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Sedimentological characterization of Bara Formation sandstone, BhitNala Section Laki Range Southern Indus Basin, Pakistan

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Abstract: Sedimentological characteristics of the Bara Formation sandstone which is exposed at BhitNala Section (BHNS), Laki Range, Lower Indus Basin are studied based on textural and petrographic attributes in order to determine depositional environment,provenance and tectonic setting. The Bara Formation of middle Paleocene is dominantly composed of sandstone along withsiltstone shale and carbonaceous shale.Statistical parameters (kurtosis, skewness, sorting, median and mean) calculated through sieve analysis suggest that the Bara Formation sandstone is medium to fine grained, moderately sorted, ranging in skewness from near symmetrical, positive to negative with very Leptokurtic, Leptokurtic and Mesocratic kurtosis. Based on textural parameters and discriminatory diagrams Bara Formation sediments deposited in fluvial to deltaic environment.The modal analysis data of 10 studied sandstone thin sections dominantly plot on cratoninterior along with few points plot at recycled orogen. Hence, it is inferred that the source of Bara Formation sediments isgranitic Indian craton occurring on the south east of study area with contribution from recycled detritus from post Bara Formations. Besides, Bara Formation sandstone is classified as ferruginous quartz arenite and quartz wacke

Keywords: Bara Formation, Grain Size Analysis, Petrography, Provenance, Depositional Environment.

1. INTRODUCTION

Sedimentological characterization through grain size analysis is useful tool for the identification of depositional environment and inference about various sedimentary processes. Friedman (1967), Tucker (1991) and Solangi (1992).26 friable sandstone samples of Bara Formation at BhitNala Section were selected for grain size analysis by using Folk (1968) procedure. Sandstone petrography is useful method in the search of origin and tectonic setting of prehistoric clastic deposits. The use of framework mineral composition for the determination of tectonic setting was initially proposed by Crook (1974), afterwards improved by Dickinson and Suczek (1979), Dickinson *et al.* (1983) Weltje (2002), Basu (2003). Certain tectonic setting produces specific composition, Dickinson and Suczek (1979), Dickinson *et al.,* (1983), Dickinson (1985), whichis used in present study to determine the corresponding tectonic setting.Bara Formation, exposed at BhitNala Section, is dominantly sandstone along withsiltstone, shale and carbonaceous shale strata. The southern indus basin contains good exposures of tertiary rocks. The Bara Formation part of Ranikot group(Shah,2009) is dominantly composed of sandstone which varies in colour, it is fine to coarse grained, occasionally very coarse grained, subangular to subrounded, moderate to poorly sorted, trough cross bedded, tabular cross bedded and ripple marked. Bara Formation shows repeated finning upward trends in grain size, characteristic of fluvial deposition environment, Hakro and Baig (2013and 2014). Its lower contact with Khadro Formation is conformable while upper contact with Laki Formation is unconformable. Middle Paleocene age is assigned to the Bara Formation (Shah, 2009).

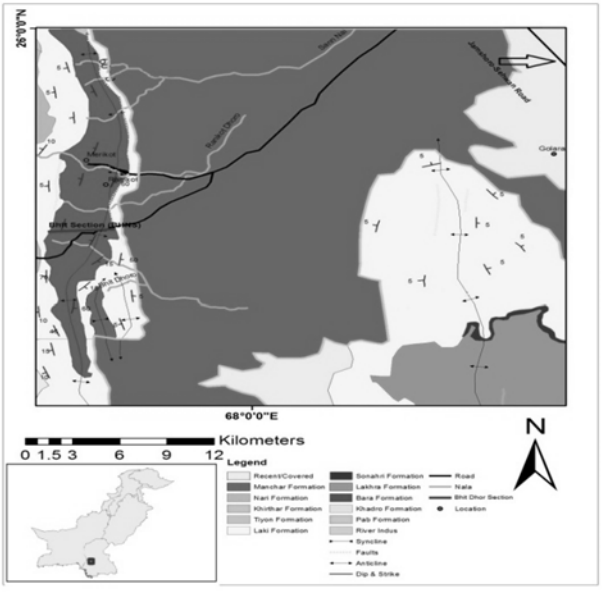

Fig.1 Geological Map of study area

The study section **(Fig. 1)** islocated 9 Km south of Ranikot fort which can be accessed by link road to the west of Indus highway from townSann on Toposheet No. 35 O/13, Survey of Pakistan with coordinates,

