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An Appraisal of Microfacies and Depositional Environment of the Early Eocene Habib Rahi Limestone, Sulaiman Range, Pakistan

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ABSTRACT

Early Eocene Habib Rahi Limestone was investigated in Sulaiman Range at four outcrops in Afiband and Mughal kot areas, where its measured thickness range from 25 to 40 m. The formation comprehensively studied based on microfacies, sedimentological parameters that lead to its paleodepositional environment. According to field observations, the lower part of the formation mainly comprises fossiliferous limestone, the middle part with platy limestone bedded with chert, and upper part associated with marl and shale. Moreover, formation makes conformable lower and upper contacts with Baska Shale and Domanda Shale, respectively. As a result of detailed petrographic observation, five microfacies of the Habib Rahi Limestone were examined, which are richly associated with larger benthic foraminifera e.g. *Assilina spinosa, Assilina subspinosa, Nummulites mammillatus,* and *Nummulites atacicus.* Therefore, litho- as well as microfacies of the Habib Rahi Limestone depicts the carbonate ramp depositional environment.

Keywords: Lithofacies; Microfacies; Depositional environment; Habib Rahi Limestone; Sulaiman Range; Pakistan

INTRODUCTION

In some areas of the eastern Sulaiman Province, the Kirthar Formation is divided into four members: the Pir Koh Member, Sirki Member, Habib Rahi Limestone Member, and Drazinda Member (Warraich and Nishi, 2003). Habib Rahi Limestone belongs to the early Eocene and well exposed in Zain Section, Dawagarh Section, Sanghar Nala Section, and Mughal kot Section in the Sulaiman Range, Central Indus basin, Pakistan. Assilina spinosa, A. exponens, A. cancellata, Nummulites beaumonti, and Discocyclina sowerbyi, which are equivalent to biozones SBZ13–SBZ18 (Eames 1951; Nagappa 1959; Weiss 1993; Serra-Kiel et al., 1998; Babar et al., 2018), are abundant in the lower part of the Kirthar Formation and suggest a shallow marine environment, which may explain the gap in the planktonic foraminiferal records (Afzal, 2011). The formation mainly comprises platy to thin-bedded dominantly argillaceous and grade into marl merely at certain places with dark brown shale in it. Habib Rahi Limestone constitutes of highly fossiliferous *Assilina* rich limestone in the lower part, limestone intercalation with marl, irregular chert beds at the middle part, and alternate bed of limestone with marl and shale in upper part. The basal bed *Assilina* limestone emits a fetid smell from a freshly broken surface.

At the end of the 19th century, several researchers (e.g. Griesbach 1884; Oldham 1890) explore the geology of Sulaiman Province. Different names are given to the Habib Rahi Limestone such as *Assilina* Beds (Eames 1951a), platy limestone (La Touche 1893), and Habib Rahi Limestone (Tanish *et al.,* 1959). The Stratigraphy Committee of

Pakistan has given them the formal name Habib Rahi Limestone. After those numerous researchers (Shah 1977; Jadoon 1991; Humayoun *et al.*, 1991; Kemal 1991; Haq and Davis, 1997; Macedo and Marshak, 1999; Sheikh 2003; Iqbal *et al.*, 2012; Asim *et al.*, 2014; Reynolds *et al.*, 2015; Jadoon *et al.*, 2016) contributed to the geology of the Sulaiman Range. However, a detailed sedimentological study of the Eocene strata particularly the Habib Rahi Limestone on the various sections of the Sulaiman Range is scant.

Following are the objectives of this paper:

1. To identify the microfacies in Afiabad area, in four sections namely Zain, Dawagarh, Sanghar Nala, and Mughal Kot Sections.

2. To understand the relevant positions of these laterally correlatable sections in the depositional model.

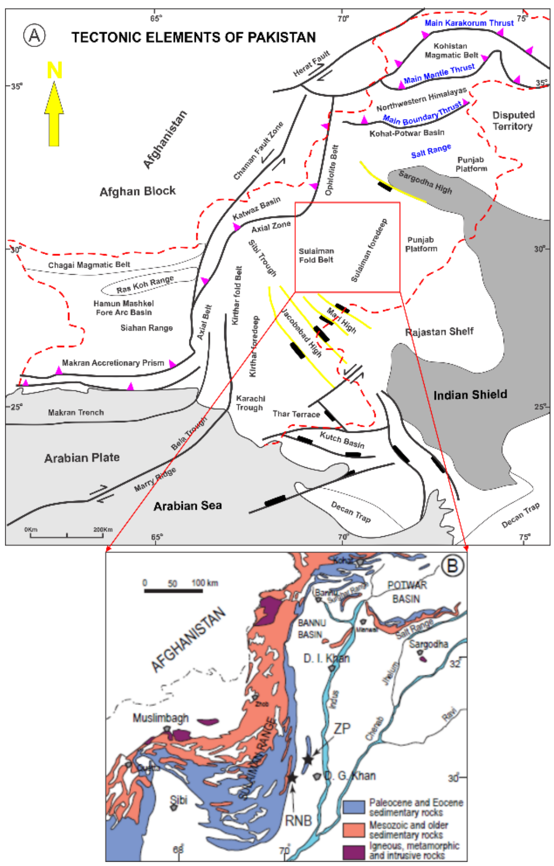

Fig. 1. **(a)** Tectonic map of Pakistan in which red square shows the studied area of Sulaiman Range in the Middle Indus Basin (Modified after Kazmi and Rana, 1982; Ghazi *et al.*, 2020a); **(b)** Generalized stratigraphy of the Sulaiman Range (Modified after Özcan *et al.*, 2019).

GEOLOGICAL SETTING

The Indian Plate's northwest continental shelf border setting is represented by the lower Cenozoic succession of the Greater Indus Basin (Figs. 1, 2). At around 55 Ma, close to the Paleocene-Eocene boundary, the Indo-Pakistan plate in the north and northwest of Pakistan was susceptible to subduction and orogenic processes (Pivnik and Wells, 1996.). This suggests that portions of the northwest Lower Indus Basin, which was fragmented by marine deposition of limestone and shale of the upper Ghazij and lower Kirthar formations during early Lutetian period, were a bridging contact of the Indian plate with the Asian plate (Afzal, 2011). The upper Kirthar Formation in the south-southwest and the corresponding uppermost Kohat Formation in the north-northwest indicate the late Lutetian-Priabonian regression (Haq and Davies, 1997). However, as evidenced by the upper Kirthar Formation in the Lower Indus Basin and the corresponding uppermost Kohat Formation in the Upper Indus Basin, late Lutetian-Priabonian marine deposition persisted in some areas (Ullah, 2019).

