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Sedimentology of pir koh formation exposed at Dholi and Rakhi Gaj, Central Sulaiman Range, Pakistan

Saif Ur Rehman*, Muhammad Ahmad Riaz, Mahboob Ahmed, Muhammad Fahad Ullah, Muhammad Kashif, Faisal Rehman

Department of Earth Sciences, University of Sargodha, Sargodha, Pakistan

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Abstract

Middle Eocene Pir Koh Formation is well exposed throughout the Sulaiman Range and acts as good hydrocarbon reservoir. In present research, two sections of Pir Koh Formation exposed at Dholi and Rakhi Gaj have been investigated for detailed sedimentological studies to depict the depositional environments and modeling. The formation is mainly composed of off-white to creamy white limestone and marl with black chert at places. Petrographic analyses show that Pir Koh Formation is composed of a rich assemblage of benthic and planktonic foraminifera with minor bioclasts. Four microfacies including Planktonic Wacke-Packstone microfacies, Marl microfacies, Discocyclina-Nummulities Wacke-Packstone Microfacies and Chert microfacies were framed with help of petrographic data. The microfacies analyses and paleoecology of fauna suggest a ramp model for the deposition of Pir Koh Formation and it was deposited over mid ramp to upper slope settings.

***Corresponding Author:** Saif Ur Rehman ✉ saif.rehman@uos.edu.pk

Introduction

The Sulaiman Range is situated on the north-western margin of the Indian Plate and constitutes the middle part of the Indus basin which has also been named as Sulaiman Basin (Sarwar and Dejong, 1979; Jaumé and Lillie, 1988). Sulaiman Basin is comprised of a thick sedimentary sequence ranging in age from Upper Paleozoic to Recent (Shah, 1977, 2009).

The Paleogene succession of Sulaiman Basin acts as good quality source and reservoir for hydrocarbons exploration (Kadri, 1995). The Paleogene succession is represented by the clastic, carbonate and mixed clastic-carbonate rocks (Shah, 1977, 2009). Paleocene sequence is conformably overlain by the Eocene succession in Sulaiman basin.

The Baska shale of Ghazij Formation marks the base of Eocene succession while the upper part is calcareous and represented by Kirthar Formation (Afzal *et al*., 1997). Kirthar Formation formerly comprised of four members that include Habib Rahi limestone, Domanda member, Pir Koh member and Drazinda member (Shah, 1977, 2009).

These members later on designated as separate stratigraphic units by Stratigraphic Committee of Pakistan (Shah, 2002).

The Pir Koh Formation is well developed throughout the Sulaiman Basin and tends to pinch out northward in Kohat and Waziristan (Shah, 1977, 2009; Hunting Survey Corporation, 1961). The Pir Koh Formation is mainly comprised of limestone and marl with subordinate chert and oil shale horizons (Shah, 1977, 2009; Afzal *et al*., 1997; Ahsan *et al*., 1993; Akhtar *et al*., 1993).

Despite of its hydrocarbon potential, Pir Koh Formation has not been thoroughly understood in terms of depositional environments and modeling except few good accounts on paleontology and Sedimentology by different investigators (e.g. Afzal *et al*., 1997; Chaudhry and Ahsan, 1994; Sameeni *et al*., 1994; Ahsan *et al*., 1993; Akhtar *et al*., 1993). Pir Koh Formation exhibits significant variations in thickness and lithology in northern and southern parts of Sulaiman Basin. In present study, two complete stratigraphic sections of Pir Koh Formation exposed at Dholi and Rakhi Gaj, Dera Ghazi Khan District were selected for sampling to depict the depositional settings of this Upper Eocene unit of northern part of Sulaiman Basin.

The present appraisal mainly deals with microfacies analysis and depositional environments of Pir Koh Formation to demarcate the sea level changes and to deduce a depositional model for the Pir Koh Formation.

Materials and methods

Regional Geology of Study Area

Geologically study area is located in the Sulaiman Fold and Thrust Belt of Northern Pakistan commonly known as Sulaiman Range (Fig. 1). To the west of the Himalayas, it represents a broad and gentle dipping folds and thrust belt that is tectonically active. It was developed by left-lateral strike-slip motion along the Chaman fault and southward thrusting along the western boundary of the Indian plate (Sarwar and DeJong, 1979; Klootwijk *et al*., 1981, 1985; Lawrence *et al*., 1981).

