy of the Indus Basin, Pakistan

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ABSTRACT

The existing Late Paleocene-Early Eocene planktonic foraminiferal biostratigraphy of the Indus Basin, Pakistan is reviewed in this paper. The planktonic foraminiferal zones (i.e. P3-E5) of the currently used tropical to subtropical scheme are recognized in these successions, which has helped in the intra-basinal correlation of the Dungan and Shaheed Ghat formations (Lower Indus Basin) with the Patala and Nammal formations (Upper Indus Basin) of Pakistan. The presence of the Late Paleocene-Early Eocene planktonic foraminiferal assemblages (represented by three main genera; *Acarinina, Subbottina* and *Morozovella*) in Pakistan attest to the fact that tropical to subtropical warm surface water conditions existed through the Late Paleocene-Early Eocene interval.

Keywords: Planktonic foraminimera, biostratigraphy, Indus Basin

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INTRODUCTION

The biostratigraphical studies of the Paleogene planktonic foraminifera was originated in the Former Soviet Union (Berggren 1960). In the mid-late 1930's (e.g., Glaessner 1934; 1937a, b; Subbotinae 1934; 1936; 1939; Morozova 1939) the importance of the planktonic foraminifera in biostratigraphic studies as a reliable biostratigraphic tool was recognized because of the cosmopolitan nature of this group. Important biostratigraphical studies and reviews concerning at least part of the Paleogene were subsequently published by Subbotinae (1953), Alimarina (1962; 1963), Leonov and Alimarina (1964), Shutskaya (1956; 1958; 1960a; 1960b, 1970), Bolli (1957a; 1957b; 1966), Shutskaya et al. (1965), Krasheninnikov (1965; 1969), Berggren (1969), Krasheninnikov and Muzylev (1975), Stainforth et al. (1975), Blow (1979) and Toumarkine and Luterbacher (1985).

The Late Paleocene-Early Eocene planktonic foraminiferal biostratigraphy significantly improved in the last two decades, due to the interest in the "Paleocene Eocene Thermal Maximum" (i.e., PETM; Kennett and Stott 1991). Subsequent to which, a number of planktonic foraminiferal zonal schemes across the Paleocene/Eocene boundary have been proposed. These include the tropical to subtropical planktonic foraminiferal biostratigraphical schemes by Canudo and Molina (1992), Berggren et al. (1995), Arenillas and Molina (1996), Berggren and Norris (1997), Pardo et al. (1999), Molina et al. (1999), Berggren and Ouda (2003), Berggren et al. (2003) and Berggren and Pearson (2005).

An attempt to improve the biostratigraphical resolution across the Paleocene/Eocene boundary has been made by Arenillas and Molina (1996). They proposed the *Igorina laevigata* Zone for the lower part of the *Morozovella velascoensis* Zone of Berggren et al. (1995). However, this new zonation was not workable as *I. laevigata* is a rare morphotype and may be a junior synonym of *Igornia albeari* (e.g., Blow 1979; Berggren and Norris 1997). Later, Zone P5 of Berggren et al. (1995) was subdivided by Pardo et al. (1999). This proposed subdivision was based on the Lowest Occurrence (LO) of *Acarinina sibaiyaensis* and/ or *Acarinina africana*. Following the work of Pardo et al. (1999), Molina et al. (1999) subdivided the *M. velascoensis* Zone of Berggren et al. (1995) into five subzones.

Berggren and Pearson (2005) proposed that distinct and stratigraphically limited planktonic foraminifera "excursion taxa" are associated with the Carbon Isotope Excursion (CIE). These taxa are of great value in identifying the Paleocene/Eocene boundary (e.g., Kelly et al. 1996) and occur within the middle part of Zone P5 of Berggren et al. (1995). Following the work of Pardo et al. (1999) and

Molina et al. (1999), Berggren and Pearson (2005) divided the Zone P5 of Berggren et al. (1995) based on the LO of one of the excursion taxa, *Acarinina sibaiyaensis*. They also used the Lowest occurrence of *Pseudohastigerina wilcoxensis* to further subdivide Zone P5 (*sensu* Berggren et al. 1995).