The study area is located in the Central Indus basin, Zindapir anticlinorium of the Sulaiman Range which is separated from the upper Indus basin by the Sargodha high and Pezu uplift in the north (Asim *et al.,* 2014). In the east, it is surrounded by Indian shield and in the west by marginal of the Indian plate, as well as Sukkur Rift in the south (Raza *et al.,* 1989; Szeliga *et al.,* 2012; Reyonlds *et al.,* 2015) (Fig. 1). The basin is dominantly composed of sedimentary succession from Triassic to Paleogene (Except Oligocene, as it is absent from the Indus Basin) (Kadri 1995). The major changes in lithology and stratigraphy are detected in Sulaiman fold belt and Sulaiman foredeep throughout the Paleocene to Eocene. Paleocene Khadro Formation was the result of the northward movement of the Indian plate that further forms ophiolitic mélange when it collides with the Eurasian plate. Paleocene Ranikot and Drug formations are present in the core of Zindapir and Afiband anticlines respectively during short term transgression. The Eocene strata in the Sulaiman Range associated with Ghazij Formation, Habib Rahi Limestone, Domanda Formation, Pirkoh Formation, and Drazinda Formation whose mostly thickness decreases towards the western Sulaiman Range. Oligocene is marked by dramatic climatic changes when shallow-water carbonates were deposited in Kirthar Range (Lower Indus Basin), while limited exposure of Oligocene Nari Formation present in the northern part of the Sulaiman Range.

MATERIALS AND METHODS

The study area “Sanghar Nala Section, Zain Section, and Dawagarh Section” are well exposed in the Eastern Sulaiman Range along the Afiband Anticline while the fourth section “Mughal kot Section” exposed in the Mughal kot area of Sulaiman Range. The study area extended; 70º 27′ 00″ to 70º 28′ 25″ E and 30º 35′ 3.0″ to 30º 42′ 21.6″ N in Sulaiman Range. The thickness of Habib Rahi Limestone in these sections (Zain Section, Sanghar Nala Section, Dawagarh Section, and Mughal kot Section) is 40 m, 25 m, 34 m and 15 m, respectively (Fig. 2). The formation in these studied sections makes conformable upper and lower contact with chocolate clay of Domanda Shale and Baska Shale, respectively (Figs. 2a-b, d). Moreover, the systematically samples were executing and making lithological logs of each outcrop section (Fig. 3). For a detail microscopic study, almost 200 samples from all four sections were taken from bottom to top of the Habib Rahi Limestone. These samples were comprehensively observed under the microscope. Photomicrographs of these slides were taken that provide basin informa -tion about the fabric of the formation.