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(67°54' 00" E; 25° 49' 20" N). Numerous studies on Bara Formation have been carried out, e.g. Gingerich *et. al.,* (1979), Wnuk, *et. al.,* (1993), Abdullah *et al.* (1997), JaleelAsad (2002), Ahmed (2004), Abbas, *et. al.,* (2005), Baig *et al.* (2007), Siddique (2008), Shah (2009), Hakro (2012 and 2013), Khokhar *et. al.* (2014), Hakro and Khokhar (2015) overits various attributes.Present study, based on grains size analysis and petrography, will be useful contribution in understating the Bara Formation from source to sink.

2. MATERIAL AND METHODS

Bara Formation at BhitNala Section is 370 meters thick which is measured with tape and brunton compass method, Compton (1962). 57 rock samples from every litho facies of Bara Formation at BhitNala Section were collected out of them 26 friable sandstone samples were selected for sieve analysis and 10 samples were selected for thin section preparation and petrographic study. Grain size measurement scale proposed by Udden (1914), Wentworth (1922) and Friedman and Sanders (1978) was used.The grains size data was processed by adopting Folk's (1968) procedure. Sieving of rock samples was made on the stack of sieves of (-1 φ, 0φ, 1φ, 2φ, 3φ and 4φ) size, placed on Sieve shaker (Fritch Laborgeratebau).

The framework mineral composition of ten (10) Bara formation sandstone thin sections (Table 02) were determined by applying the point count method on petrographicmicroscope, Dickinson and Suczek(1979), Ingersoll *et al.* (1984). Minimum of 300 points were counted per thin section.

3. RESULTS AND DISCUSSION

3.1 Grain Size Analysis

Cumulative curves of friable sandstone samples from BhitNala Section were prepared by plotting grade size along x-axes and cumulative weight percent along y-axes on bivariate plot,Boggs (1987). The plotting of the data produces distinctive S-shaped curve. The cumulative frequency curves are used to calculate the statistical parameters **(Table 1and 2).** The results of statistical parameters of studied samples are correlated with standard statistical parameters chart, Folk (1966). The mean grain size of Bara Formation sediments ranges from fine (73%) to medium (27%), which is characteristic of deltaic to fluvial depositional environment. The sorting of the samples ranges from, moderately sorted (69%), poorly sorted (15%), moderately well sorted (12%) and well sorted (4%). The dominant moderate to poor sorting indicate simpersistent energy environment indicative of fluvial depositional environment. The studied sediments show variable values of skewness ranging from near symmetrical (46%), fine skewed (31%), strongly fine skewed (19%), and coarse symmetrical (4%). The dominantly symmetrical to fine skewness shows the lower reaches of stream to deltaic depositional environment. The kurtosis of the studied samples range from lepokurtic (46%), very lepokurtic (35%) and Mesokurtic (19%).Bivariate diagram based on statistical parameters are important indicators of environment analysis, Folk and Ward (1957), Friedman (1961, 1967), Moiola and Weiser (1968), Sahu (1964), Boggs (1987). In present study two bivariate discriminatory diagrams are adopted, Stewart (1958) interpretation diagrams by plotting sorting against median**(Fig. 2A)**and Friedman (1967) interpretation diagram by plotting skewness against the sorting **(Fig. 2B).**The outcome of the plotted data on these diagrams indicated that Bara Formation at BhitNala Section was deposited in fluvial to deltaic environment.