The Dungan Formation in the Lower Indus Basin and the Patala Formation in the Upper Indus Basin are Late Paleocene-Early Eocene in age (see e.g., Latif 1964; Samanta 1973; Warraich and Natori 1997; Gibson 1990; Afzal 1997; Warraich et al. 2000; Shafique 2001). The Dungan and Shaheed Ghat formations (Lower Indus Basin) and Patala and Nammal formations (Upper Indus Basin) are correlated and the existing planktonic foraminiferal biostratigraphical schemes are reviewed (Fig. 1), using the Late Paleocene-Early Eocene planktonic foraminiferal zones P3 to E5 of Berggren and Pearson (2005). The planktonic foraminifera extracted by Hanif et al. (in press) were also identified and utilized in this literature review (see Plates I-III), methodology for planktonic foraminifera extraction is described in Hanif et al. (in press) and in references therein. In order to avoid confusion created by the acronym 'LO' denoting both 'lowest' and 'last' occurrences in the literature the lowest (LO) and highest (HO) occurrences of palaeontological events are adopted here (after Berggren and Pearson, 2005) to define the limits of a biozone. They applied the first appearance datum (FAD) and last appearance datum (LAD) of palaeontological events to define time limits of a biochron (*sensu* Aubry 1995). The Paleocene/Eocene notation of Berggren and Pearson (2005) is used in this research.

PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY

Zone P3. *Morozovella angulata* Lowest-Occurrence Zone (Fig. 1)

The planktonic foraminiferal zone P3 (i.e., *Morozovella angulata-Globanomalina pseudomenardii* Zone of Berggren et al. 1995; Berggren and Norris 1997; Olsson et al. 1999) from the Lower Indus Basin has been identified by Warraich et al. (2000). Following the convention that the nominated taxon should be present within the zone, Berggren and Pearson (2005), retaining the definition, re-named the P3 Zone as the '*Morozovella angulata* Lowest-Occurrence Zone'. This Zone was also subdivided by Berggren et al. (1995) as subzones P3a and P3b based on the LO of *Igorina albeari*. This subdivision was also followed by Berggren and Pearson (2005). However, because of the sporadic occurrence of *I. albeari*, the LO of *Morozovella acuta* was used for this subdivision in the Lower Indus Basin. Bergrren and Pearson (2005) adopted the recalibrated age of the *G. pseudomenardii* (FAD) as 59.4 Ma (after Berggren et al. 2000) instead of 59.2 Ma (after Berggren et al. 1995). The Subzone P3a was modified after Berggren et al. (1995) and designated as the *M. angulata-M. acuta* Interval Subzone by Warraich et al. (2000) in the Lower Indus Basin. However, following Berggren and Pearson (2005) this Subzone can be renamed as the *Igorina pusilla* Partial-Range Subzone. In order to avoid the use of *M. angulata* as the nominate taxon for both P3 and P3a, this Subzone is redefined here as the Partial-Range of *Igorina pusila* between the LO of *M. angulata* and the LO of *M. acuta*. Similarly, the Subzone P3b of Warraich et al. (2000) can be re-named and modified after Berggren and Pearson (2005) as the *M. acuta* Lowest-Occurrence Subzone. The Zone P3 is equivalent to the *G. angulata* Zone of Dorreen (1974) of the Kirther Range (Lower Indus Basin). The Zone P3 is not reported from the Upper Indus Basin (Afzal 1997).

Zone P4. *Globanomalina pseudomenardii* Taxon-Range Zone (Fig. 1)

The name and definition of Zone P4 in the Lower Indus Basin follows Warraich et al. (2000). However, the nomenclature of its two-fold subdivision is revised. As a result of the absence of *Parasubbotinae variospira* the P4a/P4b subzonal boundary cannot be demarcated, although the P4b/P4c subzonal boundary can be identified by the LO of *A. soldadoensis* as reported by Warraich et al. (2000). Therefore, the P4a and P4b jointly and P4c subzones of Berggren and Pearson (2005) are equivalent to the *Globanomalina pseudomenardii-Acarinina soldadoensis* Interval Subzone and the *Acarinina soldadoensis soldadoensis*/*Globanomalina pseudomenardii* Concurrent Range Subzone respectively of Warraich et al. (2000). In the Kirther Range (Lower Indus Basin) Zone P4 is equivalent to the lower part of the *G. velascoensis* Zone of Dorreen (1974). Zone P4 in the Upper Indus Basin can be established following the work of Afzal (1997) on the Total Range of the *Planorotalites pseudomenardii* (=*G. pseudomenardii*). Similar to the Lower Indus Basin, only the P4b/P4c subzonal boundary in the Upper Indus Basin can be established, based on the *Muricoglobigerina soldadoensis* (LO) reported by Afzal (1997). Therefore, the subzones P4a and P4b of Berggren and Pearson (2005) are equivalent to the *P. pseudomenardii* Zone of Afzal (1997) and the P4c Subzone of Berggren and Pearson (2005) is equivalent to the *Mg. soldadoensis* Zone of Afzal (1997).

