3. STRATIGRAPHY

The statigraphic sequence in Pakistan ranges from Precambrian to Recent. The Mesozoic and Paleogene sedimentary rocks form a thick pile of shelf deposits along the north and northwestern margins of Indo-Pakistan Plate. The Cenozoic sedimentary sequences are widespread in famous fold and thrust belts of Pakistan. These deposits largely consist of Paleogene marine sedimentary sequences covered by dominantly non-marine Neogene sedimentary formations throughout the Indus Basin.

According to the paleoenvironmental interpretations of the M. R. Cheema, S. M. Raza and H. Ahmad (in Shah, 1977), the close of the Mesozoic Era is marked by a period of emergence in parts of Pakistan. The Tertiary rocks thus have lower contact relationships with older units. The contact is unconformable in the Sulaiman Ranges, however, it is reported to be transitional in some parts of the Southern Indus Basin (Hunting Survey Corporation, 1961) and in the Baluchistan Basin.

Cenozoic rocks were deposited in a broad sea that gradually narrowed and retreated southwards with passage of time to occupy its present position as the Arabian Sea. The rocks of the Cenozoic Era exhibit variation in thickness and lithology in different areas. However, the Paleocene and Eocene sediments are mainly limestone and siltstone/ mudstone whereas the younger ones are dominantly sandstone, siltstone and mudstone. The Paleocene sediments are

AGE			Sulaiman Range, southern Indus Basin, Pakistan				
			Eams, 1952b		Shah, 1977	Kazmi, 1995	ThisWork, 1999
			Zinda Pir	Rakhi Nala	Siwalik Group	Chitarwata Formation	Chitarwata Formation
TERTIARY	OLIGOCENE		Pellatispira Beds	Pellatispira Beds			
	EOCENE	Late	Upper Chocolate Clays Passage Beds	Upper Chocolate Clays Passage Beds	Kirthar Formation: Darazinda Member	DarazindaFormation	Kirthar Formation: Darazinda Memb.
		Middle	White Marl Band	White Marl Band	Pir Koh ls & Marl Member.	Pir Koh limestone & Marl Formation	Pir Koh limestone & Marl Member
			Lower Chocolate Clays	Lower Chocolate Clays	Sirki Member	Domanda Formation	Sirki Member
			Platy Limestone	Platy Limestone	Habibrahi Ls. Member	Habibrahi Limestone Formation	Habibrahi Limestone Member
		Early	Shales with Alabaster Rubbly Limestone Green and nodular Sh. Ghazij Shales Zinda Pir Ls.(u. part)	Shales with Alabaster Rubbly Limestone Green and nodular Sh. Upper Rakhi Gaj Sh.	Bska Sh. & Alabaster Mb. Ghazij Formation	Ghazij Group: Baska Formation Drug Formation Shaheed Ghat Formation	Ghazij Group: Baska Formation Shaheed Ghat Formation
	PALEOCENE	Late	Zinda Pir Ls. (Lower part) Zinda Pir Shales	Lower Rakhi Gaj Shales	Dunghan Formation	Dunghan Formation	Dunghan Formation
Maastrchitian			Pab Sandstone	Pab Sandstone	Pab Sandstone	Pab Sandstone	Pab Formation

Figure 6. Cenozoic lithostratigraphic correlation of this work with that of previous workers (Eames, 1952b; Shah, 1977; Kazmi, 1995) in the Sulaiman Range, Southern Indus Basin, Pakistan.