Table (1): Statistical Parameters of Bara Formation, at BhitNala Section (BHNS)

Sample No.	Mean	Median	Standard Deviation	Skewness	Kurtosis
BHNS- 1	2.08	2.09	0.912	0.069	1.156
BHNS- 3	2.52	2.6	0.998	-0.217	1.288
BHNS- 4	2.06	2.09	0.74	-0.02	0.906
BHNS- 6	2.28	2.1	1.052	0.277	1.032
BHNS- 8	1.38	1.4	0.902	0.131	1.393
BHNS- 9	2.5	2.5	0.781	-0.004	1.703
BHNS-10	2.65	2.59	0.831	0.051	1.535
BHNS-12	2.41	2.45	0.749	0	1.708
BHNS-15	2.4	2.4	0.919	0.354	1.076
BHNS-18	2.01	2	0.896	0.118	1.168
BHNS-20	1.53	1.51	0.748	0.137	1.784
BHNS-22	2.44	2.49	1.027	-0.064	1.409
BHNS-24	1.77	1.65	0.92	0.273	1.518
BHNS-28	2.64	2.41	0.7	0.402	1.302
BHNS-30	1.84	1.7	0.699	0.379	1.26

BHNS-31	2.46	2.48	0.628	0.053	1.639
BHNS-33	1.82	1.71	0.838	0.163	1.037
BHNS-34	2.57	2.56	1.05	-0.1	1.508
BHNS-36	2.18	2.24	0.837	0.013	1.178
BHNS-40	2.11	2.07	0.863	0.203	1.109
BHNS-42	1.91	1.62	0.909	0.558	1.748
BHNS-47	1.93	1.79	0.815	0.387	1.25
BHNS-48	2.5	2.5	0.78	0.033	1.66
BHNS-52	2.25	2.3	0.658	-0.063	0.997
BHNS-54	2.16	2.17	0.834	0.137	1.117
BHNS-58	2.81	2.7	1.037	0.023	1.267

Table (2):Point counted data of the Bara Formation Sandstone at BhitNala Section (BHNS)

Sample	Qm	Qp	Plag	K-Feldspar	Lithicks	Clays	Muscovite	Iron oxide cement	chert	Zircon	Calcite cement	Total
BHNS-1	268	5	2	5	15	66	3	19	0	2	0	385
BHNS-3	281	3	1	5	8	3	1	204	0	1	0	507
BHNS-6	270	13	2	4	6	7	3	31	0	2	105	443
BHNS-7	283	12	0	2	3	1	0	287	0	0	0	588
BHNS-9	259	7	3	12	12	62	2	6	0	5	6	374
BHNS-17	264	15	4	6	9	10	2	30	0	0	133	473
BHNS-18	223	10	2	22	37	27	3	24	0	3	0	351
BHNS-33	267	15	2	2	10	10	4	52	0	0	0	362
BHNS-55	275	11	4	6	2	14	0	52	0	2	84	450
BHNS-58	279	9	2	2	4	22	3	78	0	1	0	400