Zones P5, E1 and E2 (Fig. 1)

Zone P5 of Warraich et al. (2000) in the Lower Indus

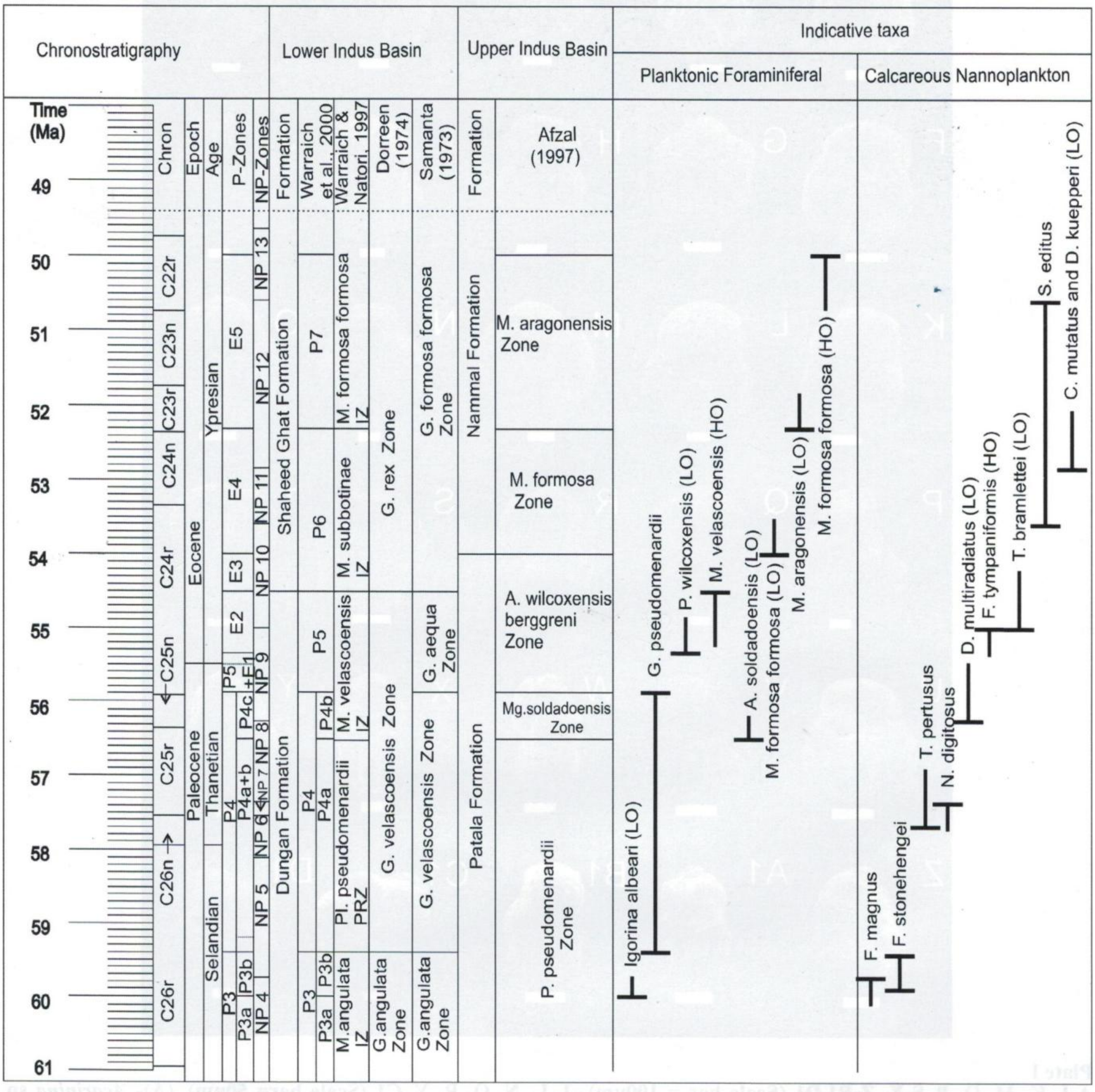

Fig. 1: Planktonic foraminiferal and nannofossil zones for the Late Paleocene-Early Eocene of the Indus Basin. Biostratigraphical data is compiled from various sections of the Indus Basin; e.g., Samanta (1973), Dorreen (1974), Kothe et al. (1988), Afzal (1997), Warraich and Natori (1997), Warraich et al. 2000. Planktonic foraminiferal zones of the Indus Basin correspond to the zones of Berggren and Pearson (2005). P-Zones = Planktonic foraminiferal zones of Berggren and Pearson (2005). NP-Zones=Calcareous nanoplankton zones of Martini (1971), Chronostratigraphy of Berggren et al. (1995) with modifications of Berggren and Pearson (2005).