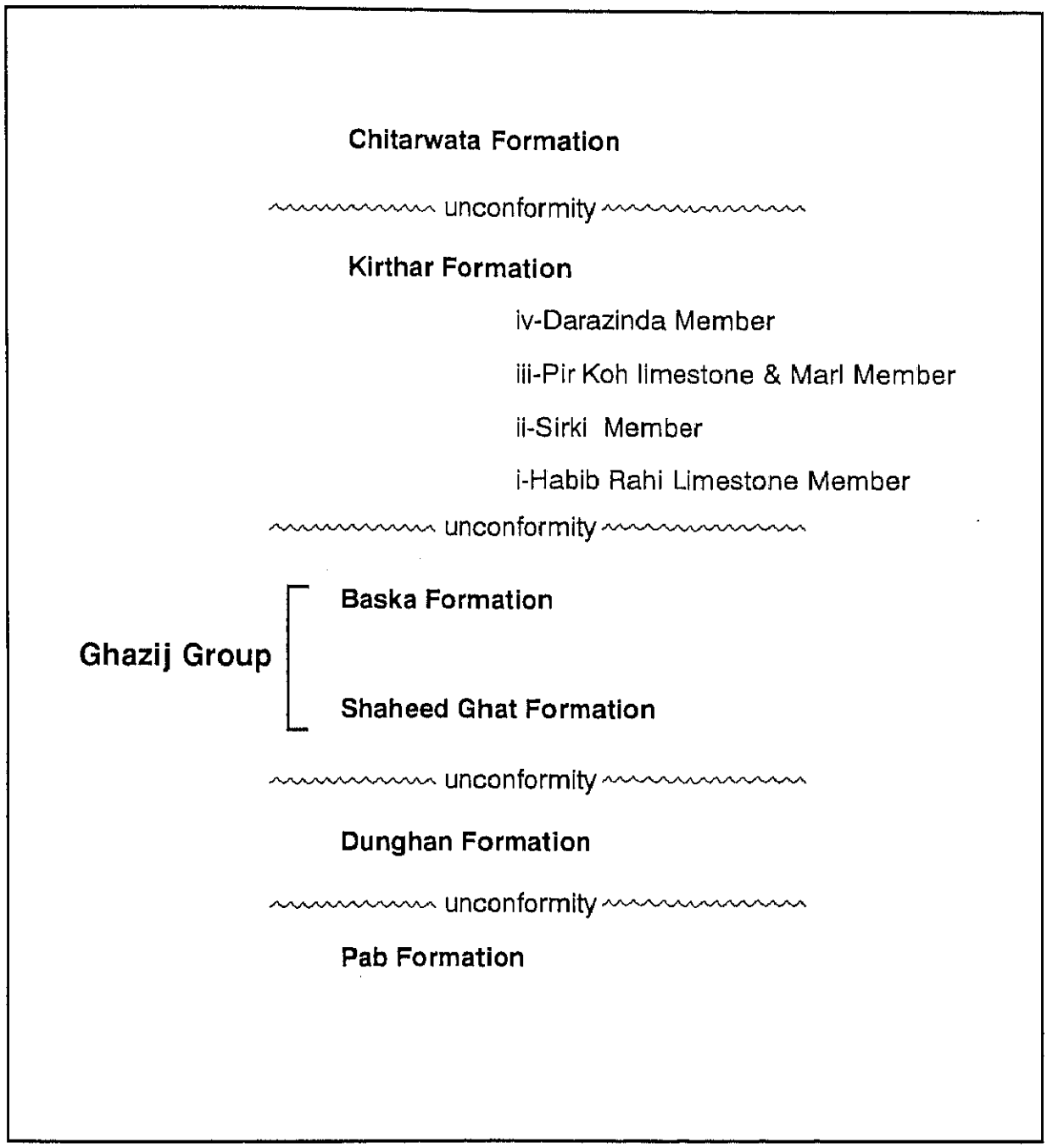

Figure 7. Cenozoic lithostratigraphc setup of the Sulaiman Range, Southern Indus Basin, Pakistan (used in this work).

almost entirely of the marine environments. The Eocene sequence consists of limestone, calcareous shale with subordinate sandstone and conglomerate. Locally red beds, gypsum, anhydrite, salt and coal are also found and reported in different parts of the Indus Basin.

Towards the end of the Paleocene, there was a partial emergence followed by submergence in the Early Eocene when the sea inundated major parts of the Pakistan. Nagappa (1959) has reported a short-lived regression at the end of the Early Eocene as a result of which evaporites were formed in Kohat area, Sulaiman Range and in the Axial belt. There was a widespread submergence after the regression, which has affected large areas including Kohat, Southern Indus Basin, Axial belt and Baluchistan.

