9. PALEOCENE/ EOCENE BOUNDARY TRANSITION

Despite tremendous works done, Paleocen-Eocene boundary remains without a well defined Global Stratotype Section and Point (GSSP) (Covie et al., 1986). Berggren and Aubry, 1999 (in: Late Paleocene Early-Eocene Climatic and Biotic Events, Aubry, M. –P. and Berggern, W.A., eds.) have reviewed the all the existing data related to the problem. They presented an estimated chronology of some 17 events between the Chron C25C(0) and C24n.3n(0) ranging over stratigraphic period of 2 million years. They concluded that the choice of δC^{13} excursion in mid-biochron NP9 which is correlative with the major benthic foraminiferal extinction event (BFEE) and has been recorded in both marine and terrestrial stratigraphies would have the virtue of unifying the Paleocene/ Eocene Series boundary, which is stratigraphically and temporally midway between the top of the Thanetian Stage and base of the Ypressian Stage.

In this study an attempt is made to understand the Paleocene-Eocene boundary transition through quantitative analysis over the planktonic foraminifera and also some results of benthic foraminifera are also used.

9.1 Planktonic foraminifera

A high resolution planktonic foraminiferal biostratigraphy (Figures 8~11) which covers the Paleocene-Eocene boundary events is established and discussed in all three section (Chapter 5).

The quantitative analysis was only done on samples from late Paleocene to early Eocene Dunghan Formation that covers the Paleocene-Eocene transition interval (Zone P5). The quantitative index such as plankton ratio, dominance and species diversity was carried out in the interval from the upper part of Zones P3B to P5 (discussed in Ch.8, 10).

9.2 Benthic foraminifera

The benthic foraminifera that suffered an abrupt mass extinction of approximately 50% in the deep sea (Tjalsma and Lohmann, 1983; Pak and Miller, 1992; Kennet and Stott, 1995). This mass extinction is considered due deep water warming, decreased productivity and lower dissolved oxygen content (Miller et al. 1987; Pak and Miller, 1992). This event together with negative excursion of δC^{13} was occurred just prior to Paleocene-Eocene boundary (Miller et al. 1987; Pak and Miller, 1992; Thomas et al., 1996).

In order to mark the position of the benthic foraminiferal event (BFEE), Dr. Ritsu Nomura of Shimane University, Japan has conducted a separate study over the same sample collected and used by the author for planktonic foraminiferal biostratigraphy in this paper from Rakhi Nala section. His qualitative data (Table 6) clearly shows that all of the velasco-type of fauna extinct between the sample R32 and R33 and hence he marked the BFEE-event in the interval between these two samples (Figure 13).

Table 6. Distribution of the benthic foraminiferal species identified from the Dunghan Formation exposed in the Rakhi Nala section, Sulaiman Range, Southern Indus Basin, Pakistan. Here X represents the occurrence of the species.

Benthic foraminiferal species/Samples	R23	R25	R26	R27	R28	R29	R30	R32	R33	R34	R35
AGGLUTINATED TAXA											
Ammodiscus turbinatus Cushman				+							+
Bathysiphon sp.	+										
Dorothia bulletta (Carsey)		+				+					
Dorothia trochoides (Marsson)									+	+	
Dorothia sp.									+		
Gaudryina cf. laevigata Franke				+		+	+		+		
Gaudryina pyramidata Cushman	+	+	+	+	+	+	+	+	+		
Glomospira gordialis (Parker and Jones)										+	+
Gaudryina gradata Berthelin						+	+		+		
Spiroplectammina plummerae Cushman			+	+	+		+			+	
Spiroplectammina rossae Plummer		+									
Spiroplectammina spectabilis (Grzybowski)							+				
Textularia midwayensis Lalicker		+									
Tritaxia globulifera (ten Dam and Sigal)			+								
Vulvulina spinosa Cushman						+	+		+		
CALCAREOUS HYALINE TAXA											
Alabamina midwayensis Brotzen										+	
Anomalinoides acutus (Plummer)										+	
Anomalinoides bradyi Haque									+		
Anomalinoides rubiginosus (Cushman)		+				+	+	+	+		+
Bulimina farafuraensis LeRoy											+
Bulimina impendens Parker and Bermudez				+							
Bulimina midwayensis Cushman and Parker			+		+		+			+	+
Bulimina tuxpamensis Cole										+	
Cibicidoides alleni (Plummer)			+	+							
Cibicidoides alleni carinata (Haque)								+			
Cibicidoides blumbonatus (Fursenko and Fursenko)											+
Cibicidoides hyphalus (Fischer)		+	+								
Cibicidoides acutus (Plummer)						+	+	+			
Cibicidoides eocaena Gumbel										+	+
Cibicidoides pseudoperlucida (Bykova)		+	+	+			+	+	+	+	
Cibicidoides tuxpamensis (Cole)											+
Cibicidoides vulgaris (Plummer)								+			
Coryphostoma midwayensis (Cushman)			+				+	+			
Dentalina spp.	+		+			+	+	+		+	
Elipsoidella pleurostomelloides Leoblich and Tappan									+	+	
Ellipsopolymorphina sp.						+					
Anglulogavelinella avnimelechi (Reiss)		+	+			+	+	+			
Globulina gibba d'Orbigny										+	
Gloobcassidulina globosa (Hantken)				+							
Gyroidinoides globosus (Hagenow)		+	+			+		+			
Gyroidinoides girardanus (Reuss)								+			
Hanzawaia ammophila (Gumbel)				+		+		+		+	
Lenticulina alabamensis (Cushman)		+					+	+			
Lenticulina degolyeri (Plummer)							+	+			
Lenticulina midwayensis (Plummer)	+										
Lenticulina pilulifera (Cushman)					+						
Lenticulina rossetta (Gumbel)						+					
Lenticulina rotulata (Lamarck)			+	+						+	
Lenticulina turbinata (Plummer)	+					+	+				
Lenticulina spp.									+		+
Loxostomum applinae (Plummer)							+	+			
Marginulina earlandi (Plummer)						+	+	+		+	
Marginulina sp.		+						+			
Nodosaria affinis Reuss											+
Nodosaria catenula (Reuss)			+								
Nodosaria monile Hagenow								+			
Nuttallides truempyi (Nuttall)											+
Oridorsalis plummerae (Cushman)			+	+			+	+		+	
Osangularia plummerae Brotzen		+		+			+		+		
Praebulimina quadrata (Plummer)			+	+	+			+			
Pullenia quinqueloba (Reuss)										+	
Saracenaria sp.						+					
Siphogenerinoides eleganta (Plummer)									+		
Sphaeroidina ? sp.										+	+
Stilosotmella subspinosa (Cushman)			+		+		+	+			
Trifaria herberti Cushman and Renz				+							
Trifarina wilcoxensis (Cushman and Ponton)									+		+
Turrillina brevispira ten Dam											+
Vaginulinopsis sp.	+										
Valvulineria allomorphina (Reuss)	+	+			+	+					
Valvulineria sp.										+	