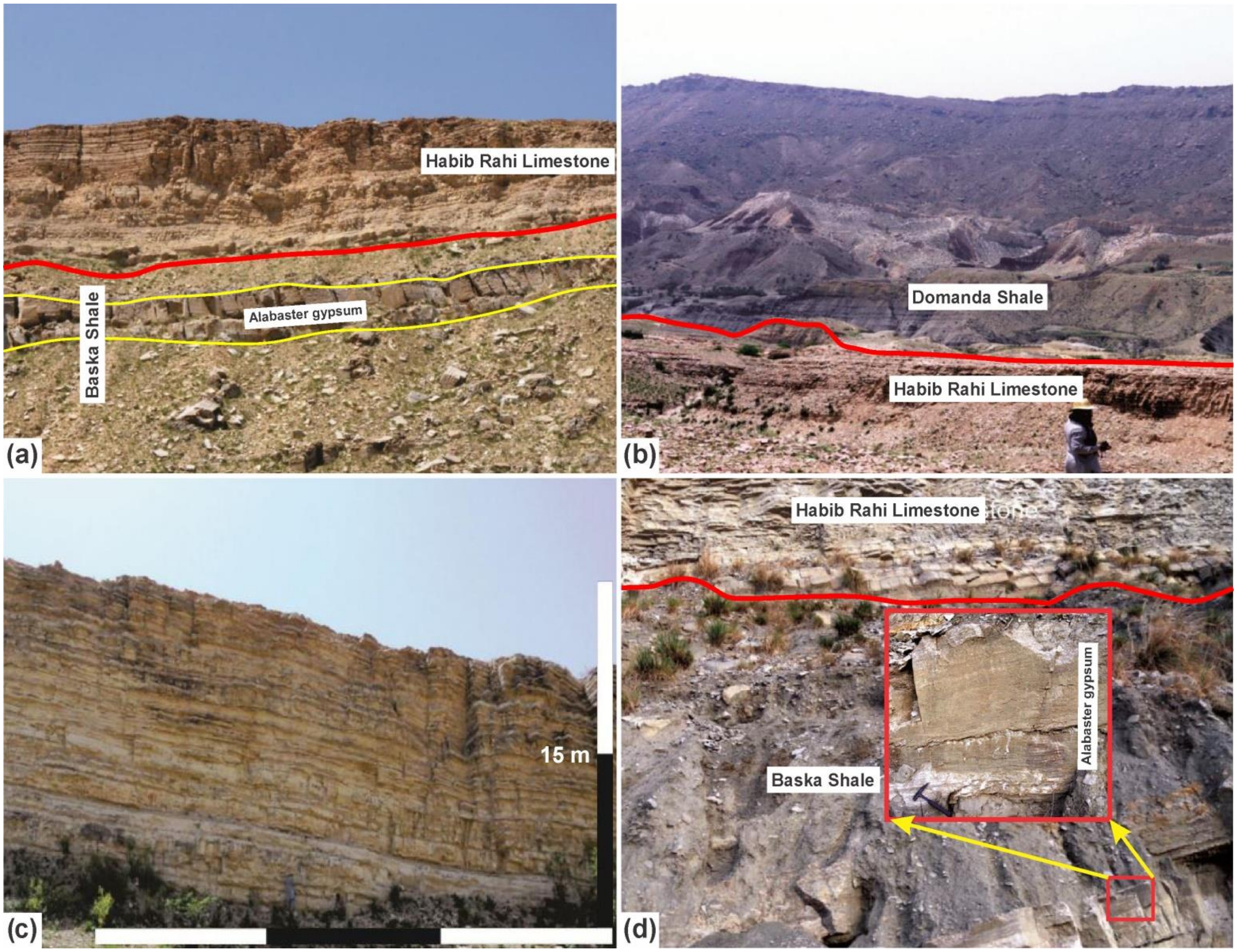

Fig. 2. **(a)** Field photograph shows the outcrop exposure of lithostratigraphic unit of the Habib Rahi Limestone whose lower contact with Baska shale in Afiband Area, Sulaiman Range, Pakistan; **(b) O**utcrop exposure of the upper contact of Habib Rahi Limestone with Domanda shale; **(c) O**utcrop exposure of the Habib Rahi Limestone at Zain Section, Afiband area, Sulaiman Range; **(d) O**utcrop exposure of the Habib Rahi Limestone having lower wavy contact with Baska shale in Mughal kot Section, Sulaiman Range; The zoom part shows the Alabaster gypsum of Baska shale unit.

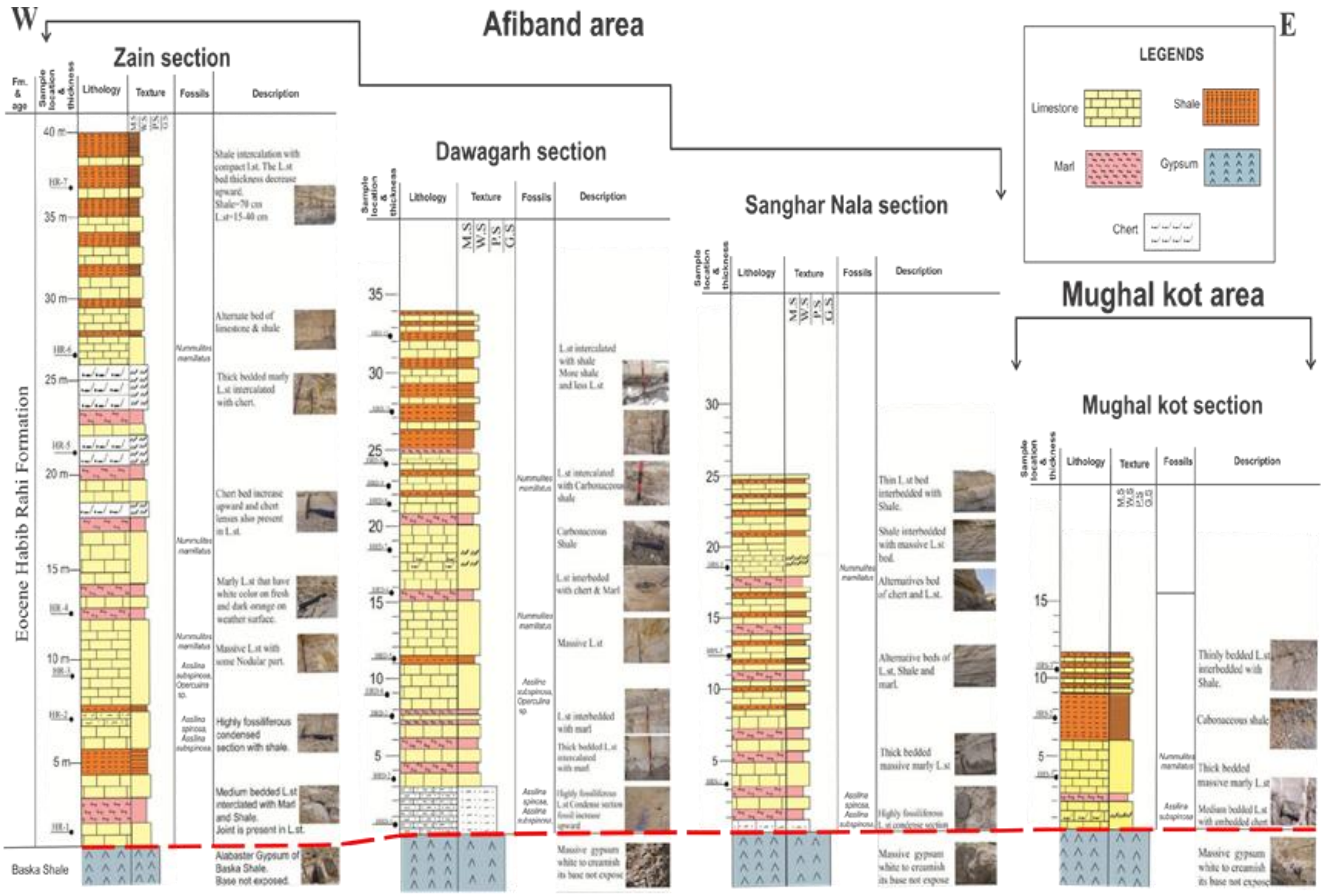

Fig. 3. Sedimentological log of Habib Rahi Limestone at Zain, Dawagarh, Sanghar Nala and Mughal kot sections of Sulaiman Range.

RESULTS

Lithofacies of the Habib Rahi Limestone

Habib Rahi Limestone in studied sections associated with five lithofacies including 1) fossiliferous limestone; 2) alternate limestone and marl; 3) chert lenses with irregular bedded chert; 4) alternate beds of limestone, shale, and marl; 5) limestone intercalation with shale (Fig. 3). The detailed description of lithofacies is given below;

1) Fossiliferous Limestone

Description: In the Afiband area, the basal part of Habib Rahi Limestone comprises highly fossiliferous limestone (Fig. 4a). The fossiliferous limestone is buff to creamish color and rich in *Assilina spinosa*, *Assilina subspinosa* with *Nummulites mammillatus* (Afzal, 2011). However, this fossiliferous limestone is not observed in the Zain Section and Mughal kot Section (Fig. 3).

