

10. PALEOENVIRONMENT

The marine sedimentary sequence of the Sulaiman Range that consists of the following four formations: Dunghan, Shaheed Ghat, Baska and Kirthar Formations in ascending order. In order to interpret the depositional environment of this marine-succession, research work done includes 1) quantitative analysis of the planktonic foraminifera such as P-ratio, species relative abundance, species diversity, and 2) Microfacies analysis over the representative samples mainly from intercalated limestone facies. Some thin-sections were also made and studied from typical siltstone/ mudstone facies.

10.1 Planktonic foraminifera

The quantitative analysis was only done on samples collected from the Dunghan Formation that covers the Paleocene-Eocene transition interval and range in age from late Paleocene to early Eocene (Zone P3~P8). The specimens of planktonic foraminifera in the Zone P3A are less than 100 in number, and exceed 200 individuals between the upper part of Zone P3B and Zone P5 in the Zinda Pir sections (Table 2). Hence, the calculation of quantitative index (plankton ratio, dominance and species diversity) was carried out in the interval from the upper part of Zones P3B to P5. In the Rakhi Nala section, lower part also does not yield any planktonic foraminifera, however, rich planktonic foraminiferal assemblage was recovered from the upper part of the formation and hence all samples were

used for quantitative analysis (Table 1).

10.1.1 Plankton-ratio

The Plankton-ratio (P-ratio) is expressed by the following formula:

$$\text{P-ratio} = P/(P+B)*100$$

Where P and B are the number of specimens of planktonic and benthic foraminifera, respectively. The trend of P-ratio differs between the eastern and western sections in the Zinda Pir area (Figures 14, 15). In the eastern section, the P-ratio of Zone P4A is high value of 90%, and decrease gradually to the minimum value (39%) in Zone P4B. This ratio is recovered again upward 89% in Zone P5. In the western section, the P-ratio is consistently high (80-90%) during Zones P3B to P5, except 31% of sample ZPW-17 in the lowermost part of Zone P4A. In Rakhi Nala section, the values of P-ratio remain very high (98 to 99%) throughout the section, however, slightly low values (96%) are found in the base of the section (R23, R28) and in the uppermost sample (R41) (Figure 13).

10.1.2 Species abundance

The trends of the relative abundance of the characteristic planktonic foraminiferal species from zone P3~P8 from all three sections are already documented and discussed in chapter 8.

10.1.3 Diversity and dominance trends

I calculated the diversity of species of each sample from the upper part of

both Zinda Pir sections (Zone P3B to P5) and for all Rakhi Nala samples using the Shannon-Weaner Function by the following mathematical expression:

$$H(S) = \sum_{i=1}^s p_i \ln p_i \text{ (from } i=1 \text{ to } S)$$

Where p_i is relative abundance of i th species in a sample and S is a number of species. The Dominance is expressed as percentage of most abundant taxon. The relationship between Shannon-Weaner diversity and dominance displays a distinctly opposite trend in all the three sections (Figures 13~15). A highest diversity (2.6) was recorded with the lowest dominance (10%) at the base of Zone P4A in the western limb of Zinda Pir Anticline, whereas in the Rakhi Nala section this trend is just opposite as sample R25 shows low diversity (1.6) with the maximum dominance (60%).

In the western side, the species richness of the Zones P3B to P4 is consistently high (17–20 species), except for sample ZPW-18 of Zone 4A (16 species), whereas the species diversity varied largely between 2.1 and 2.6. The lowest values of both richness (15 species) and diversity (2.1) were recorded at the earliest Eocene sample of ZPW-22. In the eastern section, the richness decreases gradually from 20 to 15 species between Zones P4A and P5. The diversity index is, however, relatively constant, ranging between 1.9 and 2.0, and generally lower than that in the western samples. The low value of 15 species is also recorded in the earliest Eocene sample ZPE-26, but the diversity of this sample is relatively high (2.0).

In the Rakhi Nala section, the species richness of Zones P3B to P4 is high

(19 to 22 species) except for sample R23 which has lowest value of 8 species, whereas the species diversity remains constant (>2) except for samples R23 and R25 which have low diversity values (1.6). For the Zones P5 to P8 species diversity remains close to 2.5 while with species richness varies between 16 to 20, however, dominance curve shows distinctly different pattern with minimum values of 5%. These results suggest that 1) the trends of diversity of planktonic species are different between the eastern and western sections, and 2) the species diversity of the Dunghan Formation may have been affected strongly by the equitability of species rather than species richness.

10.2 Microfacies analysis

The results of the microfacies coupled with field observation of different lithofacies and occurrence of microfauna of the Paleogene marine sedimentary rocks from the Sulaiman Range contributed a lot to my understanding of the depositional sequences and their correlation for reconstruction and interpretation of depositional environment. In this study, definitions, descriptions and interpretations of the microfacies are adopted from Dunham (1962) and some parts from Folk (1962).