The Sulaiman fold and thrust belt (SFTB) is bordered with Zhob-Muslimbagh ophiolites and Chaman fault in the north and west and truncated by the Kirthar Fold and Thrust Belt (KFTB) in south. In the east and southeast, it is truncated along the Punjab platform (Sarwar and DeJong, 1979). Stratigraphically, Sulaiman Fold and Thrust Belt are comprised of 10Km thick sedimentary sequence of Upper Paleozoic to Holocene (Table 1).

Rocks of Sulaiman fold and thrust belt can be divided into three main sedimentary packages resulted by different tectonic events. These sedimentary packages include Oligocene to Holocene molasse deposits, Paleozoic to Late Eocene shallow to deep marine strata and Late Eocene to Early Oligocene Khojak Flysch underlain by the Late Cretaceous-Paleocene ophiolites (Lawrence *et al*., 1981).

Table 1. Stratigraphic column of Sulaiman Range (modified after Shah, 2002, 2009).

Period	Epoch	Group	Formation	Lithology
Quaternary	Holocene	Surficial deposits, Gravel, sand, silt & clay		
	Angular Unconformity			
	Pleistocene		Dada Formation	Conglomerate, sandstone & clays
	Angular Unconformity			
Neogene	Pliocene	Vihowa Group	Chaudhwan Formation	Clays, conglomerate & sandstone
			Litra Formation	Sandstone, clays & conglomerate
	Miocene		Vihowa Formation	Clays, sandstone & conglomerate
Paleogene	Oligocene		Chitarwata Formation	Clays, conglomerate & sandstone
	Disconformity (Eocene-Oligocene boundary which represents major tectonic phase)			
	Eocene	Kahan Group	Drazinda Formation	Shale with minor coquina
			Pir Koh Formation	Limestone, marl & shale
			Domanda Formation	Shale with minor coquina & gypsum
			Habib Rahi	Limestone, marl & shale
			Chamalang, Baska Formation	Gypsum, shale with minor silty dolomite
		Ghazij Group	Drug Formation	Rubbly limestone & mudstone / shale
			Kingri Formation	Red muds/shale & grey to white sandstone
			Toi Formation	Sandstone, shale, rubbly limestone & coal
			Shaheed Ghat	Shale with minor marl /sandstone
	Paleocene	Sangiali Group	Dungan Formation	Limestone, marl & shale
			Rakhi Gaj Formation	Shale, mudstone, siltstone & limestone
			Sangiali Formation.	limestone, glauconitic shale & sandstone
Cretaceous	Disconformity (KTB)			
	Upper	Fort Munro Group	Vitakri Formation	Two red mud units with sandstone Beds
			Disconformity (KTB)	
			Pab Formation	Sandstone with subordinate shale
			Fort Munro Formation	Limestone, shale & coquina beds
	Lower		Mughal Kot Formation	Shale, marl, sandstone, limestone & muds
		Parh Group	Parh Formation	Limestone with minor marl & shale
			Goru Formation	Shale & marl with minor limestone
			Sembar Formation	Mainly shale with minor marl & mudstone
	Disconformity (JKB)			
Jurassic	Upper	Sulaiman Group	Chiltan Formation	Mainly Limestone
	Middle		Loralai Fmormation	Limestone, marl & shale
	Lower		Spingwar Formation	Shale, marl & limest