Interpretation: The fossiliferous limestone in lower part of the Habib Rahi Limestone mainly associated with *Assilina* sp. and *Nummulites* sp. that indicate its deposition in shallow marine environment (Ghazi *et al.*, 2020b).

2) Alternate limestone and marl

Description: The limestone in Afiband area is thinly bedded and highly fossiliferous (Fig. 4b). The weathered surface of limestone is yellowish, creamish to light-grey, while the fresh surface is light-brownish to grey. The thickness of limestone beds are 15-20 cm, and interbedded with marl. The marl is light brown to light grey. The thin-bedded limestone is often platy to wavy in their appearance. Moreover, the bedding plane is marked with broken shells of fossils.

Interpretation: The alternative beds of limestone and marl indicate the episodic variation in relative sea-level. The fossiliferous limestone shows the shallow marine environment whereas marl depict the relative deeper environment (Warraich and Nishi, 2003).

3) Chert lens with Irregular bedded chert

Description: Chert lens with irregular bedded chert is the typical feature of the formation (Figs. 3, 4c). It breaks with a conchoidal fracture. The chert is a very fine grain and non-porous sedimentary rock which deposited by a different kinds of marine organisms like radiolarian diatoms and sponges which secrete silica. The thickness of chert in the Habib Rahi Limestone is 5 cm to 8 cm (Fig. 3).

Interpretation: Chert lens with irregular bedded chert indicate the deep environment (Murray 1994). These evidences support the relatively deep environment of the bedded chert.

4) Alternate bed of limestone, shale and marl

Description: The alternative thin beds of limestone with shale, and marl form middle part of the formation (Figs. 3, 4d). The approximately thickness of limestone and shale is 5-15 cm and 10 cm, respectively (Fig. 3).

Interpretation: The alternative beds of limestone, shale and marl portrays the mainly transgressive event. The shale and marl show the transgressive event at small scale and deposited in relatively deep environment whereas limestone depicts the regressive event and deposited shallow marine limestone.

5) Limestone intercalation with shale

Description: The upper part of the formation in three sections is associated with the intercalation of limestone and shale (Figs. 3, 4e). The thickness of the shale is more than limestone (Fig. 4f). Moreover, limestone is yellowish to creamish, and shale is dark brownish to grey. *Interpretation:* The upper part of the Habib Rahi Limestone also indicates the episodic variation in relative sea-level. Shale show the deeper while limestone depicts the shallow environment (Warraich and Nishi, 2003; Afzal, 2011). The thickness of the shale is more than limestone that clarify the large span of relatively deeper environment than shallow marine limestone.

Microfacies of the Habib Rahi Limestone

The mainly five microfacies have been recognized in the Habib Rahi Limestone at studied sections of the Sulaiman Range (Fig. 3). The detail descriptions of these microfacies are given below:

1) Bioclastic wackestone (H-1)

Description: The microfacies contain ample fine-grained micritic matrix which is more than 70-75% (Fig. 5a, b). It contains bioclasts of foraminifera encountered in a mud matrix. The dominant fossils in bioclastic wackestone are the *Assilina spinose* (Davis and Pinfold, 1937), which

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are floating in the matrix and displays no significant shell mineralogy replacement. Further, pelloids, Miliolids, intrasparite, and biosparite are also present in this microfacies (Fig. 5b).

Interpretation: Assilina spinose along with Miliolids, skeletal fragments and bioclast within sparite cement reflect the deposition under relatively low energy water conditions with restricted circulation in shallow shelf environments (Ghazi *et al.,* 2006; Flügel 2010).