The Cenozoic stratigraphy of the whole Indus Basin has been well studied by various oil companies, Geological Survey of Pakistan and other geologic agencies because of its good mineral and hydrocarbon potential. A correlation showing horizontal and vertical distribution of the Paleogene litostratigraphic units recognized in the Southern Indus Basin are shown in Figure 6.

The Paleogene succession which is the focus of present studies and is well exposed in all three land section of the Zinda Pir and Rakhi Nala areas is unconformably underlain by the Cretaceous Pab Formation and overlain by the Chitarwata Formaion of Oligocene age. This marine succession consists of three formations namely Dunghan Formation, Ghazij Formation and Kirthar Formation. Apart from the detailed geologic mapping (Figure 3, 4) all three sections were also measured in which the details of the lithological variations and sample location are

shown (Figures 9, 10, 11). The stratigraphic sequence is summarized in Figure 7 and is discussed as below.

3.1 Pab Formation

General. The term Pab Sandstone was introduced first by Vredenburg (1906) and is derived after Pab Range in the Kirther Province. The formation consists mainly of white, cream or brown colored, thick to massive bedded, medium to coarse-grained quartzose sandstone with intercalation of subordinate limestone and shale. The thickness of this formation at Wirahab Nai (25° 31′ 12″ N; 67° 00′ 19″ E) in the Pab Range is described as type section (Williams 1959) is 490m.

Rakhi Nala and Zinda Pir sections. Pab Sanstone is an informal name, therefor in this study Pab Formation is used to represent the "Pab Sanstone" of the Vredenbeurg (1906). This formation is extensively exposed with its typical lithology at Rakhi Nala section whereas at Zinda Pir area, its limited exposure (16m) is restricted to core of the Zinda Pir Anticline. In the Rakhi Nala section, it shows cross-bedding, ripple marks and intercalated conglomerate (Pl. 1, Figs. A, B, C).

3.2 Dunghan Formation

General. The name "Dunghan Limestone" was introduced by Oldham (1890) to replace the " Alveolina Limestone" of Griesbach (1881) which is thick

limestone sequence between Parh limestone and Ghazij Formation. Williams (1959) redefined the term as "Dunghan Formation" while excluding the basal beds (his Fort Munro limestone member) which were found to have unconformable relationship with rest of the unit. Shah (1977) redefined Dunghan Formation of the Williams (1959) and included "Lower Rakhi Gaj Shales", "Zinda Pir Shales", and "Zinda Pir Limestone" of Eames (1952b) excluding (Moro Formation), "Dab Formation and "Karkh group" of Hunting Survey Corporation (1961). Williams (1959) has described Mirhab Tangi George, (lat. 30° 08′ 38″ N; long. 67° 59′ 33″E) 8 km northeast of Harnai, Loralai District as type section.

The Dunghan Formation mainly consists of nodular to massive limestone with subordinate siltstone, marl, sandstone and limestone conglomerate. Limestone is dark gray to brown and creamy white, weathers brown, gray and buff yellow. The dark blue-gray, brown and olive siltstone weathers green becomes dominant in the southern Sulaiman Range. The Dunghan Formation is widely distributed in the Sulaiman Range. It is reported to be 365 m thick. The lower contact of the Dunghan Formation is unconformable and marks one of the major unconformity of the basin. The upper contact with Ghazij Formation is reported conformable. It contains rich fossil assemblage including foraminifera, gastropods, bivalves and algae (Hunting Survey Corporation, 1961; Latif, 1964; Samanta, 1973; Doreen, 1974; Kazmi, 1988, Warraich and Natori, 1997).

