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Lithofacies of Bara Formation at Wadi Sawri Nala Section, Northern Laki Range, Southern Indus Basin, Pakistan

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Abstract: Detailed account of Bara formation Lithofacies is carried out at Wadi Sawri Nala Section (WSNS) on basis of physical characteristics such as color, texture, lithology, sedimentary structures and contact relationship. The two hundred eighty (280) meters thick Bara Formation at (WSNS) is conglomeratic sandstone, sandstone, siltstone, shale, and mudstone succession. In Bara Formation eight Lithofacies have been recognized, these are Conglomeratic sandstone facies (Gt), Fine to coarse grained trough cross bedded sandstone facies (St), Fine to very coarse grained planar cross-bedded sandstone facies (Sp), Ripple cross laminated sandstone facies (Sr), Fine to medium grained flat bedded sandstone facies (Sh), Parallel laminated siltstone and shale facies (Fl), Massive mudstone & shale facies (Fm), Carbonaceous shale facies(C). These lithofacies show recurrent fining upward cycles. The sedimentary structures identified in Bara Formation are planar and trough cross beds, asymmetrical ripple marks, planar laminations, fissile & carbonated shale and massive mudstone. The study of these structures indicate that Bara formation was deposited in fluvial depositional system.

Keywords: Lithofacies, Bara Formation. Fluvial Depositional Environment

1. INTRODUCTION

Lithofacies are rock units having characteristic features suggestion particular environment of depositions. The study of lithofacies have greater importance for the interpretation of depositional environment of sediments. For the detailed study of depositional processes, a sequence of sedimentary strata should be resolved and described first into distinct lithofacies (Nichols, 1999). Bara Formation (middle Paleocene) of Ranikot group has significant position in the stratigraphic column of Sindh, due to discovery of coal deposits at various places i.e. Lakhra, Sonda, Jherruk, Thar and Badin. It is well exposed in the northern part of Laki Range. Most of the studies of Bara Formation in past were directed towards the exploration and exploitation of coal, little has been contributed to lithofacies representation of this formation. The study area is accessible through Sann town, located at the main Indus High Way (N55), and then a link road from Sann town leads to Miri Kot in Ranikot Fort at about 40 Km to the west of Sann town. Then the studied section can be accessed at about two and half hours walk through a Nala in the north east of Mirikot. In past Bara Formation has been studied by many researchers, including Wnuk, *et. al.,* (1993), Abbas, *et. al.* (2005), Siddique (2008), Shah (2009), Hakro (2012), Hakro and Baig (2013) for its, coal resources, paleontology, stratigraphy, sedimentology, geochemistry and mineralogy. Bara Formation was named by Ahmed and Ghani (1971) for the "Lower Ranikot (sandstone)" of Vredenburg (1906) and "Lower Ranikot" of later workers. The section of Bara Formation is Bara Nai, Laki Range, in accordance with the Stratigraphic Code of Pakistan. The major focus of this research paper is to recognize, describe and interpret the lithofacies of Bara Formation at Wadi Sawri Nala Section which is located in the northern part of Laki range, district Jamshoro Sindh, Pakistan. Lying on the survey of Pakistan Toposheet No. 35 O/13, with coordinates, 250 55' 06''N, Latitude, and 670 55' 09''E, Longitude. **(Fig. 1)**

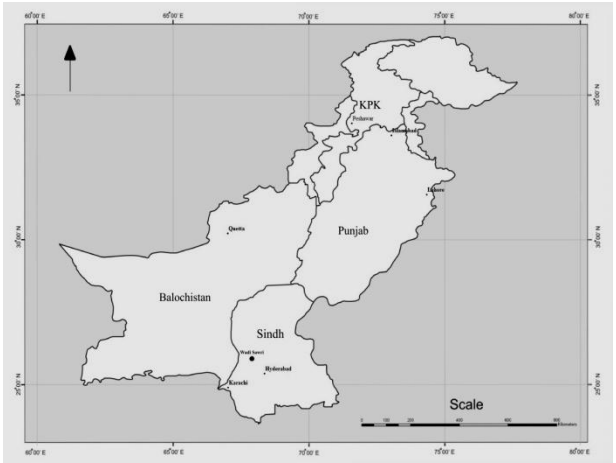

Fig. 1: Map showing the location of study area

2. GEOLOGICAL SETTING

Tectonically Pakistan is placed on the boundaries of three plates i.e. Indian, Eurasian and Arabian plates. According to Warwick *et. al.* (1998) and Clyde *et. al.* (2003), the collision of Indian and Eurasian