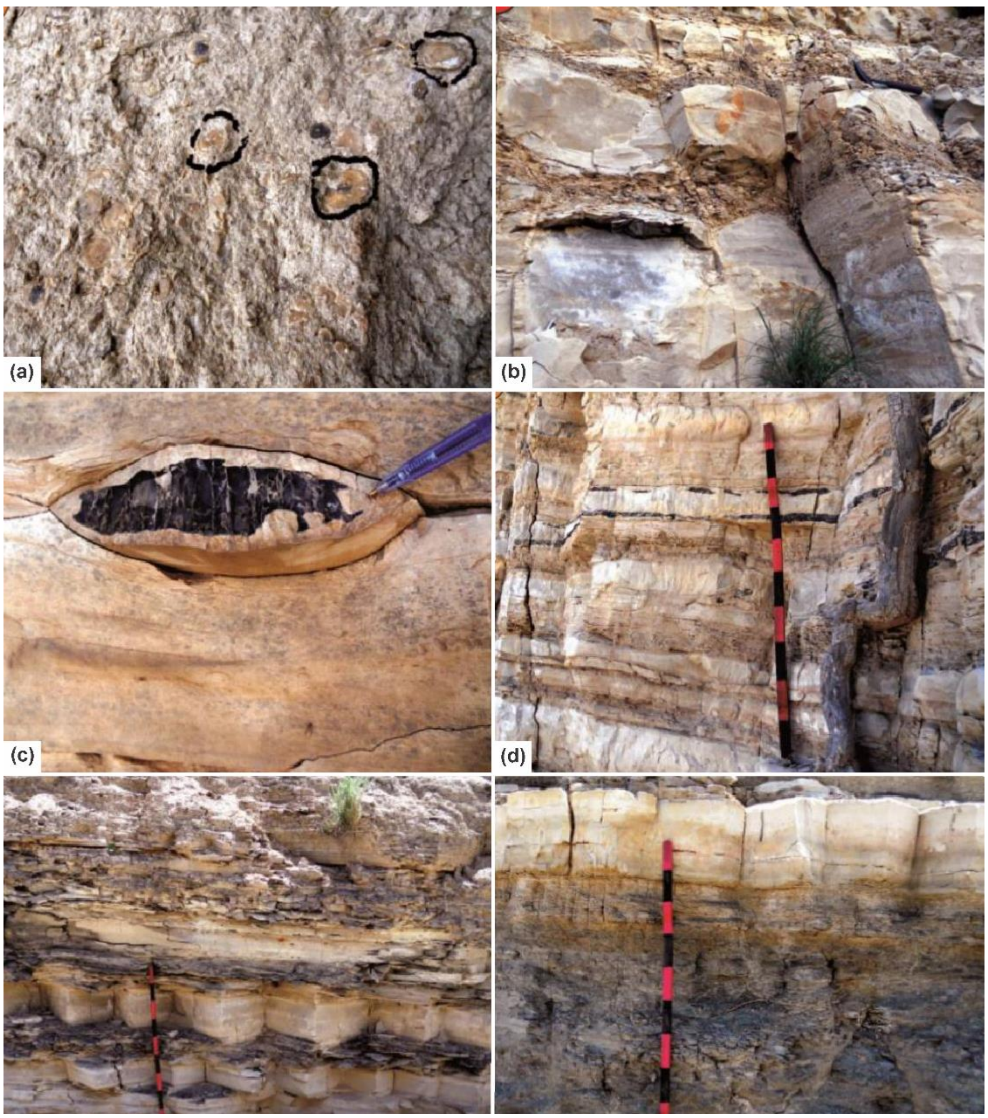

Fig. 4. Photographs show main lithofacies of the middle Habib Rahi Limestion in Zain Section, Dawagarh Section, Sanghar Nala Section, and Mughal kot Section, Sulaiman Range: **(a)** Highly fossiliferous limestone unit at Sanghar Nala Section, Afiband area; **(b)** Limestone intercalation with marl unit at Zain Section, Afiband area; **(c)** Chert lenses in limestone unit at Dawagarh Section, Afiband area; **(d)** Alternate bed of limestone with shale and marl with irregular chert at Dawagarh Section, Afiband area; **(e)** Alternate bed of limestone and shale at Zain Section, Afiband area; **(f)** Limestone interbedded with massive shale unit at Mughal kot Section.

2) Bioclastic packstone (H-2)

Description: The facies mainly comprises larger benthic foraminifera (*Assilina* sp.), *Nummulites mamillatus*, broken shells fragments of foraminifera and micrite (Fig. 5c, d). The fauna contains typical Eocene accumulation of *Assilina spinose and Assilina subspinosa* (Fig. 5c) (Davis and Pinfold, 1937), *Nummulites mamillatus* (Fig. 5d) (Fichtel and Moll, 1798).

Interpretation: The presence of larger benthic foraminifera such as *Assilina subspinosa* and *Nummulites mamillatus* indicate the shallow marine high energy environment (Ghazi *et al.*, 2006, 2020b).

3) Bioclastic Mudstone (H-3)

Description: This microfacies is fine-grain limestone, the major constituents of this facies are the micrite, which is abundantly replaced by microcrystalline sparry calcite (Fig. 5e, f). Moreover, this facies comprises fragment of bioclast in the surrounding area of sparite (Fig. 5e, f). Moreover, patches of dark micrite (Fig. 5e) and fracture (Fig. 5f) are also observed in this microfacies.

Interpretation: The fragment of bioclast in surrounding matrix of sparite show the high energy environment (Ghazi *et al.,* 2020b). Moreover, fracture show the overburden pressure or tectonic forces (Abdulghani *et al.,* 2020). Fracture in the formation make it important for oil industry (Abdulghani *et al.*, 2020).

5) Bioclastic Packstone to Grainstone (H-4)

Description: The microfacies associated with foraminiferal shell, red algae, and lithoclasts. The shells are highly fragmented and abraded. The bioclasts are mainly *Assilina subspinosa*, and *Nummulites mamillatus* (Fig. 5g, h, i).

Interpretation: Assilina subspinosa and *Nummulites mamillatus* show the shallow marine high energy environment (Ghazi *et al.,* 2006, 2020b).

6) Bioclastic grainstone (H-5)

Description: The basic components are foraminiferal shells, and lithoclasts (Fig. 5j). Shells are well-preserved. The majority of the bioclasts are *Assilina subspinosa*, with *Nummulites mamillatus* (Fig. 5j, k).

Interpretation: Lithoclasts are eroded and transported within or from outside of the basin of deposition (Flügel 2010). *Assilina subspinosa* and *Nummulites mamillatus* depicts the shallow marine high energy environment (Ghazi *et al.*, 2006, 2020b).