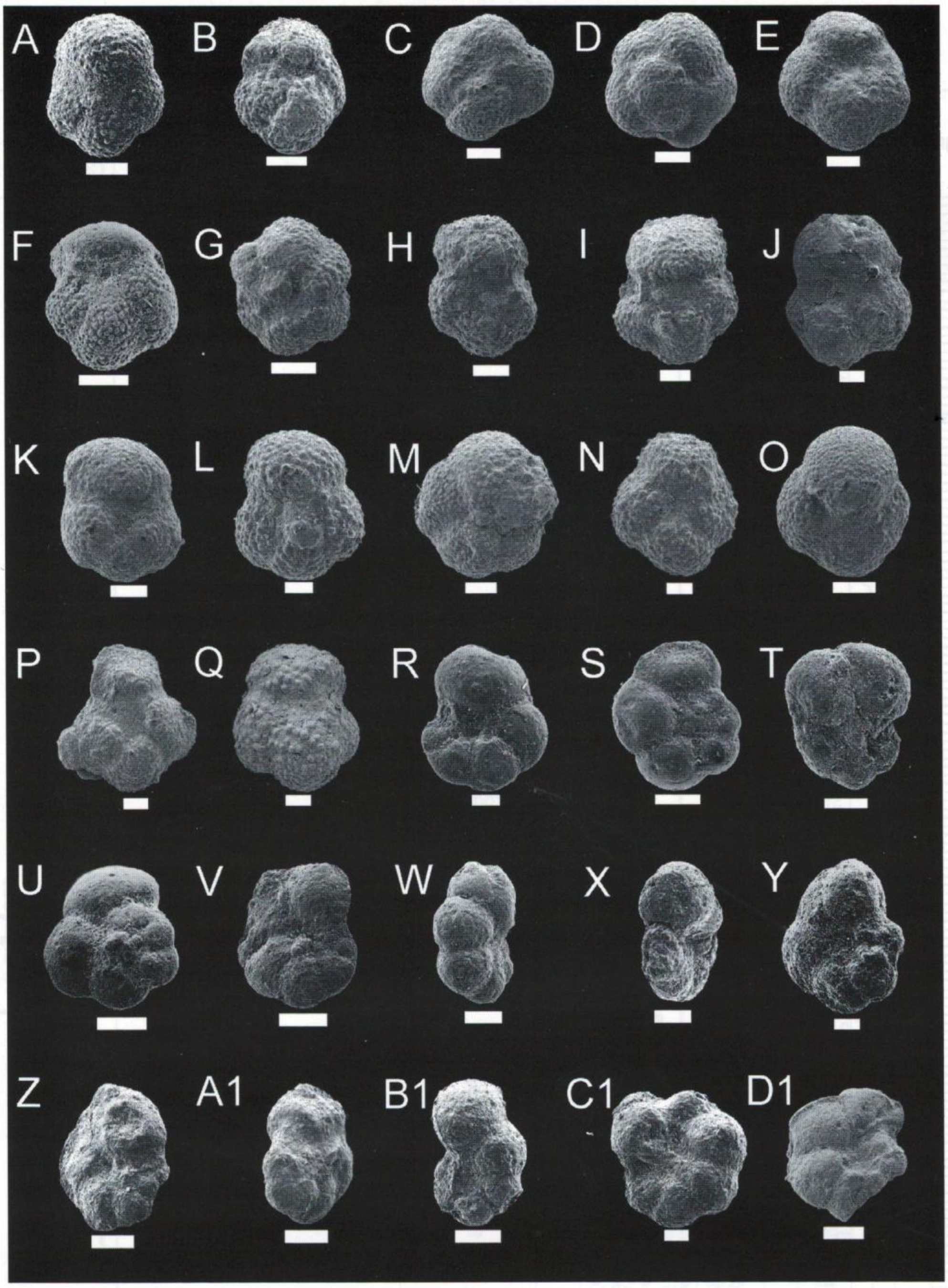

Plate I

A-I, K, M, O, P, S-X. Z-B1,D1 (Scale bar = 100µm), J, L, N, Q, R, Y, C1 (Scale bar= 50µm), (A)- *Acarinina* sp. cf. *A. wilcoxensis*, sample # (Td-33), (B)- *Acarinina* sp., (Td-30), (C)- *Acarinina* sp., (Td-50), (D)- *Acarinina* sp., (Td-50), (E)- *Acarinina* sp., (Td-50), (F)- *Acarinina* sp., cf. *A. pseudotopilensis* (Td-32), (G)- *Acarinina* sp., (Td-45), (H)- *Acarinina* sp., (Td-43), (I)- *Acarinina* sp. cf. *A. wilcoxensis*, (Td-43), (J)- *Acarinina* sp., (Td-44), (K)- *Acarinina* sp., (Td-44), (L)- *Acarinina* sp. cf. *A. wilcoxensis*, (Td-44), (M)- *Acarinina* sp., (Td-44), (N)- *Acarinina* sp., (Td-44), (O)- *Acarinina* sp., (Td-44), (P)- *Acarinina* sp., (Td-44), (Q)- *Acarinina* sp., (Td-44), (R)- *Globanomalina chapmani*, (Td-32), (S)-*Globanomalina* sp. cf. *G. chapmani*, (Td-32), (T)- *Pseudohastigerina* sp. cf. *P. wilcoxensis*, (Td-32), (U)- *Globanomalina* sp. cf. *G. chapmani*, (Td-32), (V)- *Globanomalina* sp., (Td-42), (W)- *Globanomalina* sp., (Td-42), (X)- *Pseudohastigerina* sp. cf. *P. wilcoxensis*, (Td-47), (Y)- *Globanomalina* sp., (Td-45), (Z)- *Globanomalina* sp., (Td-44), (A1)- *Globanomalina* sp., (Td-44), (B1)- *Globanomalina* sp. cf. *G. luxorensis*, (Td-44), (C1)- *Globanomalina* **sp., (Td-44), (D1)- *Globanomalina* sp., (Td-45). Sample numbers are after Hanif et al. (in press).**