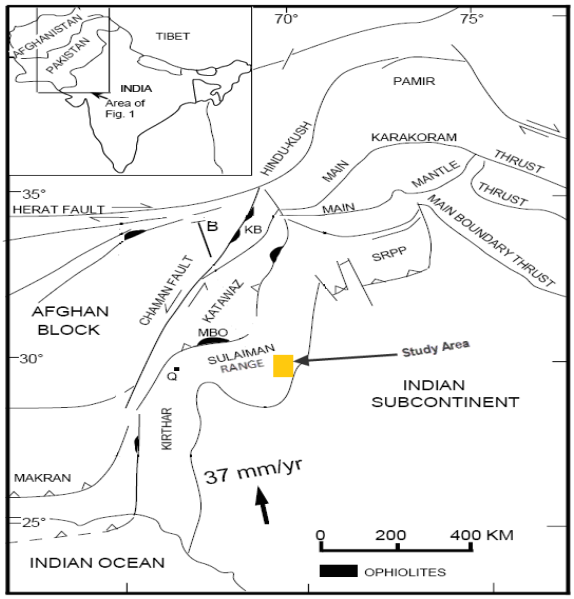

Fig. 1. Regional tectonic map showing the location of study area (modified after Minster & Jordan, 1978).

Section Measurement

Detailed field excursion was carried out in the study area using the published geological maps and literature to select the complete stratigraphic sections of Pir Koh Formation. After thorough investigations, two complete stratigraphic sections of Pir Koh Formation exposed at Dholi and Rakhi Gaj were selected for sedimentological studies with preserved bottoms and tops and least deformation as prescribed in literature.

Outcrop Investigations and Sampling

After the selection, both sections were thoroughly investigated in field and all outcrop and stratigraphic information including lithology, texture, thickness, bedding, fauna and contact relationship etc were recorded and logged. Each rock type and bed was sampled and mentioned on sedimentary log.

Petrography and Microfacies Analysis

The collected samples were thin sectioned for petrographic studies. Thin sections were stained by adopting the Dickson method (Dickson, 1996) to distinguish the carbonate minerals. The petrographic studies were conducted by using Polarizing microscope to determine the skeletal and non-skeletal constituents and matrix types.

The petrographic data was used to classify the carbonate rocks after Dunham classification (Dunham, 1962) and construct the microfacies. The depositional environments of microfacies were deduced with the help of faunal types and their paleoecology. The vertical stacking of different microfacies was employed to demarcate the sea level fluctuations and develop the depositional model.

Results and discussion

Outcrop Geology

At both studied sections, Pir Koh Formation is mainly comprised of limestone and marl with subordinate chert and marly limestone. Limestone is generally creamy to white, dirty off white and whitish grey and thin to medium bedded. Limestone and marly limestone contain large benthic foraminifera including *Discocyclina, Lockhartia* and *Nummulites* at the basal part and is abruptly replaced by unfossiliferous beds. Marl horizons are of same color as limestone and generally fine grained and laminated. Chert is generally blackish grey to black and occurs as thin hard layers. Chert layers appear in upper part of this formation in both sections. In Rakhi Gaj section, fossiliferous marly limestone grades into limestone and limestone grades into cherty limestone and then chert. In Dholi section, limestone is platy and interlayered with marl and is entirely different from Rakhi Gaj section in lithological pattern. The Pir Koh Formation is conformably overlain by Drazinda Formation and underlain by Domanda Formation at both localities.

Petrography

The petrographic analyses of studied carbonate samples from both sections reveal that Pir Koh limestone is dominantly composed of large benthic foraminifera and planktonic foraminifera. The large benthic foraminifera dominantly occur in the basal part of rock unit comprising of limestone and marly limestone and mainly include *Discocyclina, Lockhartia, Nummulites, Bolivina, Bigerina, Nodosaria* and broken pieces of these organisms and some unidentified organisms. *Assilina, Operculina* and *Calcrina* also occur as rare.

Planktonic foraminfera abundantly constitute limestone of middle and upper parts and mainly include the different species of *Globorotalia, Globigerina, Globigerapsis, Truncorotaloids* and *Chiloguembelina* genera. The groundmass is mainly composed of yellow to yellowish brown micrite. Some chert samples were also thin sectioned and analyzed under microscope. Chert samples are mainly composed microcrystalline quartz and contain sponage spicules.

Microfacies Analysis

The petrographic data including the skeletal and non-skeletal grains was used classify the carbonate rocks by using the scheme of Dunham classification (Dunham, 1962); and to construct the microfacies. The dominancy of faunal types among the skeletal grains was used to assign the nomenclature of microfacies. Total four microfacies have been constructed on the basis of petrographic data and the detail of each microfacies is discussed in the following session.