Rakhi Nala and Zinda Pir sections. At Rakhi Nala and along both limbs of the Zinda Pir Anticline, the Dunghan Formation shows typical lithology, however, siltstone is the dominant unit. The thin-bedded siltstone (Pl. 2, Figs. A, B) is dark black and sandy near the base. Some hard cream white to beige colored beds of quartzite and greenish gray glauconitic sandstone beds are also found intercalated with silstone in the lower part (Pl. 2, Fig. A). These beds are relatively abundant in the Rakhi Nala section compared to Zinda Pir sections. Moreover, at Rakhi Nala, basal portion and exhibit sedimentary structures like cross-bedding, ripple marks and trace fossils. However, in the Zinda Pir section, cross-bedding and ripple marks were not observed whereas trace fossils were found in the middle part of the formation (Pl. 3, Fig. A). The siltstone exhibit spheroidal style of weathering (Pl. 3, Fig. B).

Several limestone beds flooded with larger foraminifera were found intercalated in the upper part of the formation at Zinda Pir (Pl. 2, Fig. C). The limestone intercalated with siltstone is thicker (Pl. 4, Fig. A), in the Zinda Pir area compared to Rakhi Nala succession.

The stratigraphic concept of Shah (1977), who has included "lower Rakhi Gaj Shales" from Rakhi Nala, "Zinda Pir Shales" and "Zinda Pir Limestone (lower part)" from Zinda Pir of Eames (1952b) in the definition of the Dunghan Formation is adopted here. The relationship between the Dunghan Formation and the overlying Shaheed Ghat Formation had been recognized as a conformable relationship (Shah, 1977), whereas Eames (1952b) reported an unconformable relationship between the "Zinda Pir Shales" (Dunghan Formation) and the "Zinda

Pir Limestone" (lowermost part of the Shaheed Ghat Formation) in this area. In this paper, I also concluded that the Dunghan Formation is unconformably overlain by the Shaheed Ghat Formation as suggested by Eames (1952b). This is further supported by the presence of conglomeratic to brecciated limestone beds and formation of the hard-ground in the basal part of the Shaheed Ghat Formation (Pl. 3, Figs. C; Pl. 4, Fig. A).

The Dunghan Formation is measured 300m thick at Rakhi Nala section (Figure 9) whereas it is only 135m thick in the Zinda Pir section (Figure 10. 11).

3.3 Ghazij Group

General. The "Ghazij Group" of Oldhalm (1890) redefined as "Ghazij Formation" by Williams (1959). Ghazij Formation was also adopted by Shah (1977) who also included "Shales with Alabaster, Rubbly Limestone, Green and Nodular Shales, Upper Rakhi Gaj Shales, and Zinda Pir Limestone (upper part)" of Eames (1952b) described from Rakhi Nala and Zinda Pir areas. He also has included "Chat beds" of Nagappa (1959) and the "Ghazij Shales", "Tiyon Formation" and upper part of the "Gidar Dhor Group" of the Hunting Survey Corporation (1961) in the definition of his Ghazij Formation.

Shah (1977) introduced two members in the upper part of the formation. In eastern and southeastern Sulaiman Range "*Baska shale and Alabaster Member*" was introduced which cover "Shales with Alabaster" of Eames (1952b) and "Baska shale" of Hemphil and Kidwai (1973). He introduced "*Marap conglomerate Member*" for conglomerate which is present in subordinate amount in the western

Sulaiman Range after the "Marap Formation" of the Hunting Survey Corporation (1961). However, Shah (1987, 1990) has published a revised-version of his stratigraphy in which he has replaced his Ghazij Formation with "*Ghazij Group*" which consists of the following four formations in ascending order: Shaheed Ghat, Drug, Toi and Baska Formations.

In this study, based on my detailed field mapping in three sections, it is very difficult to draw a boundary between the "*Shaheed Ghat*" Formation and "*Drug*" Formation of Shah (1990). Therefore, I has revised and redescribed the Shaheed Ghat Formation. In my concept of Shaheed Ghat Formation, it includes both the "*Shaheed Ghat*" Formation and the "*Drug*" Formation of Shah (1990). The lithology of the Shaheed Ghat Formation dominantly consists of green gray to olive green mudstone, gradually changes from siltstone to nodular siltstone to limestone from base to upwards. There is no vivid, sharp and distinct lithofacies change to divide it into two distinct formations as done by Shah (1990) as the Shaheed Ghat and Drug Formations. However, the Baska Formation is retained same as in Shah (1977). Hence, the "Gahzij Group" of Shah (1990) is here redefined. In this study, Ghazij Group consists of two formations: the Shaheed Ghat and the Baska Formations.