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plates took place during late Paleocene and the middle Eocene. The process of collision between two plates is on-going and anticlines parallel along the suture zone are outcome of this collision, (Farah and DeJong, 1979), Farah *et. al.* (1984) and Haq and Milliman (1984). The folding of some of the structures in southern Pakistan is attributed to collision between the Indian and Eurasian plates; among these structures is the Ranikot anticline which is part of Laki range. It is a north south trending asymmetrical anticline with steep eastern limb, dipping at 55^0 to 65^0 SE, whereas its western limb is gently dipping with 10^0 to 15^0 NW**.** The area under investigation is part of southern Indus basin with Indian shield in east, Jacobabad high in north, offshore in south and Kirthar folded range in the west**.** The stratigraphy of the study area comprises of oldest to youngest, Khadro Formation, Bara Formation, Laki Formation, and Manchhar Formation as shown in the **(Table - 1).**

Table – 1: Stratigraphy of the study area

Age	Formation	Lithology
Upper Miocene to Pliocene	Manchhar Formation	Sandstone, shale and conglomerate.
Disconformity		
Eocene	Laki Formation	Limestone, Sandstone and Shale
Disconformity		
Paleocene	Bara Formation	Sandstone, Siltstone and Shale.
	Khadro Formation	Sandstone and Shale with minor Limestone.

3. MATERIALS AND METHODS

Wadi Sawri Nala Section is selected for the current study because it is well exposed and tectonically least disturbed and presents maximum lithological characteristics. The measurement of the geological section was carried out with the Jacob's staff method and wherever applicable the layers were measured directly. During section measurement representative samples from each lithofacies were collected.

Bara Formation is two hundred and eighty (280) meters thick at Wadi Sawri Nala Section **(Fig. 4).** The lower conformable contact of Bara Formation with Khadro Formation at the core of Ranikot anticline was selected as beginning point for the measurement, and it was continuously measured up to its unconformable upper contact with Laki Formation. Detailed outcrop lithofacies analysis was performed. On the basis of physical characteristics such as color, texture, lithology, sedimentary structures and contact relationship, helping in the interpretation of environment of deposition. From every lithofacies a sample was collected.

4. RESULTS

By adopting partially the classification scheme of Miall (1985, 1996) present study has successfully recognized eight lithofacies in Bara Formation, which are described below:

4.1 Conglomeratic sandstone facies (Gt)

It exists at the base of each complete finning upward cycle. It is dark brown to black, medium to very coarse grained, angular to subangular in shape, contains pebble to gravel sized intraclasts. The grains are poorly sorted and mostly composed of quartz with moderate interstitial clay. It is friable but in parts contains ferruginous cement. It has poorly developed trough cross beds with stratified pebbles, generally filling the channelized erosive basal area. The basal part of the unit appears to be channel deposit. Clasts are intraformational clays ranging in size up to 1 cm in diameter, they are spheroidal, elliptical to tabular in shape. Clay clasts are lying parallel to the surfaces of the cross bed lamination, and geometrically it appears lenticular **(Fig. 1)**.

Fig, 1: Conglomeratic sandstone facies (Gt)

4.2 Fine to coarse grained trough cross bedded sandstone facies (St)

It is colorless, gray, brown to yellowish brown, fine to coarse grained, sub angular to sub rounded in shape with finning upward trend in grain size.. The grains are moderate to poorly sorted . It is mostly composed of quartz with some interstitial clayey and silty matrix, containing dark minerals. This lithofacies is poorly cemented, though at places it has ferrogenous cement. It contains high angle trough cross beds and at places the cross beds truncate one another at low angle. It contains intraformational clay clasts formed from reworked concretions; Numerous internal reactivation surfaces are visible within individual cross-bed sets; in places it has some carbonaceous and shaley laminations. This lithofacies exists as isolated or in group set. Geometrically it occurs as lenticular or wedge shaped body (**Fig. 2)**.

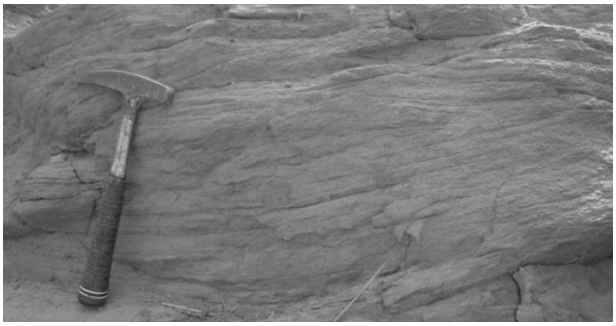

Fig. 2: Fine to coarse grained trough cross bedded sandstone facies (St)

4.3 Fine to very coarse grained planar cross-bedded sandstone facies (Sp)

It is colourless, yellow, light brown, fine to very coarse grained, sub angular to sub rounded in shape. It is poorly sorted. This lithofacies is dominantly composed of quartz with clayey and silty matrix. It is poorly cemented and is friable. It contains tabular cross beds, which are at low angle and truncate at low angle. Occasionally it also shows high angle tangential cross beds. Due to burrows, parts of the facies homogenized by bioturbation as shown in **(Fig. 3)**.