Microfacies from all the formations recognized in the field have been described and summarized in a number of associations (Microfacies A to G) as described below.

10.2.1 Microfacies A (planktonic foraminiferal mudstone-wackestone)

This facies consists of gray to dark gray, fine-grained and thin-bedded calcareous mudstone/siltstone. The microfacies A contains abundant to common planktonic and benthic foraminifera (Pl.27, Figs. A, B; Pl. 28, Figs. A, B) embedded in fine-grained muddy matrix. Some samples contain glauconite grains and some small foraminifera totally replaced by glauconite. This facies is very common in the upper part of the Dunghan Formation, in the basal part of the Shaheed Ghat Formation and in some parts of the Kirthar Formation, especially in the Habib Rahi Limestone Member and in the Pirkoh Limestone and Marl Member.

10.2.2 Microfacies B (limestone turbidite-wakestone-packstone)

This facies consists of hard, compacted, gray brown to beige colored limestone facies. In the field, it occurred as 1/2 to 1m thick beds of limestone embedded in the siltstone/ mudstone sequence. The facies B (Pl. 30, Fig. B) consists of large carbonate clasts, large sized larger foraminifera (nummulites, miliolids), and planktonic foraminifera. There are many glauconite grains present in this facies (Pl. 29, Figs. A, B), occur both as individual grains as well as shell filling. This facies abundantly occur below the Facies A in the upper part of the Dunghan Formation.

10.2.3 Microfacies C (brecciated/conglomeratic limestone-wakestone)

This brecciated / conglomeratic limestone facies consists of very hard, cream to brown colored thick bedded limestone. The thick-bedded limestone is present in both sides of the Zinda Pir Anticline (about 16m) and is flooded with

10.2.6 Microfacies F (glauconitic limestone-grainstone)

This facies is not so common and it occurs in the upper part of the Drazinda Member of the Kirthar Formation. It contains abundant glauconite grains (Pl. 33, Fig. B), some larger foraminifera and also some molluscs.

10.2.7 Microfacies G (gypsum-anhydrite)

This facies consists of thin to thick bedded, black brown colored gypsum. It occurs in the uppermost part of the Baska Formation. Petrographically two forms of the secondary gypsum: porphyroblasts and alabasterine are recognized. Gypsum porphyroblasts (Pl. 34, Fig. A) are large crystals often poorly-defined interlocking crystals with original laminated texture of anhydrite (Holliday, 1970). The other variety of the secondary gypsum is alabastrine gypsum (Pl. 34, Fig. B) formed by the replacement of anhydrite.

10.3 Paleoenvironment

The depositional environment of the Dunghan, Shaheed Ghat, Baska and Kirthar Formations is summarized in Figure. Here, I will discuss depositional environment in detail for each formation separately taking all above discussed factors into account as following.

10.3.1 Dunghan Formation

A number of workers have used foraminifera in order to reconstruct ancient

environment of marine sedimentary rocks. In general, the percentage of plankton specimens increase from shelf to open ocean environment, and exceed 50% in the deeper environment out of outer shelf (e. g. Grimsdale and Van Morkhoven, 1955; Smith, 1955; Ingle, 1980). Gibson (1989) studied the modern patterns of planktonic benthonic foraminiferal ratios and has also tested his results for their applicability to Paleogene sedimentary sequence over Paleogene strata of the southeastern United States. He found that the results derived from planktonic percentage data were reliable and are in accordance with the paleoenvironmental interpretations through other methods.

The high P-ratios found in all the three sections of the Dunghan Formation 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. Comparison between the western and eastern sections of the Zinda Pir Anticline indicate that increase of species richness in the western section in addition to the higher P-ratios and westward thinning of limestone beds may suggest existence of slope environment in the western side dipping from the east to west.

Microfacies 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 limestone within the siltstone sequence. The deposition continued with occurrence of some "limestone turbidites" containing squashed (compacted) larger foraminifera (Pl. 29, Figs. A,

B), possibly due to unstable tectonics causing rapid sea level changes. These limestone bands contain glauconite (Pl. 29, Figs. A, B) which enabled the correlation of microfacies for long distances.

The sequence of the Dughan Formation is much thicker at Rakhi Nala than in the Zinda Pir Anticline. At Rakhi Nala six biostratigraphic zones (P3B to P8) are recognized whereas from the Zinda Pir Anticline, only three zones (P3A to P5) are recognized. This indicates a facies change from siltstone dominant sequence in Rakhi Nala to carbonate dominant sequence (calcareous siltstone) in the Zinda Pir area forming transgressive series.

Therefore the gray-black colored calcareous-siltstone sequence of the Dughan Formation with limestone intercalations were mainly deposited in relatively deep waters along the stable shelf since it produced highly diversified planktonic foraminiferal assemblage with higher P- ratios.