3.3.1 Shaheed Ghat Formation

General. The Shahid Ghat Formation was introduced by Shah (1987, 1990) which includes "Upper Rakhi Gaj shales" and "Green and Nodular Shales" of Eames (1952b), "Ghazij Formation" of Oldham (1890) and "Rakhi Gaj Shale

Member" of Jamiluddin et al., 1971. Shaheed Ghat (30° 24′ N; 70° 28′ E) is described as type section which is about 5km southwest of the Zinda Pir. The Shaheed Ghat Formation is dominantly composed of olive green, brown, chocolate and gray colored clays, with associated gypsum beds and fossiliferous to marly horizons. Subordinate limestone and argillaceous limestone beds occur frequently and irregular calcite veins are described as common in the middle part of the formation.

The thickness of Shaheed Ghat Formation is reported 689m at Shaheed Ghat and at Mughal Kot is 340m. The Shaheed Ghat Formation is reported conformably underlain by the Dunghan Formation and overlain by the Drug Formation. The age of this formation is described as Paleocene (Hunting Survey Corporation, 1961) to early Eocene (Eames, 1952a; Latif, 1964; Samanata, 1973; Warraich and Natori, 1997).

Rakhi Nala and Zinda Pir sections. In this study, the Shaheed Ghat Formation is adopted here to include also Drug Formation of Shah (1987, 1990). As discussed above, it looks difficult to distinguish between the two formations in the field. A gray-colored, hard, massive, brecciated to conglomeratic limestone weathering beige-brown ((Pl. 3, Fig. C; Pl. 4, Fig. A), caps the Dunghan Formation, is taken as the base of the Shaheed Ghat Formation. This limestone bed varies in thickness from about 1m in Rakhi Nala section to about 16m thick in the Zinda Pir western section. Shah (1977) has also included this limestone in his

Ghazij Formation that was previously defined as "Zinda Pir Limestone (upper part)" of Eames (1952b). This limestone is flooded with larger foraminifera (Pl. 4, Fig. B), and is quite persistent and looks like a wall against the overlying thick pile of soft mudstone sequence. In the Rakhi Nala section, It contains *Vasticardium*and *Chlamys* mollusca species (Pl. 4, Figs. C), identified by Dr. Kenshiro Ogasawra (personal contact).

The mudstone sequence of the Shaheed Ghat Formation is very well exposed and distributed in all three sections. It exhibits pale-greenish gray to dark gray to khaki-brown colored mudstone (Pl. 5, Figs. A, B). It changes into green colored nodular mudstone (Pl. 5, Fig. C) having mollusca and larger forminifera. Towards the top, the limestone occurs in nodular form (Pl. 7, Figs. C), some limestone beds are made of shell debries (Pl. 7, Figs. A, B). There are few thin beds of fossiliferous limestone in the lower and middle part of the formation. The nodular mudstone gradually changes into thin-bedded limestone intercalated with dark gray mudstone (Pl. 6, Figs. A, B) becoming dominant lithology upwards. Towards the top, thin to thick-bedded limestone intercalated with thin beds of gray mudstone becomes very abundant. Some limestone beds also exhibit trace fossils (Pl. 6, Fig. C)

The formation has conformable sharp contact with overlying Baska Formation (Pl. 8, Figs. A, B). It is measured 735m at Rakhi Nala and Zinda Pir western side, it is 623m thick. .