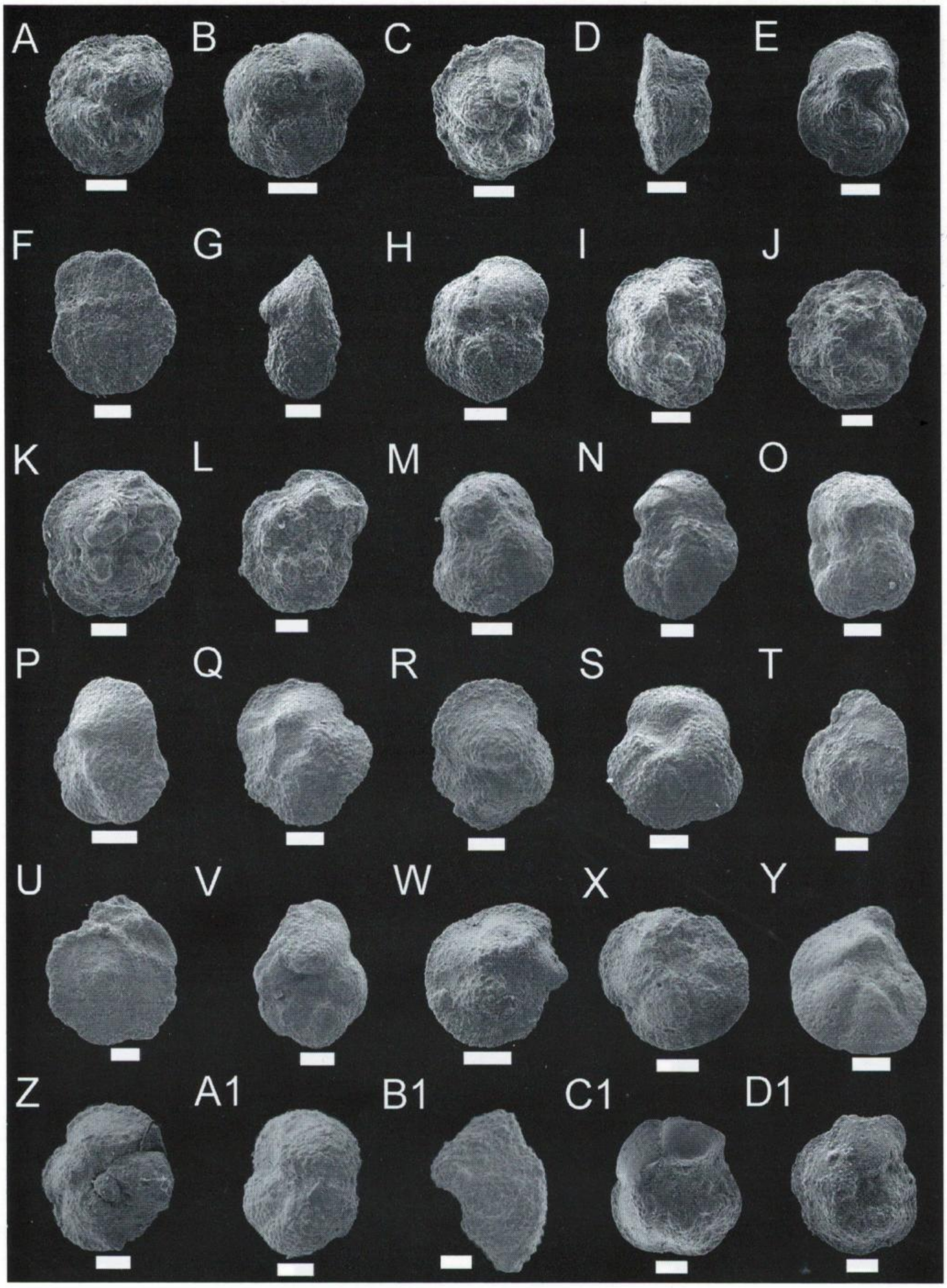

Plate II

A-A1, C1, D1 (Scale bar= 100µm), B1 (Scale bar= 50µm), (A)- *Morozovella* sp. cf. *M. conicotruncata*, sample # (Td-43),(B)- *Morozovella* sp. cf. *M. formosa formosa*, (Td-33),(C)- *Morozovella aragonensis*, (Td-33), (D, E,F)- *Morozovella acutispira*, (D-Td-33, E-Td-33, F-Td-33), (G)- *Morozovella aequa*, (Td-33), (H)- *Morozovella formosaformosa*, (Td-33),(I)- *Morozovella* sp. cf. *M. conicotruncata*, (Td-30), (J,K)- *Morozovella* sp. cf. *M. aragonensis*, (J-Td-30, K-Td-30), (L)- *Morozovella acutispira*, (Td-30), (M,N)- *Morozovella subbotinae*, (M-Td-48, N-Td-48), (O)- *Morozovella* sp., (Td-48), (P,Q,R)- *Morozovellaaequa*, (P-Td-50, Q-Td-45, R-Td-45), (S)- *Morozovellasubbotinae*, (Td-45), (T)- *Morozovella* sp., (Td-45), (U)- *Morozovella* sp., (Td-44), (V)- *Morozovella* sp., (Td-48), (W)- *Morozovella occlusa*, (Td-45), (X)- *Morozovella acuta*, (Td-47), (Y)- *Morozovella* sp., (Td-47), (Z)- *Morozovella acuta*, (Td-44), A1. B1. *Morozovella aequa*, (C1)- *Morozovella acuta*, (Td-32), (D1)- *Morozovella* sp. cf. *M. acutispira*, (Td-32). Sample numbers are after Hanif et al. (in press).