Planktonic Wackestone and Packstone Microfacies

This microfacies is the most abundantly occurring microfacies of both studied section and is represented by off-white to creamy white, thin to medium bedded, fine grained limestone. These limestone beds commonly constitute the upper part of Pir Koh Formation at both studied sections. The allochemical constituents of the microfacies predominantly comprises of planktonic foraminifera. Plankton abundance ranges from 40% to 70% with an average of 45% at Rakhi Gaj section and 30% to 60% with an average of 35% at Dholi section. At Rakhi Gaj section, these planktons are well preserved and shell fragments are rare to less common. Due to good preservation, it is easy to recognize the different planktons even to species level at Rakhi Gaj section (Fig.: 2 A). These microfacies contain total five genera and their twelve species of planktons which have been identified under microscope. These identified planktonic genera are *Globorotalia, Globigerina, Globigerapsis, Truncorotaloids* and *Chiloguembelina*. Among the planktons, *Globorotalia* and *Globigerina* are the most frequently occurring genera.

Planktons generally range in size from 0.06mm to 0.43mm. Subordinate gains are smaller benthons like *Bolivina, Bigerina* and *Nodosaria* which make up 3% to 4% (Fig. 2 B). The chambers of planktons and benthons are mainly affected by the neomorphism.

Marl Microfacies

This microfacies are characterized by the off-white to creamy white, thin, cleaved and laminated marl. Marl is commonly fine grained and contains no coarse detritus like sand or silt grains (Fig. 2 C). At Dholi section marl horizons are interbedded with limestone and marly limestone. At Rakhi Gaj section, they frequently appear in the middle and upper part. The calcimeteric analyses of marl samples show that they are dominantly composed of clay minerals with subordinate calcite (30%-45%). Some hard substrate of marl were thin sectioned and analyzed under the polarizing microscope. Thin section studies show that they dominantly comprised of a rich assemblage of nanoplanktons (Fig. 2 D). These nanoplanktons are distributed over the fine grained clayey and calcitic ground mass and their abundance ranges from 70% to 80% with an average of 75%.

Discocyclina-Nummulites Wackestone and Packstone Microfacies

Discocyclina-Nummulites wackestone and packstone microfacies are comprised of off-white to creamy white, fine grained, fossiliferous medium bedded marly limestone and occur in the lower part of Pir Koh Formation at Rakhi Gaj section. Benthic foraminifera are dominant skeletal grains that range in abundance from 40% to 60% (Fig.: 2 E).

The mode of preservation is good. Due to well preservation, benthons are easily recognizable to genera level. The identified benthic genera are *Discocyclina, Nummulites, Lockhartia, Assilina, Operculina* and *Calcarina* (Fig. 2 F). Other than these skeletal grains, the broken shells of these organisms also occur in significant amounts and range from 5% to 8%. The intact to broken ratio is estimated at 5:3. Among the benthons, *Discocyclina* is the most frequently occurring skeletal type of this microfacies. *Nummulites* and *Lockartia* are subordinate to *Discocyclina*. *Assilina, Operculina, Calcarina, Bryozoa* and *algae* also occur as traces. The size of benthons generally ranges from 1.4mm to 3.8mm. The planktons also constitute this microfacies in significant amounts (3% to 7%). The planktons mainly include *Globorotalia* and *Globigerina* and show good preservation. These grains are distributed in the micrite ground mass. Chambers of benthons and planktons exhibit effects of neomorphism and are replaced by the ferron calcite. Calcite veins are common.

Chert Microfacies

Chert microfacies are represented by massive, hard and black thin layers associated with off-white to creamy white limestone at Dholi section and Rakhi Gaj section. The thickness of chert layers varies from 1cm to 1.5cm. These microfacies occur near upper part at Rakhi Gaj and in the middle and upper part at Dholi section. In thin sections, chert microfacies are represented by the abundance of microcrystalline siliceous grains.

These micro grains are mainly of sponge spicules (Fig. 2 G). Siliceous sponge spicules generally composed the chert grains and cherty matrix and resulted in the formation of spicular chert. These chert grains of sponge spicules are preserved by microcrystalline quartz and chalcedonic quartz. Major source of silica in Pir Koh Formation is sponge spicules.