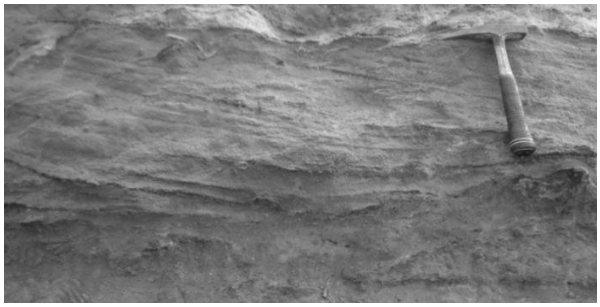

Fig. 3 Fine to very coarse grained planar cross-bedded sandstone facies (Sp)

4.4 Ripple cross laminated sandstone facies (Sr)

It is colourless, medium gray, yellowish brown, occasionally black, fine to medium grained, at places, it becomes silty and is inter laminated with thin siltstone and claystone layers. The grain are subangular to subrounded in shape and are predominantly well sorted. This facies is dominantly composed of quartz with little interstitial clay. It is poorly cemented and is friable but in parts, it contains calcareous cement. Moreover sparse mica flakes and rare dark minerals are also observed in the unit. It contains asymmetrical ripple marks, small scale sets of trough and planar cross stratification and occasionally small oscillation ripple marks are observed. It is partially to abundantly burrowed, and homogenized. Some petrified wood fragments and secondary gypsum have been observed in the unit **(Fig. 4)**.

Fig. 4: Ripple cross laminated sandstone facies (Sr)

4.5 Fine to medium grained with flat bedding sandstone facies (Sh)

It is maroon, gray to very light gray, red brown in colour, fine to medium grained. Some layers of this lithofacies become fine enough to grade into silty shale and shows dark gray siltstone laminations and clay bands. The grains are subangular to sub rounded in shape. Grains are poorly sorted but occasionally they become moderately sorted. The dominant mineral composition of this lithofacies is quartz with abundant interstitial clay. Few dark colour minerals and some mica flakes are also observed, though it is poorly cemented and is friable but it contains ferrogenous cement. Secondary gypsum, siderite nodules, numerous internal channel scours up to 1 m deep are observed in the unit **(Fig. 5)**.

Fig. 5: Fine to medium grained with flat bedding facies (Sh)

4.6 Parallel laminated siltstone and shale facies (Fl)

It consist of laminated siltstone and shale. It is variegated, light gray to gray brown, light pink, maroon. It is silty, grading into very fine grained sand and become extremely sandy. It is fissile and blocky, composed of quartz with clay mineral, containing dark minerals. It consists of planar laminated and in places the lamination sets truncate one another at low angle. This facies contains scattered carbonaceous debris on the bedding plane surface, **(Fig 6)**.

Fig. 6 Parallel laminated siltstone and shale facies (Fl)

4.7 Massive mudstone and shale facies (Fm)

It is gray, olive gray, yellowish brown in colour; in parts it becomes silty. It is fissile, blocky, massive, partly containing very fine grained quartz sand. It contains rare clayey nodules, rootlets, plant mega fossils. It contains carbonaceous debris on bedding planes and occasionally rounded ferruginous concretions are observed, **(Fig 7)**.

Fig. 7: Massive Mudstone and shale facies (Fm)

4.8 Carbonaceous shale facies (C)

It is black, dark gray, red brown in colour. It is extremely fissile, having low density, appears papery with abundant whole plant mega fossil remains, containing rootlets, at places it has sulfurous odor and contains abundant carbonaceous debris, **(Fig. 8)**.