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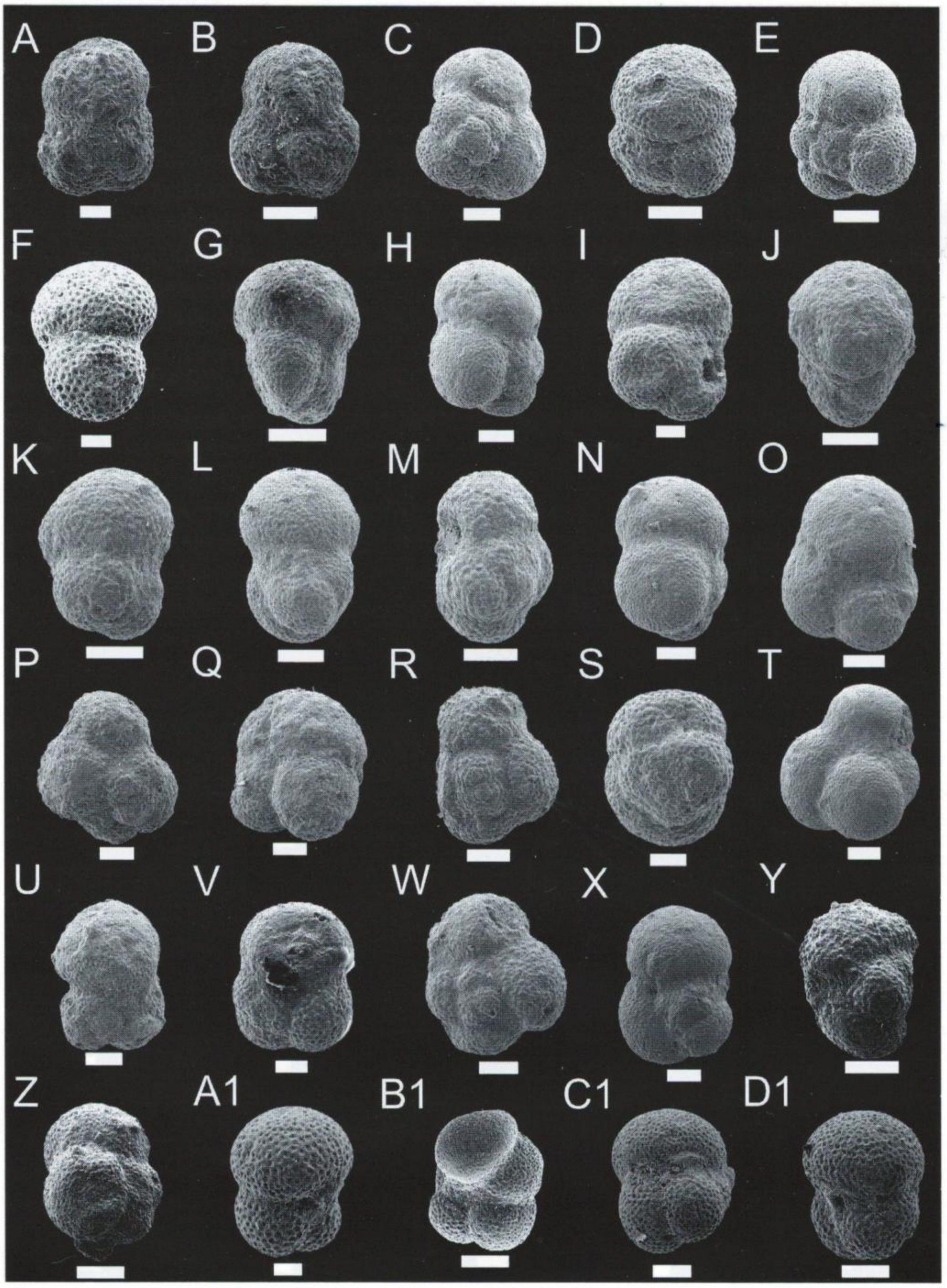

Plate III

B-E, G, H, J-R, T, U, W, X, Y, Z, B1-D1 (Scale bar= 100µm), A, F, I, S, V, A1 (Scale bar = 50µm), (A)- *Subbotinae triloculinoides*, sample # (Td-43), (B,C)- *Subbotinae triangularis*, (B-Td-43, C-Td-33), (D)- *Subbotinae velascoensis*, (Td-33), (E)- *Subbotinae triangularis*, (Td-33), (F)-*Subbotinae triloculinoides*, (Td-33), (G)- *Subbotinae velascoensis*, (Td-48), (H)- *Subbotinae triangularis*, (Td-50), (I)- *Subbotinae* sp. cf. *S. triloculinoides*, (Td-50), (J)- *Subbotinae* sp., (Td-50), (K,L)- *Subbotinatriloculinoides*, (K-Td-50, L-Td-50), (M,N)- *Subbotinae* sp. cf. *S. triangularis*, (M-Td-50, N-Td50), (O)- *Subbotinae triangularis*, (Td-50), (P)- *Parasubbotinae* sp. cf. *P. varianta*, (Td-43), (Q)- *Subbotinae* sp. cf. *S. velascoensis*, (Td-43), (R)- *Subbotinae* sp. cf. *S. triangularis*, (Td-44), (S)- *Subbotinae* sp., (Td-48), (T)- *Subbotinae* sp. cf. S. patagonica, (Td-50), (U,V)- *Subbotinae* **sp. cf. *S. triloculinoides*, (U-Td-43, V-Td-44), (W)- *Parasubbotinae* sp., (Td-45), (X)- *Subbotinae triloculinodes*, (Td-45), (Y)- *Subbotinae* sp. cf. *S. velascoensis*, (Td-44), (Z)- *Subbotinae* sp. cf. *S. patagonica*, (Td-44),(A1) *Subbotinae triloculinoides*, (Td-32), (B1)- *Parasubbotinae* sp., (Td-33), (C1,D1)- *Subbotinae triloculinoides*,(C1-Td-45, D1-Td-50).Sample numbers are after Hanif et al. (in press).**