In addition to this, grey concretions of chert also occur in limestone lying above and below the bedded chert. These concretions are secondary texture of chert which represents the replacement of the limestone. This replacement is due to the dissolution and re-precipitation of sponge spicules.

In cherty limestone, much of the matrix is silicified in the form of micro-quartz or chalcedony which is found within the upper part of Pir Koh Formation. Sponge spicules or the matrix surrounding the spicules are replaced by micro-quartz or chalcedony silica.

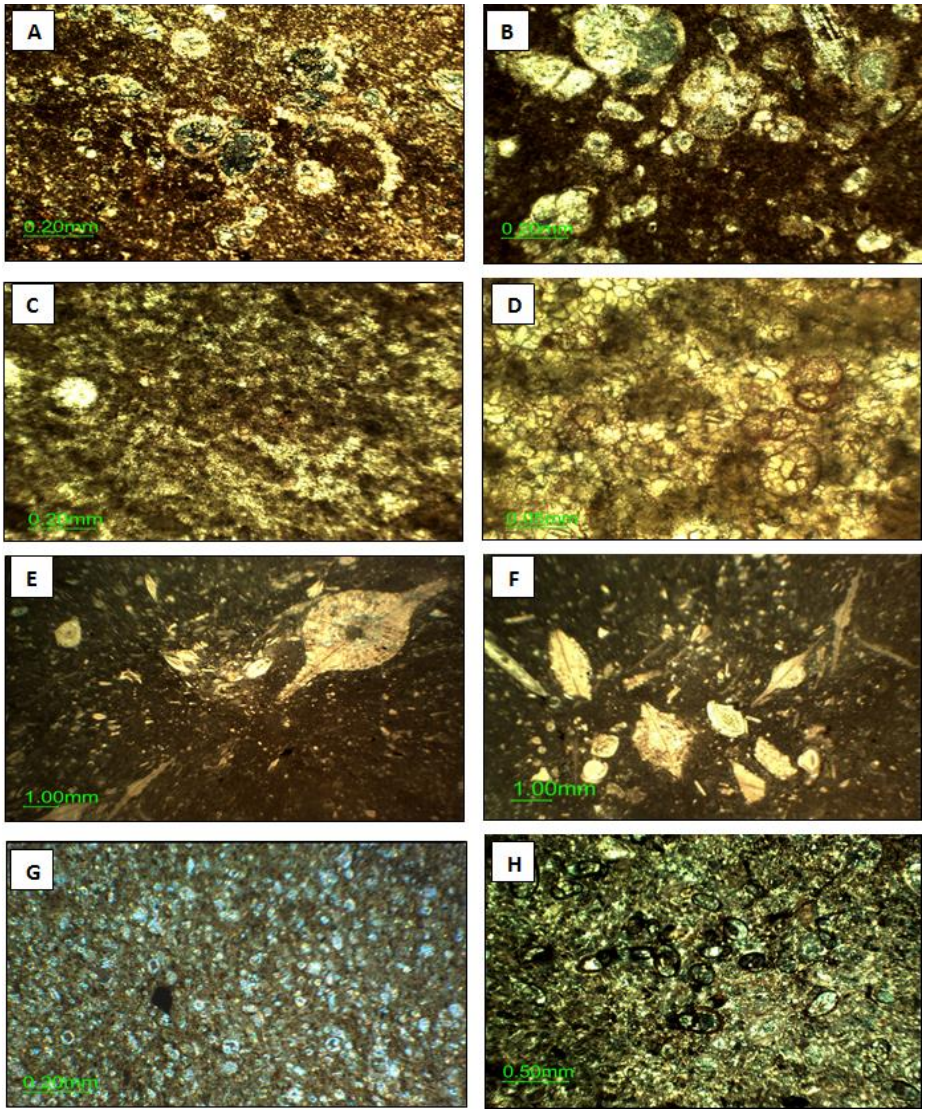

Fig. 2. Microfacies of Pirkoh Formation (A) Planktonic Wackestone and Packstone (B) Abundant Planktons & smaller benthons (C) Marl Microfacies (D) Nanoplanktons in Marl microfcies (E) *Discocyclina-Nummulites* Wackestone and Packstone (F) Larger.