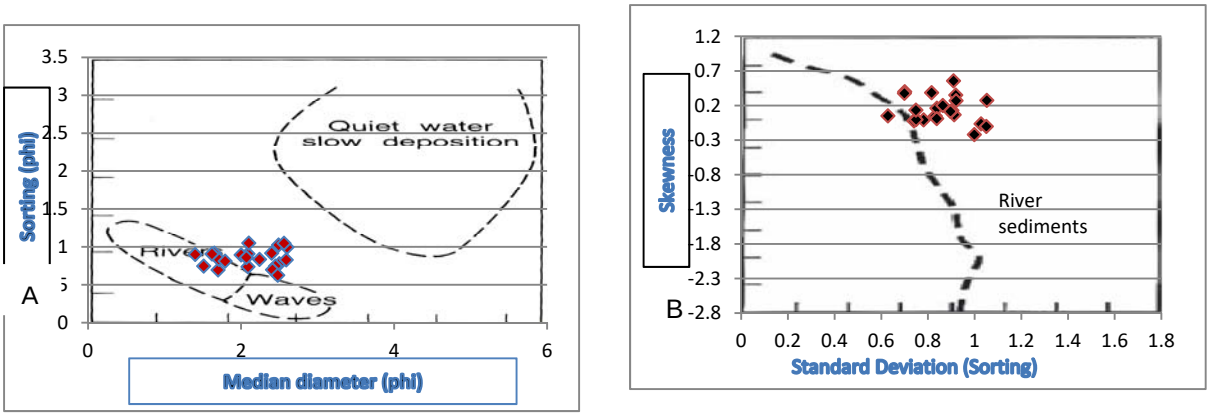

Fig.2: Interpretation diagram of Bara Formation at BhitNala Section. (A) Reproduced after Stewart 1958,(B) Reproduced after Friedman 1967

3.2 Petrography and Modal Analysis

Based on petrographic studies, Bara Formation sandstone is classified as ferruginous Quartz arenites and Wacke arenites by applying Dott-McBride scheme **(Fig. 3).**The major framework grain in studied thin sections is quartz; it is dominantly mono-crystalline, with undulatory and non-undulatory extinction **(Fig. 4).** Few quartz grains are polycrystalline with dominantly sutured contacts. Spot and needle shaped inclusions were observed in nonundulatory monocrystalline quartz potential indicator of plutonic source rocks. The feldspar is present in trace amount including few grains of microcline, and plagioclase feldspar. The feldspar is altered into clay mineral which isindicated by the presence of abundant amount of clay matrix. Few sedimentary lithic fragments were observed. The lack of feldspar and lithic components indicate that the source area hadsuffered lengthy and rigorous chemical weathering in hot and humid climate, Pettijohn *et al.*, (1987); Amireh (1991). The studied thin sections show abundant ferruginous cement along with calcareous cement surrounding the grains. Few grains of muscovite, biotite, zircon, epidote, and tourmaline are also observed. The presence of zircon and tourmaline

indicate igneous (plutonic) source rocks, Morton(1985); Morton *et al.,* (1992), Petrographic studies showed that sandstonesediments are derived from carton interior, Cassinis *et al.* (1979), Burnett and Quirk (2001) and deposited on a passive margin, Emilia and Arribas (2004). Indian craton rocks laying in the south east of study section are potential source rocks of Bara Formation. The framework mineral composition is used to infer the tectonic setting of the Bara Formation, Crook (1974),Dickinson and Suczek (1979), Dickinson *et al.,* (1983). Plotting the modal analysis data on the ternary QFL and QmFLt diagrams of Dickinson *et al.* (1983), indicated dominance of craton interior along with the recycled orogen setting **(Fig. 4).**