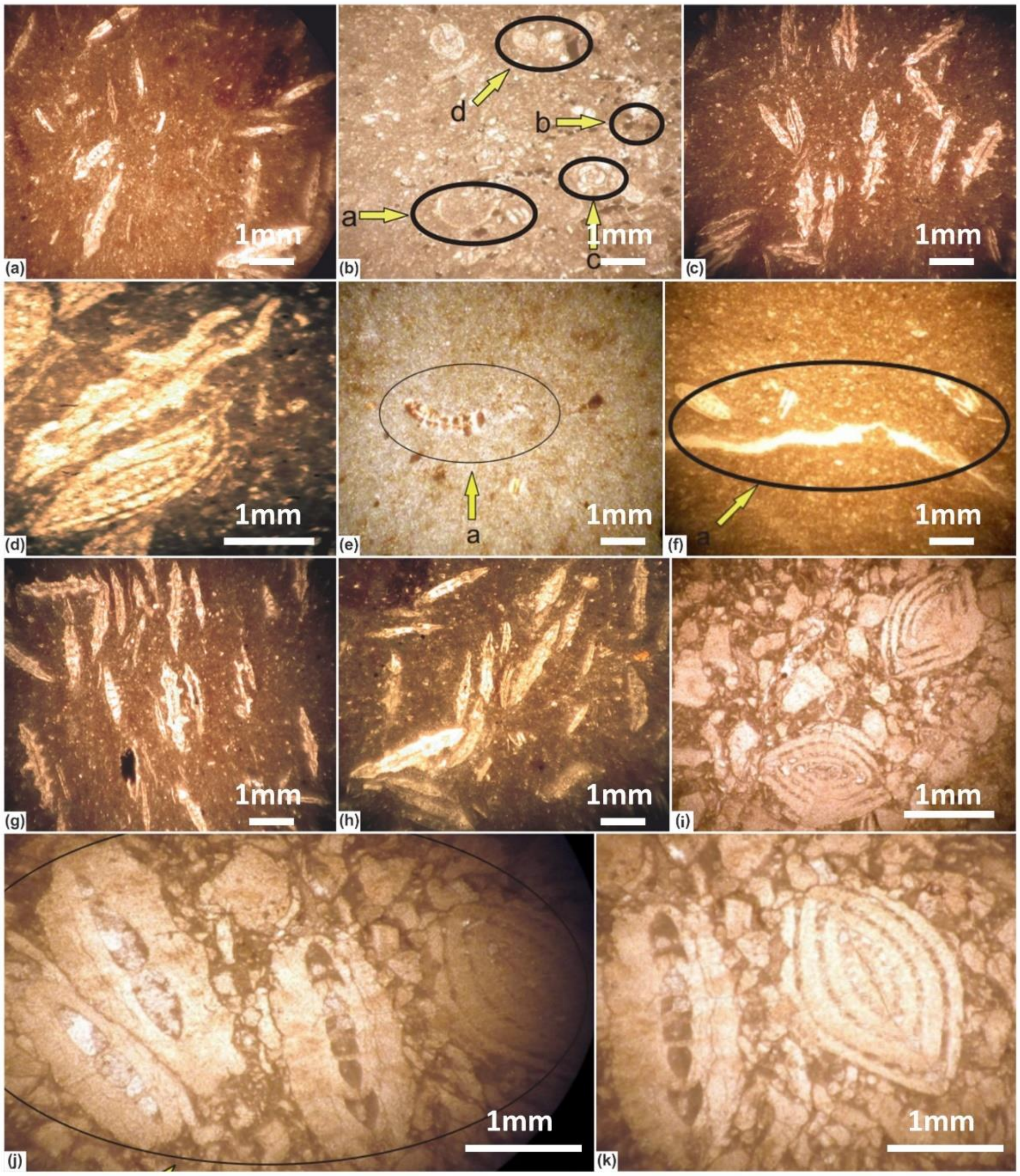

Fig. 5. Photomicrograph showing the microfacies of Habib Rahi Limestone. **(a)** Bioclastic wackestone with dominant *Assilina spinose*, Sanghar Nala Section; **(b)** Bioclastic wackestone with dominant features such as (a) skeletal fragments (b) pelloids (c) Miliolids (d) biosparite, Sanghar Nala Section; **(c)** Bioclastic packstone with predominant *Assilina* sp. in Sanghar Nala Section; **(d)** *Assilina subspinosa** with *Nummulites atacicus***, Zain Section; **(e)** Bioclastic mudstone show the fragment of bioclast (encircle part), patches of micrite within sparite cement at Zain Section; **(f)** Bioclastic mudstone showing bioclasts and fracture with calcite filling, Zain Section; **(g-h)** Bioclastic packstone to grainstone dominantely with *Assilina subspinosa**, and *Assilina* at Dawagarh Section; **(i)** Bioclastic packstone with predominant *Nummulites mamillatus** in Sanghar Nala Section; **(j, k)** Bioclastic grainstone associated with *Assilina subspinosa* and *Nummulites mamillatus* at Sanghar Nala Section. (*Davies and Pinfold, 1937; Eames, 1951a; 1951b; for identification / determination of LBF of this early Eocene Fauna were used). (Scale is present in each photomicrograph).