Depositional Model and Depositional Environments

The microfacies analyses and faunal types recorded in the studied section of Pir Koh Formation suggest that Pir Koh Formation was deposited under the well circulated, open marine conditions. The absence of carbonate shoals, organic barriers and reefal deposits in the Pir Koh Formation infer the ramp settings for the deposition of Pir Koh Formation (Fig. 3). Various workers (e.g. Abbas, 1999; Afzal *et al.*, 1997; Ahsan *et al.*, 1994) interpreted the homoclinal ramp for the deposition of Paleogene sequence of Sulaiman Basin. The presence of nanoplanktons in marl samples also indicates the some deposition over the slope setting adjacent to the ramp settings.

Ramp is further subdivided into three major zones including inner ramp, mid ramp and outer ramp and framed microfacies are further placed on the different zones of ramp on the basis of occurrence of skeletal grains and their paleoecology (Fig. 3). The detailed depositional environments of constructed microfacies are discussed in the following session.

Discocyclina-Nummulites wackestone and packstone microfacies are characterized by the dominancy of by skeletal grains of larger benthic foraminifera including *Discocyclina* and *Nummulites*. Along with these skeletal grains, the broken fragments of these organisms are also found.

The presence of *Discocyclina* and *Nummulites* along with bioclasts of same organisms suggests deposition under relatively high energy conditions over the ramp. *Lockhartia* and Planktons also constitute this microfacies in minor amounts. However, the occurrence of planktons along with larger benthic foraminifera indicates slightly deeper water depths like mid ramp (Fig. 3).

The paleoecological attributes of *Discocyclina, Nummulites* and *Lockartia* also confer same environments (Racey, 1994; Luterbacher, 1998; Anketell and Mriheel, 2000).

Planktonic Wacke-Packstone microfacies have been interpreted as deposition over the distal mid ramp to proximal outer ramp settings due to the high frequency of the planktonic foraminifers (Fig. 3). Planktons are generally considered as the good indicator of low energy and deposition over the distal parts of shelf like outer shelf (Rehman, 2009, 2017; Rehman *et al.*, 2016; Ahsan *et al.*, 2015; Flügel, 2004; Butt, 1981; Wilson, 1975).

Furthermore, the micritic groundmass and low frequency or absence of larger benthic foraminifera is also evident of low energy and deposition over the distal shelf (Butt, 1981; Wilson 1975). The presence of small benthic foraminifer like *Bolivina, Bigerina* and *Nodosaria* in minor amounts also indicates deposition of these microfacies over the deep water settings like proximal to distal outer ramp.

The bedded chert in Pir Koh Formation is spicular chert. Spicular cherts are generally associated with argillaceous limestone and dolomites are mainly originated from deep marine environments (Boggs, 2009). (Gammon, 2010) Suggested that bio-siliceous rock particularly rich in sponge spicules occur and thrive in deep sea. The silica for bedded chert is commonly supplied by the dissolution of sponge spicules occurring in pelagic deep marine limestones (Flügel, 2004). In present study, bedded cherts occur within limestone of Pir Koh Formation at both studied sections. Due to their association with planktonic microfacies, these bedded cherts are interpreted as deposition of distal outer ramp (Fig. 3).