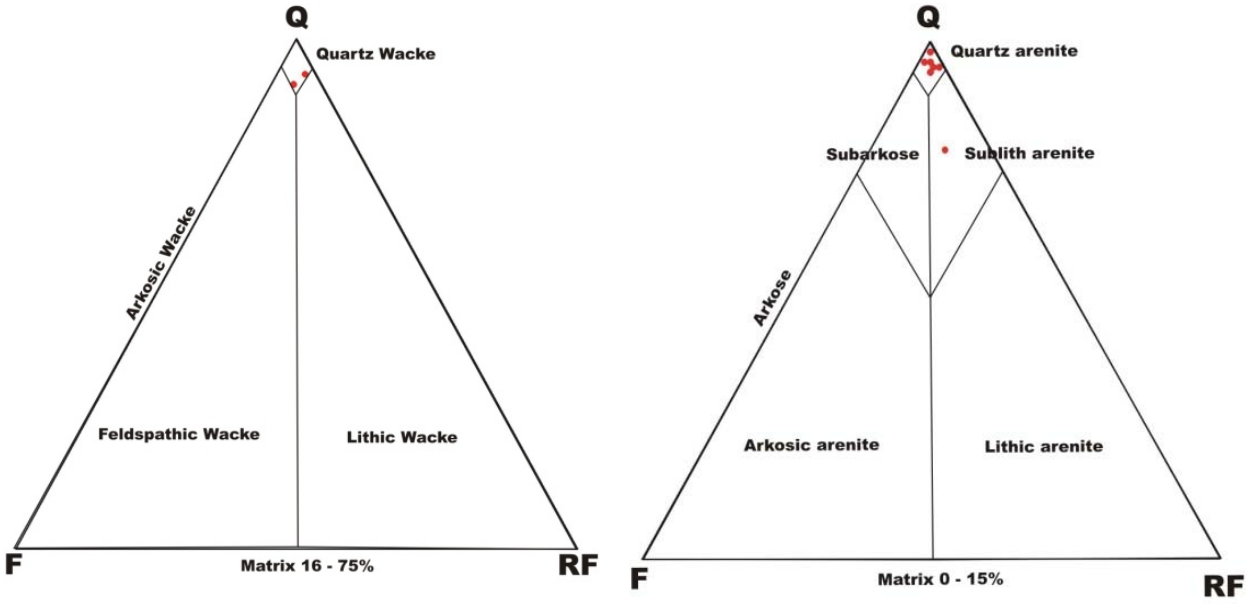

Fig. 3: QFL triangular diagram shows the classification of the Bara Formation sandstones