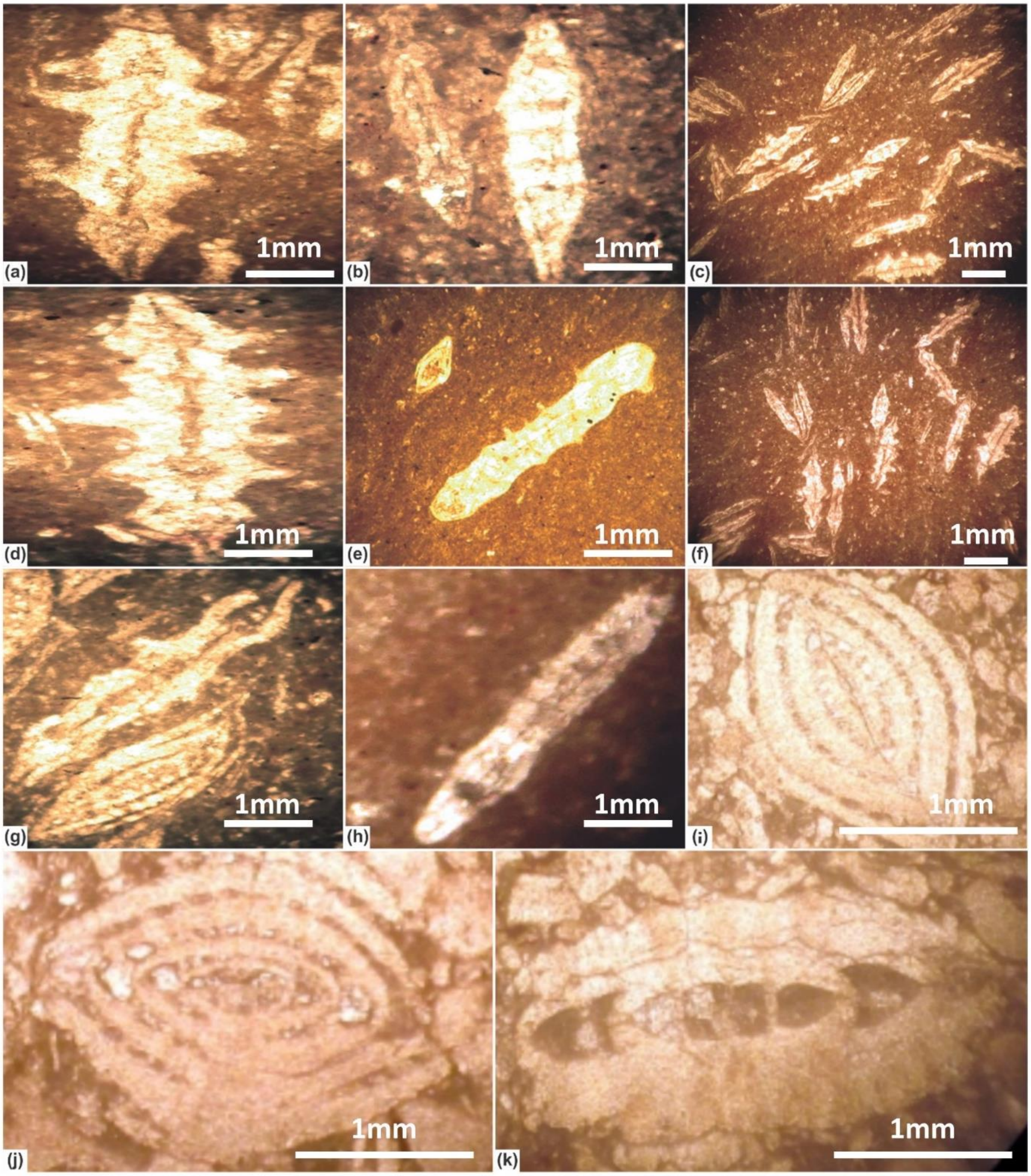

Fig. 6. Photomicrograph shows microfacies of the middle Habib Rahi Limestone at Zain Section, Sanghar Nala Section, Dawagarh Section, and Mughal kot Section of the Sulaiman Range: **(a)** *Assilina subspinoa* at Sanghar Nala Section; **(b)** Axial section of *Assilina subspinoa* at Sanghar Nala Section; **(c)** *Assilina subspinosa* at Zain Section; **(d)** *Assilina subspinosa* at Zain Section; **(e)** *Assilina subspinosa* at Dawagarh Section; **(f)** *Assilina subspinosa* and *Assilina spinosa* at Zain Section; **(g)** *Assilina subspinosa* with *Nummulites atacicus* at Zain Section; **(h)** *Assilina spinosa* at Sanghar Nala Section; **(i)** *Nummulites mammillatus* at Dawagarh Section; **(j)** *Nummulites mammillatus* at Zain Section; **(k)** *Assilina subspinosa* at Zain Section. (Scale is present in each photomicrograph).

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Biostratigraphy of the Habib Rahi Limestone

a) Genus: *Assilina*

i) Assilina subspinosa (Fig. 6a-g, k, Davies and Pinfold, 1937; Eames, 1951a; 1951b)

Remarks: *Assilina subspinosa* can be differentiating from *Assilina spinosa* as it does not have any depression and spines are prominent or nearby spread. *Assilina subspinosa* range from Paleocene to Eocene if this fauna was Paleocene then there must have some sample in which the species like *Miscellanea miscella, Lockhartia haimei, Lockhartia tippereri* and *Ranikothalia sindensis*. So, no association of Paleocene fauna is prominent. *Assilina subspinosa* is present with association of Eocene fauna.

ii) Assilina spinosa (Fig. 6h)

Remarks: This is the second most-often occurring facies through the formation. *Assilina spinosa* is characterized by having middle depression with outstanding spines. This species is also found in the lower part of the formation.

b) Genus: *Nummulites*

i) Nummulites mammillatus (Fig. 6i-j, Afzal and Butt, 2023; Kamran et al. 2021; Serra-Kiel et al., 1998).

Remarks: In all sample from bottom to top after *Assilina, Nummulites* is observed. This species is generally prevalent in the middle part of the Habib Rahi Limestone and is described by thick wall umbonal plug with marginal cord and biconvex.

ii) Nummulites atacicus (Fig. 6g, Ghazi et al., 2010; 2015)

Remarks: This species is sparse and found only in the middle part of the Habib Rahi Limestone. It is explained by large proloculus and umbilical pillar, are not significant.

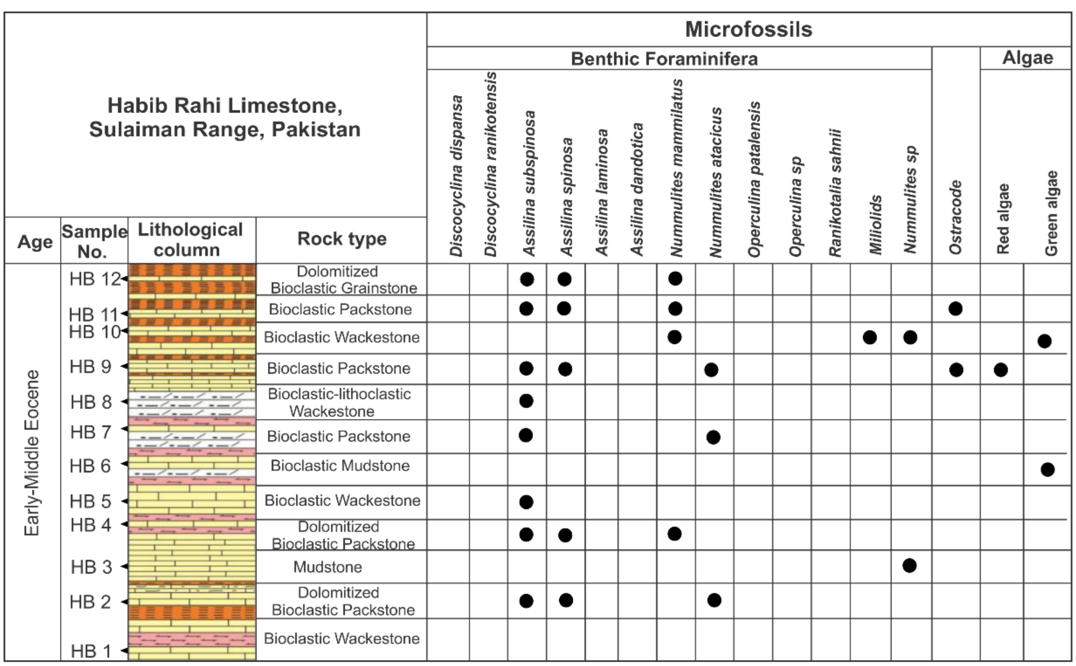

Fig. 7 Biostratigraphic Range Chart of the Habib Rahi Limestone, Sulaiman Range, Pakistan