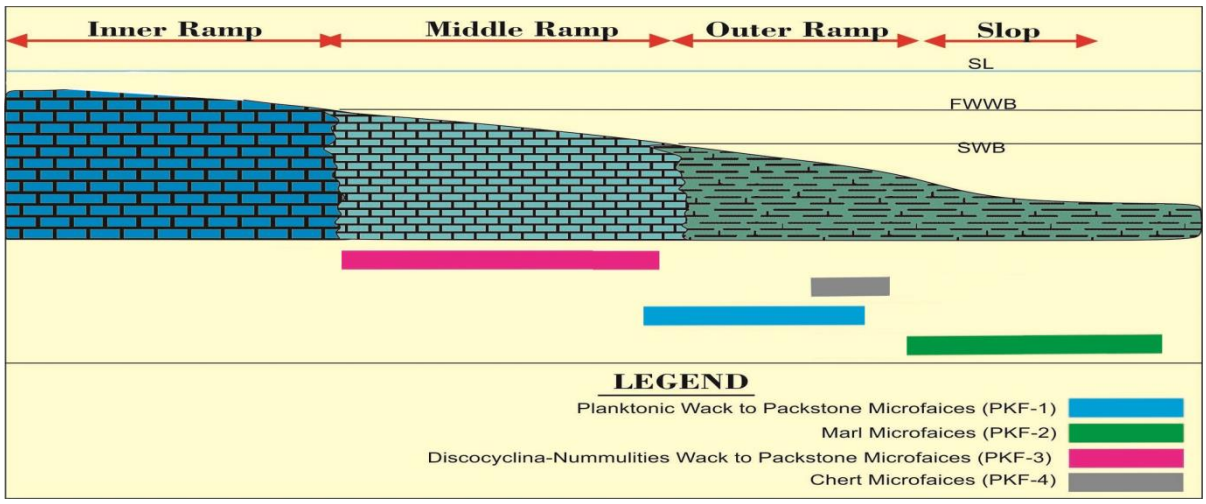

Fig. 3. Depositional modal for Pir koh Formation at central Sulaiman range Pakistan.

Marls are commonly diverse in depositional settings and generally deposit in variety of environments ranging from middle to shelf to ocean basin settings under low energy conditions (Rehman, 2017; Boggs, 2006; Flügel, 2004). In present study, Marl microfacies are interpreted as deposition of low energy distal outer ramp to upper slope environments due to the presence of high frequency of nanoplanktons and laminated nature of marls (Fig. 3). Various workers (e.g. Nichlos, 2009; Boggs, 2006, 2001; Flügel, 2004) placed the nanoplanktons in abundant amounts over the outer shelf to slope and ocean basin settings with minute storm agitation and greater water depth.

The lamination in the marls is evident of deposition of sediments under low energy conditions prevailed by the greater water depths (Boggs, 2001). The size of planktons is comparatively larger in Planktonic wack-packstone microfacies and reduces upwards into the marl which shows that basin has attained maximum depth.

Discussion

The microfacies analyses and faunal types recorded during the petrographic studies show that the Pir Koh Formation was deposited in open marine conditions over the mid ramp to upper slope settings (Fig. 4).

Afzal *et al.*, (1997) and Abbas (1999) also reported the similar depositional settings for the Pir Koh Formation over the regressive top of underlying Domanda Formation. The underlying Domanda Formation has upper transitional/gradational contact with Pir Koh Formation demarcated by the gypsiferrous shales interbedded by thin bands of limestone. The petrography of these thin limestone bands yields abundant *Miliolids* along with *ostracods* (Fig. 2H). The presence of gypsum needles in shale and abundant *Miliolids* in limestone near the upper contact of Domanda Formation are evident of restricted very shallow marine environments caused by the regression before the deposition of Middle Eocene Pir Koh Formation.