3.3.2 Baska Formation

General. The Baska Formation (Hemphil and Kidwai, 1973) is reported conformably overlies the Toi Formation in the Sulaiman Range and form the upper part of the Ghazij Group (Kazmi, 1995). The type locality is described about 2km northeast of the Baska Village (31° 29′ N; 70° 08′ E). The Bask Formation consists of green to gray shale and claystone, interbedded with alabaster, gypsiferous limestone and marl. The reported thickness of the formation ranges 160m in the north to 820m in the southern part of the Sulaiman Range. Based on the larger forminifera (*Lokhartia hunti, Dictyoconoides vredenburgi)* reported from it, the given age of the formation is early Eocene (Kazmi, 1995).

Rakhi Nala and Zinda Pir sections. The formation consists dominantly of mudstone with subordinate limestone and alabaster. The mudstone varies in color from dominantly green gray to chocolate brown to black brown (Pl. 8, Figs. A-C) and is intercalated with thin bedded, medium grained brown limestone. The limestone beds are thin to thick, sometimes arenaceous, and contain abundant larger foraminfers, gastropods and molluscs. Some limestone beds crowded with shells (shell bed) were also observed in the upper part of the formation (Pl. 7, Figs. A, B). The alabaster is gray-brown to black-brown (Pl. 9, Fig. A) that varies in thickness from a few centimeters to several meters. The uppermost bed of alabaster is 10m as observed both in the Rakhi Nala and Zinda Pir western section, however, the maximum thickness of the alabaster bed in the Zinda Pir eastern section is 2m. In all three sections, the Baska Formation is conformably

overlain by the Kirthar Formation. There occurred 2 to 5m green colored mudstone, exhibiting sulfur rusting on mudstone surface below the boundary.

3.4 Kirthar Formation

General. Blandford (1876) used the term "Kirthar" derived from Kirthar Range to describe the Eocene strata between his "Ranikot Group" and the "Nari" in western Sind. Later Noetling (1903) separated the lower as " Laki Series " and retained the name "Kirthar" for the upper unit only. Shah (1977) raised the "Kirthar" of Noetling (1903) to Kirthar Formation and included the "Spintangi Limestone" of Oldhalm (1890), "Brahui Limestone" and "Spintangi Limestone" of Hunting Survey Corporation (1961). Moreover, Shah (1977) has divided the Kirthar Formation into four easily recognizable units in parts of Sulaiman Province: Habib Rahi Limestone, Sirki, Pir Koh Limestne, and Drazinda Members. Although, Kazmi.,1995 have raised all these four members into four formation, I will apply the concept of Shah., 1977, as these members are not mapable as independent lithological units due to their thickness and contact nature. The lowermost member is named as *"Habib Rahi Limestone"* after "Habib Rahi Limestone" of Tainsh et al. (1959). The *"Habib Rahi Limestone Member"* is overlain by the "Sirki Shales" and "Lower Chocolate Clays" of Eames (1952b) described in Kohat area and Zinda Pir and Rakhi Nala sections respectively by him. The two units of Eames (1952b) which exhibit similar lithology are named as *"Sirki Member"*, after Sirki Paila of Kohat. The Sirki Member is overlain by "white marl band" of Eames (1952b) which is designated as *"Pir Koh Limestne Member"* after Pir Koh

(northwest of Dera Bugti). The *"Pir Koh Limestne Member"* overlain by "Drazinda Shale" of Hemphil and Kadwai (1973) represents the "passage beds", "Upper Chocolate Clays" and the "Pellatispira Beds" of Eames (1952b) and is named as "*Drazinda Member*".

The Gaj River Section (lat. 26° 56′ 10″ N; long. 67° 09′ 06″E) in the Kirthar Range has been designated as type section. The Spintangi George in western Sulaiman Range and Zinda Pir and Rakhi Nala areas are also proposed as principle reference sections.

The formation consists of interbedded series of limestone and shale with minor marl. The limestone is thick to massive bedded with light gray to cream in color weathering gray, brown or cream. The shale is calcareous, olive, orange yellow, gray, soft and earthy. The formation is widely distributed in the southern Indus Basin. At the type locality in the Gaj River Section, it is 1270m thick. In most of the areas, the formation transitionally overlies the Baska or Chitarwata Formation. The upper contact of the formation is mostly unconformable with overlying Chitarwata Formation.