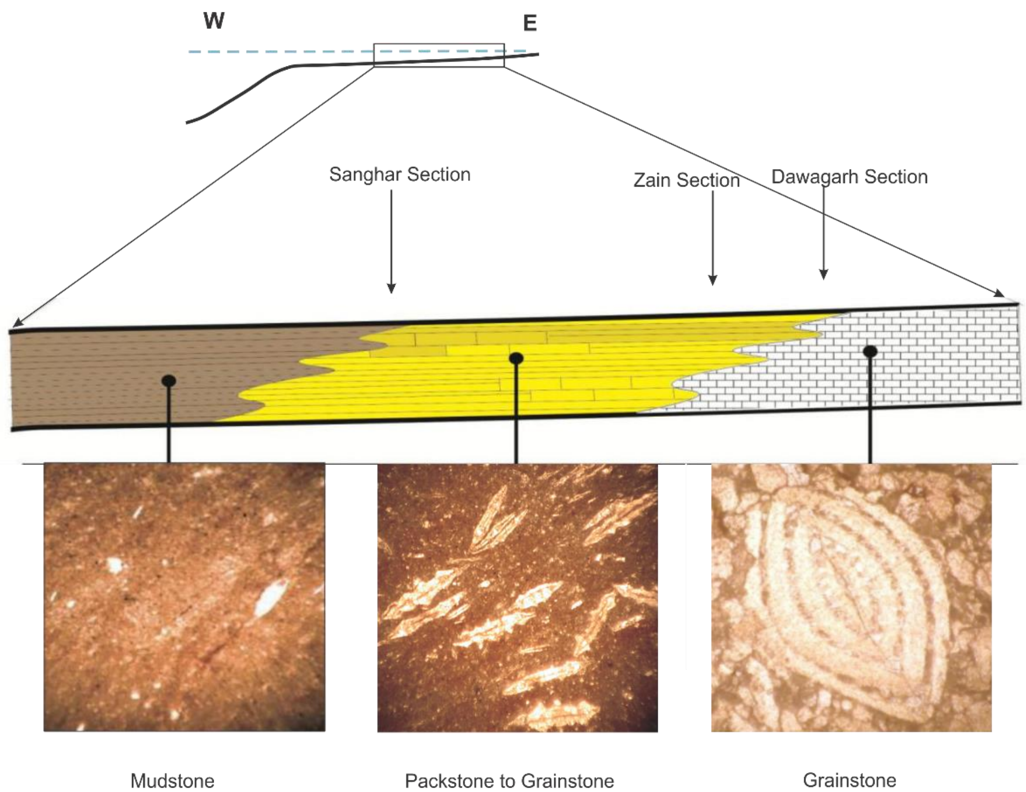

Fig. 8 Facies distribution of Habib Rahi Limestone on the Early Eocene carbonate ramp shelf.

DISCUSSION

The detailed sedimentological studies of the early Eocene Habib Rahi Limestone at Zain, Dawagrah, Sanghar Nala, and Mughal kot sections reveal that lithofacies of the formation mainly divided into three parts lower, middle and upper concerning lithological variation. The limestone in the lower part of the formation is highly fossiliferous, rich in *Assilina* sp.. The middle part comprises chert lenses with irregular beds of chert that run parallel to the limestone. The upper part is thick to thin-bedded platy limestone with the alternate bed of limestone, shale, and marl. Moreover, vertical thickness from Sanghar Nala Section to Zain Section ranges from 25 to 40 m that reveals a similar depositional trend on the platform. In contrast, Mughal kot Section shows a variable trend i.e., pinch out of certain facies and emergence of new facies in the east-west direction.

The depositional environment of the early Eocene Habib Rahi Limestone can be interpreted through microscopic analysis (Fig. 5). The bioclastic wackestone (Fig. 5a, b) depicts low to moderate energy shallow marine to deep lagoonal conditions. These microfacies also contain some floating deep-water planktonic foraminifers which clarify the deposition nearby shelf-break with deep-water environment (Reid and Dunne, 1996). Moreover, the presence of a dark micrite may depict microbial origin. The bioclastic packstone (Fig. 5c, d) demonstrates bimodal depositional trend exhibit features pointing to deposition in agitated waters as well as quiet-water conditions. The overall deposition occurs in a shallow shelf intertidal environment with high-energy conditions, enough nutrient supply, and moderate salinity. Moreover, the absence of siliciclastic material depicts no influence of nearby continental landmass. The bioclastic mudstone (Fig. 5e, f) indicates shallow marine quite water restricted environmental conditions characterized by a low-energy level or a general lack of wave and current action, thereby permitting fine-grained sediment to settle and accumulate. The microfacies "bioclastic packstone to grainstone (Fig. 5g, h, i)" comprises poor to moderately sorted grains that indicate high-energy shallow shelf. Furthermore, bioclastic grainstone (Fig. 5j, k) is characterized by a shallow to deep shelf environment. Consequently, lower, the middle, and upper part of formation comprises larger benthic foraminifera's namely *Assilina subspinosa*, *Assilina spinosa*, *Nummulites mammillatus*, and *Nummulites atacicus* (Fig. 7; Afzal, 2011; Ghazi et al., 2010; 2015). These foraminifera represent carbonate ramp facies in high-energy which can be recognized as bank bed facies. The bank bed facies with plentiful fauna are representative of early Eocene and were deposited in a shallow shelf open marine environment.

The microfacies of the Habib Rahi Limestone display parasequence cycles of regression and transgression. The formation makes conformable lower contact with Alabaster gypsum of Baska Shale that deposited during regression. The overlying *Assilina* rich limestone in the lower part of the formation deposited during early transgression. Furthermore, microfacies from packstone to wackestone display deepening of depositional environment. The development of mudstone facies after the bioclastic packstone facies signifies the abrupt rise of water depth due to a transgressive episode which progressively alters to shallow water deposits which characterize the deposition in environments of slowly falling water depths. Generally, three main cycles of the facies have been recognized with a properly repeating pattern which might be the outcome of three, unlike transgressive actions. The mudstone is characterized by individual parasequences of the transgressive surface. Facies distribution model of the early Eocene Habib Rahi Limestone was constructed based on the microfacies interpretation (Fig. 8).

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