9.3 Discussion and remarks

The high P-ratios found in all the three sections of the Dunghan Formation around Zone P3 to P5 indicate deep marine environment. Furthermore, extremely higher values of P-ratio (98 to 99%) from the Rakhi Nala section with high values of species richness and diversity indicate that the basin was relatively deeper at Rakhi Nala compared to that at the Zinda Pir sections. Petrographic studies revealed that the deposition of the sequence of the Dunghan Formation started in relatively deep waters, evidenced by the presence of pelagic fauna in the intercalated bands of limestones within the siltstone sequence.

Planktonic foraminiferal species live at restricted water depths (e.g., euphotic zone, thermocline) and at different latitutes (tropical, temperate, cool). Their habitats can be inferred by shell morphology and δO^{18} signals (Shackleton et al. 1985; Boersma and Premoli Silva, 1989; Lu and Keller, 1993, 1995a). Therefore the species assemblages and change in their populations can provide us environmental information. Surface water dwellers have generally lighter δO^{18} and heavier δC^{13} values and thermocline or deep dwellers have heavier δO^{18} and lighter δC^{13} values. Therefore they have said that *Morozovella* and *Acarinina* species have heavier (more positive) δC^{13} values and lighter (more negative) δO^{18}indicating that they have lived in the surface mixed layer. In contrast, species of *Subbotina, Chiloguembelina* and *Planorotalites* have lighter δC^{13} and heavier δO^{18} values and are considered to have lived at thermocline or deeper depth (Shackleton et al. 1985; Lu and Keller, 1993, 1995a; Canudo et al., 1995).

Now based on species relative abundance data (Figures, 13~15), some indications of temperature changes or water-mass stratification can be obtained. For example before the BFEE, the relative abundance trends of deep water dwellers *Subbotinid* such as *S. velascoensis, S. trangularis,* and *Globanomalinid* such as *Glb. ehrenbergi, Glb. imitata, Glb. chapmani* and *Glb. pseudomenardii* show higher values as they are not yet invaded by warm waters. In contrast, the surface dwellers *Acarinid (A. sold. soldadoensis, A. nitida, A. mckannai)* and *Morozovellid (M. apanthesma, M. acuta, M. aequa, M. conocotruncata, M. occlusa, M. velascoensis)* low relative abundance values. Now after, the BFEE, *Morozovellid* and *Acarinid* groupshow an increase in their relative abundance values as warm water conditions favorable for them prevailed whereas the relative abundances of cool water *Subbotinids* and *Globanomalinid* group decreased.

Therefore the occurrence of some plantonic foraminiferal faunal turnovers across P4B/P5 boundary or within Zone P5, changes in relative abundances of different groups and the presence of the BFEE indicate that the late Paleocene global warming event have also affected the planktonic as well as benthic foraminiferal faunas of the Sulaiman Range, Indus Basin, Pakistan. Now as these events and changes lies close to or within the Zone P, the Paleocene-Eocene boundary which is described just above the BFEE event and within Zone P5, it is interpreted that the Paleocene/Eocene boundary is probably placed within the limestone beds containing larger foraminifers between samples ZPE-20 and 26 in the east, and between samples ZPW-21 and 22 in the west. In the Rakhi Nala section, the Paleocene/Eocene boundary lies clearly in the siltstone unit between sample R32 and R33 evidenced by the benthic foraminiferal extinction event.