The formation is richly fossiliferous and represents different ages in different areas ranging from the early Eocene to early Oligocene. In Zinda Pir and Rakhi Nala sections, it is reported to range from the middle to late Eocene (Latif, 1961; Samanta, 1973; Warraich and Natori, 1997). Both of its upper and lower boundaries are reported as time transgressive.

Rakhi Nala and Zinda Pir sections. The Kirthar Formation is excellently exposed with all of its four members in the Rakhi Nala area as well as along both limbs of the Zinda Pir Anticline as discussed below.

3.4.1 Habib Rahi Limestone Member

This member is pale gray to buff colored, platy and thin-bedded limestone weathers whitish yellow (Pl. 9, Fig. B). It contains nodules and thin partings of the black chert (Pl. 9, Fig. C) and marly material. The limestone gives feted smell on freshly broken surfaces. A limestone bed present at the base of this member produces abundant larger foraminifera (*Assilina*). The Habib Rahi Limestone Member is 80m thick in the Rakhi Nala section. The measured thickness of the member is 50m in the western side of the Zinda Pir Anticline whereas it is only 19m thick in the eastern side. In all three sections, this member conformably overlies the Baska Formation.

3.4.2 Sirki Member

This member consists of chocolate to reddish, yellow to green-brown claystone that is silty at certain horizons. A few thin beds of limestone having shell debries were also found. The basal part contains some strings of gypsum. The Sirki Member is 185m thick in the Rakhi Nala section. The thickness of this member varies from 222m in west to 90m in the east in Zinda Pir Anticline.

3.4.3 Pir Koh Limestone and Marl Member

This member consists of gray to chalky white to brown colored limestone interbedded with marl (Pl. 10, Figs. A, B). The limestone contains some thin partings of the black chert and succeeded by 15m green brown shales in the western limb of the Zinda Pir Anticline whereas it is only 6m thick on the eastern side. In the Rakhi Nala section, Pir Koh Limestone and Marl Member is 15m thick. This member looks like a cliff wedging out prominently from the above and blow low-lying claystone.

3.4.4 Drazinda Member

This member consists of brown, gray, green, chocolate claystone that is silty at some horizons. This member contains gastropods and molluscs. A few limestone beds flooded with foraminifera were also found interbedded. This claystone consists thick deposits which contain small gypsum sheets (Pl. 11, Figs. A). It also has some interbeds of marly limestone flooded with larger foraminifera (nummulites?) (Pl. 11, Figs. B, C). The Drazinda Member is 220m thick at Rakhi Nala section. Its measured thickness is 325m in the western side whereas it is about 135m on the eastern side of the Zinda Pir Anticline.

The upper contact of the Kirthar Formation is an unconformable and lies between "*Drazinda Member*" and overlying sandstone sequences of the Chitarwata Formation. A thin, dark brown to black colored hematitic pebbly bed occurs at the boundary with overlying sandstone of the Chitarwata Formation in the Zinda Pir section. In the Rakhi Nala section, varicolored conglomeratic, hematitic-bed rusting dark brown containing trace fossils with abundant hematitic

and pyritic material on the surface ((Pl. 12, Figs. A-C) marks one of the biggest unconformity of the basin.

3.5 Chitarwata Formation

General. The Paleogene sedimentary marine sequences are unconformably overlain by the Chitarwata Formation of Oligocene age that is composed of molass-type sediments. The type section for the Chitarwata Formation (Hemphill 1973, Eams1952b, Shah 1977, Kazmi 1995) is at Chitarwata Pass ((lat. 31° 03′ 10″ N; long. 70° 14′ 06″E).

Rakhi Nala and Zinda Pir sections. Well-exposed and huge deposits of the Chitarwata Formation that cover the marine Paleogene strata in all three sections. The contact with the underlying Kirthar Formation is reported unconformable (Pl. 12, Figs. A-C) throughout the Sulaiman Range (Cheema, 1977, Kazmi, 1995.