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Basin (Sulaiman Range) is revised following Berggren and Pearson (2005). Due to the absence of Planktonic Foraminiferal Excursion Taxa (PFET) such as *Acarinina africana*, *Acarinina sibaiyaensis* and *Morozovella allisonensis*, the zonal boundary P5/E1 cannot be recognized in the Indus Basin. However, the zonal boundary E1/E2 is recognized based on the Lowest Occurrence (LO) of *P. wilcoxensis* of Afzal (1997). P5 (*Morozovella velascoensis* Partial-Range Zone) and E1 (*Acarinina sibaiyaensis* Lowest-Occurrence Zone) together and E2 (*Pseudohastigerina wilcoxensis*/*Morozovella velascoensis* Concurrent-Range Zone) are, therefore, equivalent to the P5 (lower-middle) and P5 (upper), respectively, of Warraich et al. (2000). In the Lower Indus Basin (Kirther Range) Zones P5, E1 and E2 are equivalent to the *G. velascoensis* Zone of Dorreen (1974). The P5, E1 and E2 of Berggren and Pearson (2005) are equivalent to the *Acarinina wilcoxensis berggreni* Zone (lower to middle) of Afzal (1997).

Zone E3. *Morozovella marginodentata* Partial-Range Zone (Fig. 1)

The Eocene Planktonic Foraminiferal Zone E3 can be recognized in both the Lower and Upper Indus basins. This Zone is equivalent to the P6 Zone (lower part up to the LO of *Morozovella formosa*) of Warraich et al.(2000) in the Lower Indus Basin (Sulaiman Range) and to the *Globorotalia rex* (lower part) Zone of Dorreen (1974) in the Lower Indus Basin (Kirther Range) and to the *A. wilcoxensis berggreni* (upper) Zone of Afzal (1997).

Zone E4. *Morozovella formosa* Lowest-Occurrence Zone (Fig. 1)

The Eocene Zone E4 is equivalent to the rest of the P6 Zone (from the LO of *Morozovella formosa*) of Warraich et al. (2000) in the Lower Indus Basin (Sulaiman Range) and to the middle part of the *G. rex* Zone of Dorreen (1974) in the Lower Indus Basin (Kirther Range) and to the *M. formosa* Zone of Afzal (1997) in the Upper Indus Basin.

Zone E5. *Morozovella aragonensis*-*Morozovella subbotinae* Concurrent-Range Zone (Fig. 1)

The Eocene Zone E5 is equivalent to the P7 Zone of Warraich et al. (2000) and P7, P8 of Warraich and Ogasawara (2001) in the Lower Indus Basin (Sulaiman Range) and to the upper part of *G. rex* Zone of Dorreen (1974) in the Lower Indus Basin (Kirther Range) and to the *M. aragonensis* Zone of Afzal (1997) in the Upper Indus Basin.

CONCLUSIONS

The existing planktonic foraminiferal biostratigraphy of the Indus Basin (e.g., Samanta 1973; Dorreen 1974; Afzal 1997; Warraich and Natori 1997; Warraich et al. 2000) is reviewed and this zonal scheme is used to integrate the Paleocene and Eocene stratigraphy of the Upper and Lower Indus Basin of Pakistan. Zones P3 to E5 of the currently used tropical-subtropical scheme of the Berggren and Pearson (2005) are recognized in the Indus Basin of Pakistan. Based on these zones the Late Paleocene-Early Eocene Dungan and Shaheed Ghat formations (Rakhi Nala, Lower Indus Basin) are correlated with the Patala and Nammal formations (Upper Indus Basin) respectively. Three genera; *Acarinina*, *Morozovella* and *Subbotinae* dominate the planktonic foraminiferal assemblages of the Late Paleocene-Early Eocene of the Indus Basin and suggest the presence of tropical-subtropical surface waters in the Late Paleocene-Early Eocene interval.

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