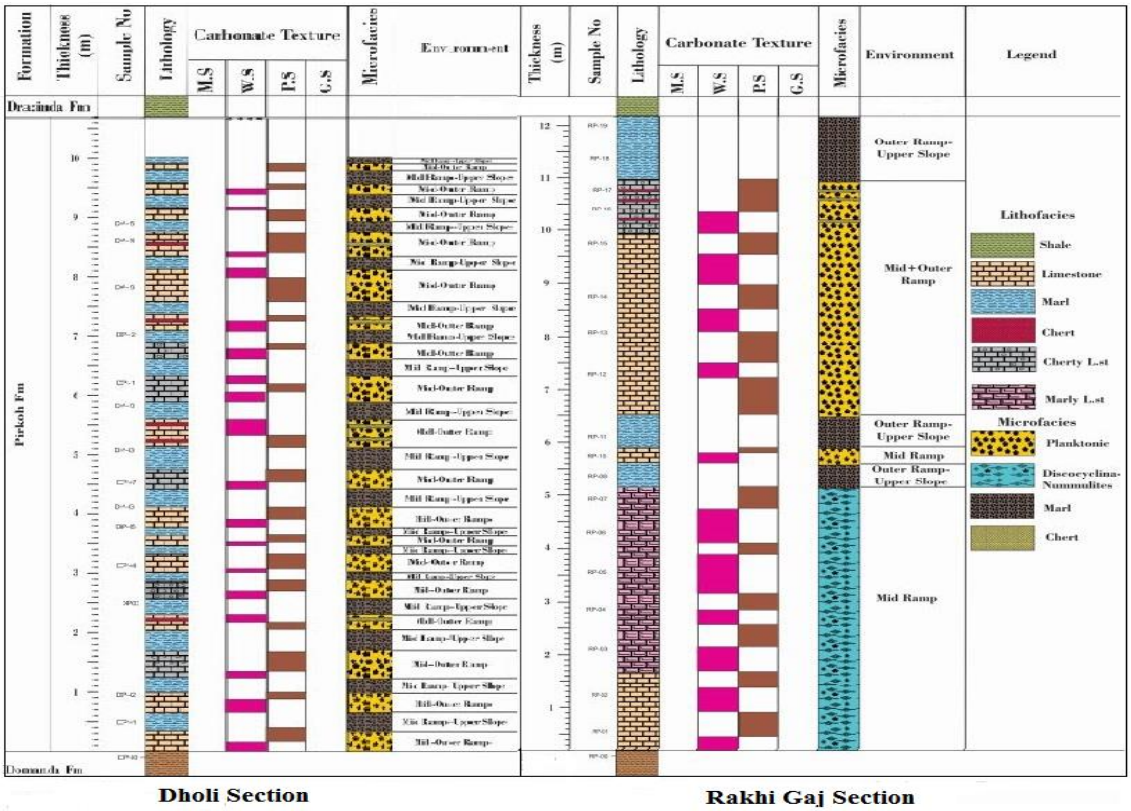

Fig. 4. Lithostratigraphic column, Carbonate Texture, Environments & Microfacies distribution at Dholi and Rakhi Gaj section Central Sulaiman Range, Pakistan.

The vertical stacking of basal microfacies of Pir Koh Formation including *Discocyclina-Nummulites* microfacies and Planktonic microfacies over the regressive microfacies of Domanda Formation suggests that the deposition of Pir Koh Formation was initiated with a transgressive cycle (Fig. 4). Nagappa (1959) and Haq *et al.*, (1988) recorded a major transgression in Indus Basin during the Middle Eocene accompanied by the tectonic activities of India-Asia collision. The further overlapping of Planktonic microfacies, Chert microfacies and Marl microfacies in the middle and upper part of Pir Koh Formation demarcates the minor sea level changes occurred during the Middle Eocene (Fig. 4).

Maximum no of minor sea level changes were recorded at the Dholi section. The *Discocylina-Nummulites* microfacies are absent at the basal part of Dholi section and are replaced by the Planktonic microfacies which suggest that Dholi section was located under more deeper conditions than that of Rakhi Gaj section (Fig. 4). Near the upper contact of Pir Koh Formation with overlying Darazinda Formation, the Planktonic microfacies are again replaced by the gypsiferous shale facies which indicate a sea level fall which terminated the deposition of Pir Koh Formation (Fig. 4). Afzal *et al*., (1997) also recorded the regressive cycle near the top of Pir Koh Formation. The final continental-continental collision was occurred at the terminal of Eocene which terminated the marine deposition in the Indus Basin after the deposition of overlying Darazinda Formation (Abbas, 1999).

Conclusions

- Following conclusions have been drawn from the research work of Dholi and Rakhi Gaj Middle Eocene Pir Koh Formation is excellently exposed in the study area and composed of limestone, marly limestone and marl with thin bands of chert that appears in the upper part of the formation.

- The petrographic analyses of studied samples show that Pir Koh Formation is composed of a rich assemblage of larger benthic and planktonic foraminifera with minor content of smaller benthons. On the basis of petrographic data, four microfacies including Planktonic wackestone and packstone microfacies, Marl microfacies, *Discocyclina-Nummulites* wackestone and packstone microfacies and Chert microfacies were constructed.

- The homoclinal carbonate ramp model is envisaged for the deposition of Pir Koh Formation as major transgressive cycle. The microfacies analysis and environmental interpretation revealed that Pir Koh Formation was deposited on mid ramp to upper slope settings.

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