Fig. 8: Carbonaceous shale facies (C)

5. DISCUSSION

Bara Formation at Wadi Sawri Nala Section consists of eight (8) main lithofacies (Gt, St, Sp, Sr, Sh, Fl, Fm, C). In the studied section the total thickness of Conglomeratic sandstone facies (Gt) is 8.7 meters accounting for the 3.1% of total thickness of the succession with 15 beds of variable thickness. This lithofacies contains poorly developed trough cross beds, poor grain sorting and very coarse grains, these characteristic features indicate fast deposition of sediment under high energy flow conditions and deposition in fluvial channels, as mentioned by Allen (1970), Miall (1988); Collinson (1996). It is interpreted that this lithofacies has deposited as channel lag deposit. Fine to coarse grained trough cross bedded sandstone facies (St) is 46.6 meters thick, constituting 16.6% of the studied succession, containing 20 beds of variable thickness. The presence of moderate to poor sorting and the occurrence of unimodal orientation of trough cross beds indicate that this lithofacies was part of fluvial bedfom, Collinson (1996); Miall (1996) and Eriksson *et. al.* (1998). It is interpreted that the migration of sinuous crested dunes in lower flow regime resulted in the development of this lithofacies, Casshyap (1970); Cant and Walker (1976); Miall (1996); Capuzzo and Wetzel (2004). The total thickness of fine to very coarse grained planar cross-bedded sandstone facies (Sp) is 23.5 meters with 10 beds of variable thickness and it occupies 8.4% of the Bara Formation in studied section. Depending upon the orientation of cross bedding and grain size, this lithofacies was formed in front of or on the lower flank of oblique bars in major channels or transverse bars of tributary channels. Besides the migration of straight crested dunes or bars has resulted in the formation of this lithofacies in lower flow fluvial conditions, Collinson (1996); Hjellbakk (1997) and Capuzzo and Wetzel (2004). The Ripple cross laminated sandstone facies (Sr) is 49.1 meters thick accounting 17.5% of the total thickness of Bara Formation with 16 beds. The asymmetrical current ripples along with cross lamination, indicate that it was produced by alternate subaqueous traction and suspension process of transportation, Miall (1996). This lithofacies documents sluggish deposition within inactive channels as fill deposits, Miall (1996). The Fine to medium grained with flat bedding facies (Sh) comprises 71.5 meters in thickness, making up the 25.5% of the total formation with 19 beds noted in studied section. As this lithofacies contain fine grained sand, which become fine enough to grade into silty shale, therefore, it indicates that the deposition has taken place at either bar top sand sheets or as in channel deposits during the vanishing stage of flood episode (Miall, 1996). Intercalation of horizontal sandstone beds with fine grained clastic rocks indicate rapid change in flood condition, where during high energy flow sandstone was deposited and during low

energy flow fine grained clastic sediments were deposited, Olsen (1988). The total thickness of Parallel laminated siltstone and shale facies (Fl) is 34.7 meters comprising 12.4% of the total thickness of Bara Formation with 21 beds noted in the section. During high energy fluvial conditions most of the heavy load is deposited first, whereas fine grained load is deposits during weak currents when energy diminishes. Extensive deposition caused by suspension on the upper parts of sandy bedform and across low relief abandoned flood plains is best indicated by the thin parallel laminations of siltstone and claystone. The Massive mudstone & shale facies (Fm) is 42.4 meters thick, containing 15.1 % of total thickness of Bara Formation with 20 beds identified in the field. This lithofacies being very fine grained deposited by extremely low energy fluvial conditions, indicating deposition from suspension in overbank setting. The deposition of interbedded fine grained sandstone and siltstone indicate the natural levee deposits that are the part of natural embankment of any stream channel. The total thickness of carbonaceous shale facies (C) is 4.1 meters with 6 beds in studied section of Bara Formation constituting 1.5% of the total thickness. It is interpreted that this lithofacies deposited in a peat bog, swamp or mire environment overbank.

6. CONCLUSION

1. Bara Formation at Wadi Sawri Nala Section consist of eight (8) principal lithofacies (Gt, St, Sp, Sr, Sh, Fl, Fm, C) each of which shows close relationship with fluvial depositional system.

2. These lithofacies occur in repeated fining upward cycles characteristics of fluvial depositional environment.

3. These lithofacies along with their characteristic texture and structure suggests deposition of Bara Formation in fluvial channels, migrating sinuous and straight crested dune and bars, inactive stream channels, sand-sheets at the fringes of streams channels, natural levees, flood plains and peat bog, swamp overbank environment

4. The lithology of Bara Formation is almost completely siliciclastic with scarcity of fossil and non-presence of marine fossils supporting the view of fluvial nature of Bara Formation sediments.

5. The presence of whole plant fossils indicate the environment was hot and humid suitable for the growth of well-developed plant of that time and an indication of subaerial exposure during sedimentation.

6. On the basis of lithofacies analysis it is concluded and proposed that Bara Formation deposited in fluvial depositional system.

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