10.3.2 Shaheed Ghat Formation

The common lithology of the Shaheed Ghat Formation is calcareous mudstone dominated in the base and limestone dominated in the upper part. Although quantitative analysis was not performed on it, the formation has produced a rich planktonic foraminiferal faunal assemblage in the lowermost part as recovered from all three sections (Figures 9~11). Moreover, in the base brecciated/conglomeratic limestone facies (Pl.4, Figs. A-C) that consists of very hard, cream to brown colored thick bedded limestone and varies in thickness from 1m in the Rakhi Nala to 16m in the Zinda Pir was found. In addition to abundant

larger foraminifera (*Nummulites irregularis* Deshayes and other foraminifers, Eames, 1952a), it contains shallow-water molluscan fauna such as *Vasticardium* (0-150m) and *Chlamys* species (0-200) (identified by Dr. Kenshiro Ogasawra). Thin-section studies also show larger foraminifera (Pl. 30, Fig. A) present both in matrix and also in the limestone fragments embedded in calcareous matrix containing pelagic fauna. Therefore it is interpreted that this limestone represents a diastem caused by deep-water debris flow triggered by some tectonic event, here proposed as Event A (Fig. 16).

Microfacies analysis over the calcareous mudstone samples from the lowermost part above the limestone beds which also has yielded rich pelagic fauna were performed. Mudstone sequence present in the basal part contains the Microfacies A (planktonic foraminiferal mudstone-wackestone) that clearly exhibits abundant pelagic fauna (Pl.28, Figs. A-B; Pl. 29, Figs. A-B). Now upwards most-part of the lower half of the Shaheed Ghat Formation does not contain any determinable pelagic fauna, however, in contrast to pelagic fauna there occur shallow-marine larger foraminiferal and molluscan fauna.

In the upper half of the formation, lithology changes from mudstone to nodular mudstone (Pl.5, Figs. B-C) to nodular limestone (Pl.7, Fig. C). At places it contains bioturbation (Pl.6, Fig. C) at limestone surface and shell-beds (Pl.7, Figs. A-B) indicating shallow water with relatively high energy conditions. Moreover, all the limestone facies present in the upper part, a very distinctive Microfacies E (restricted fauna-miliolid, nummulitid wackestone-packstone) is discovered.

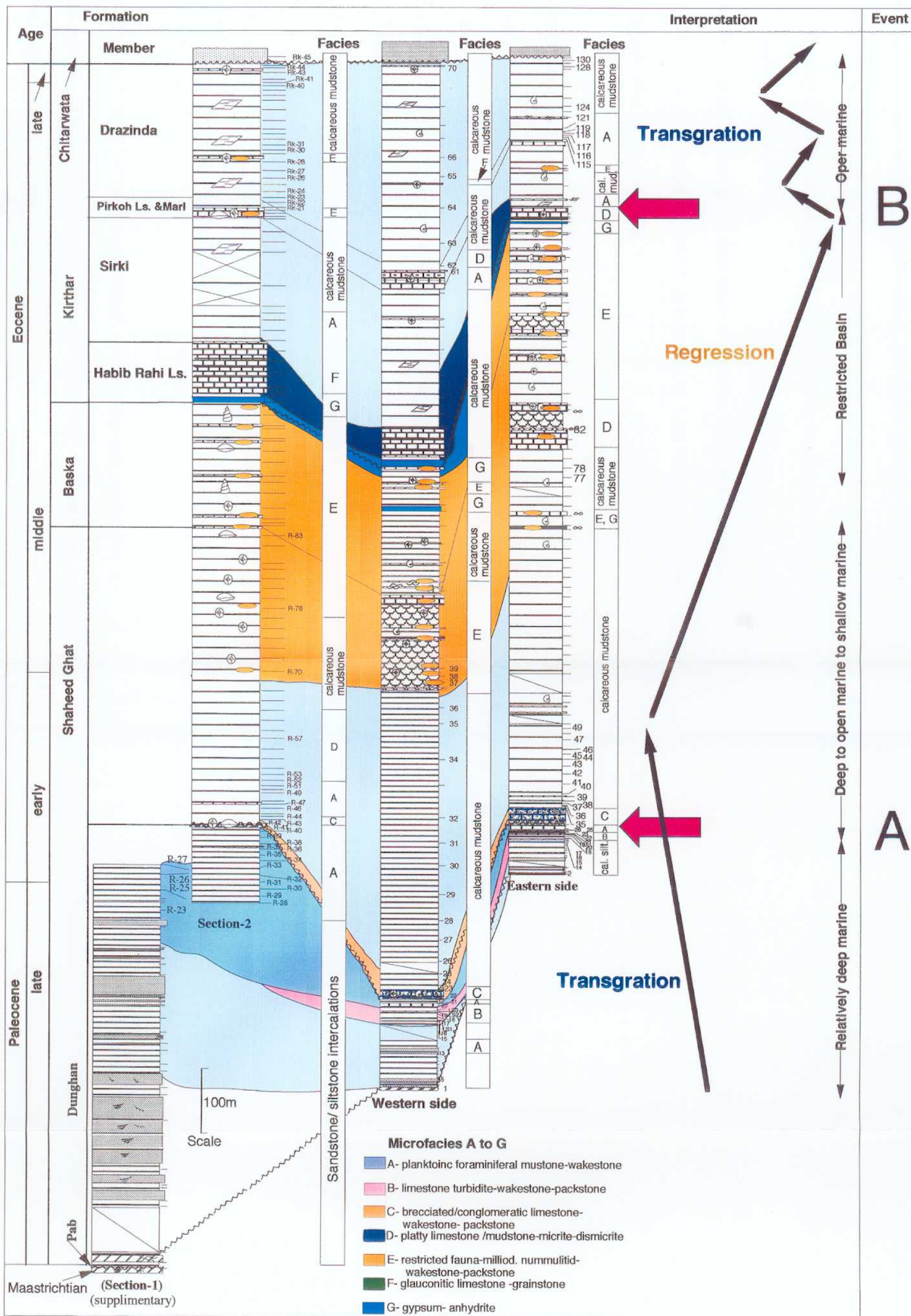


Figure 16. Lithofacies and microfacies correlation showing depositional environments of the Paleogene strata of the Sulaiman Range, Southern Indus Basin, Pakistan

This all indicates that the lower part of the Shaheed Ghat Formation which produce abundant pelagic planktonic foraminifera along with the Microfacies A, was deposited in deep to open waters. However, the upper part which produce either poor or no planktonic foraminifera and consists of nodular limestone dominated lithology with the Microfacies E was deposited in a restricted basin with very shallow water environment.

Therefore as whole during the deposition of the Shaheed Ghat Formation, the Indus Basin was very rapidly uplifted probably due to rapid collision between the Indo-Pakistan and Eurasian Plates.

10.3.3 Baska Formation

Baska Formation which mainly consists gray to chocolate colored mudstone with gypsum (alabastrine variety) intercalation, does not produce any identifiable planktonic foraminifera. Several thin-beds of fossiliferous limestone are also intercalated. Microfacies analysis has revealed that the limestone consists of a very distinctive Microfacies E (restricted fauna-millolid, nummulitid wakestone-packstone, Pl. 32, Figs. A-B). Mixing of the Microfacies E (restricted fauna-millolid, nummulitid wakestone-packstone) with the Microfacies A (planktonic foraminiferat mudstone-wakestone) due to some turbidites is also noted in some thin-sections (Pl. 33, Fig. A).

A restricted basin environment related to wide spread regression is interpreted for the Baska Formation as it is dominated by restricted fauna microfacies and has several gypsum intercalations.

There is a drastic change in lithology of the Baska Formation that is dominated by restricted fauna-microfacies to the thick-bedded gypsum deposits followed by deep marine platy-limestone in the basal part of the Kirthar Formation. Here, base of the thick-bedded gypsum (Pl. 9, fig. A) is taken as an unconformable contact between the Baska and overlying Kirthar Formations. This sub-emergence of the Indus Basin during the deposition of the Baska Formation and then again subsidence during the deposition of the Kirthar Formation is related to some tectonic event, here named as Event B (Fig. 16).

10.3.4 Kirthar Formation

The Kirthar Formation has thick-bedded (10m) gypsum present at the lowermost part consists of the Microfacies G (gypsum-anhydrite). This Microfacies G contains two types of secondary gypsum; alabastrine gypsum (Pl.34, Fig. B), and porphyroblast gypsum (Pl.34, Fig. A) along with primary gypsum.

After the gypsum deposits, the formation has platy limestone (Habib Rahi Limestone Member) in the base which is fine grained and consists of the Microfacies A (planktonic foraminiferal mudstone-wackestone) and the Microfacies D (Platy limestone/mudstone-micrite-dismicrite, Pl. 31, Figs. A-B). Rest of the formation consists of calcareous mudstone that has produced well preserved pelagic planktonic foraminifera. There are some limestone interbeds consisting of restricted fauna microfacies (Microfacies E), the Microfacies D, and Microfacies F (Pl. 33, Fig. B).

Presence of deep-water facies (Microfacies A) along with micritic

(Microfacies D) in the lowermost Habib Rahi Limestone Member of the Kirthar Formation indicates the return of open marine environment as a result of transgression. The upper sequence of the Kirthar Formation seemed to be deposited in an open marine environment with some fluctuations as it contains restricted fauna microfacies and glauconate bearing limestone facies (Microfacies F) in the middle part with the occurrence of pelagic fauna.