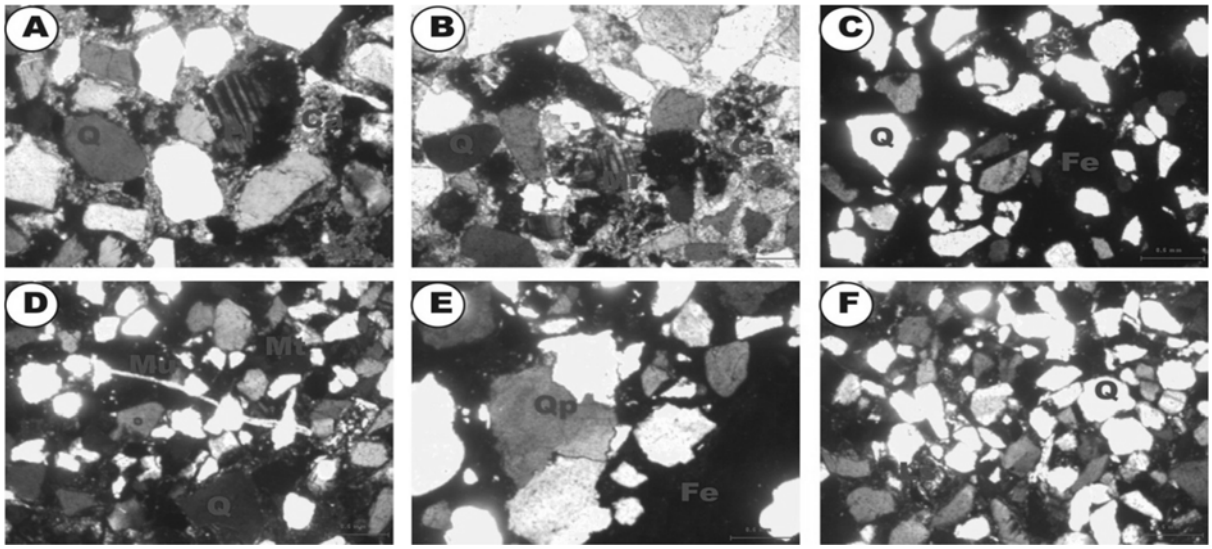

Fig. 4: (A) Photomicrograph showing quartz arenite, consist dominantly of monocrystalline quartz (Q) with few grains of plagioclase feldspar (Pl). (B) Medium to coarse, angular quartz grains surrounded my calcareous cement (Ca) and few grains of Microcline (Mi). (C) Angular Quartz grains floating into ferruginous cement (Fe) along with few sedimentary lithic (Ls) fragments. (D) Fine to medium subangular to subrounded quartz grains with point to concavo-convex contact along with Muscovite (Mu). (E) Polycrystalline quartz grain (Qp). (F) fine to very fine subangular to subrounded moderately sorted quartzarenite.

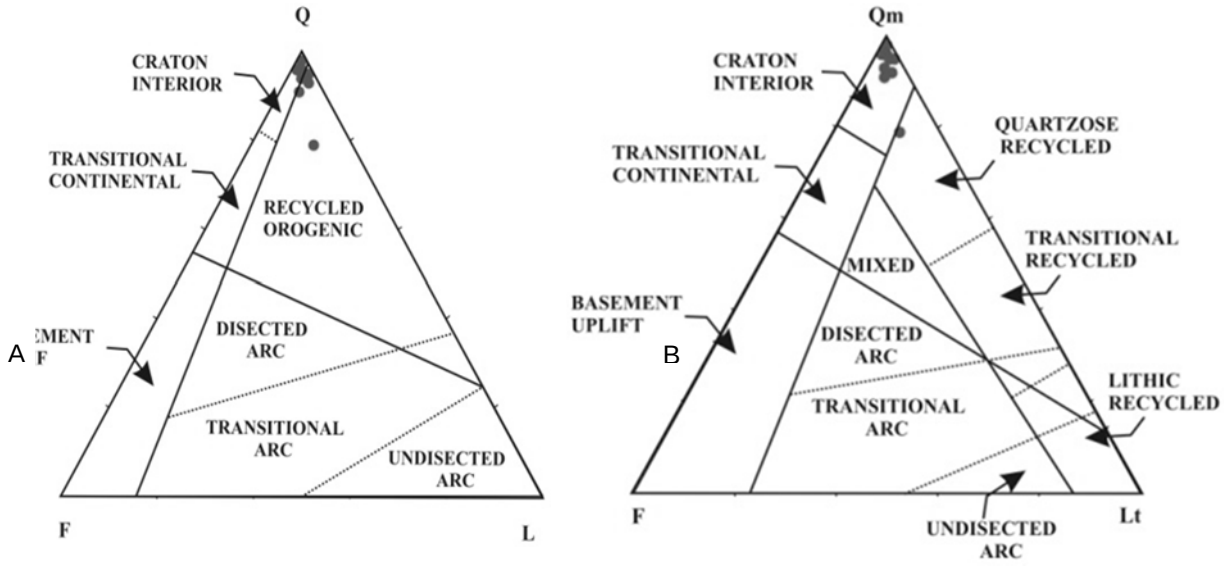

Fig. 5: (A) QFL and (B) QmFLt ternary diagrams of Bara Formation sandstone at BhitNala Section (after Dickson *et al.*, 1983).

4. CONCLUSION

The detailed analysis of sedimentological characteristics of Bara Formation indicated dominantly fine to medium grained, with varying proportion of poor, moderate to well sorted sediments along with the variable skewness. It suggests fluvial to deltaic depositional environment. The discriminatory diagrams, of Stewart (1958) and Friedman (1967) complement the fluvial to deltaic nature of Bara Formation sediments. Bara Formation sandstone is dominantly ferruginous quartz arenite, which is mineralogically mature sandstone ($Q_{94}F_3L_3$). Subangular to subrounded, poorly sorted, and loose compaction of grains suggestthe close proximity to source rock. The presence of nonundulatorymonocrystalline quartz, detrital grains of microcline and orthoclase, epidote inclusion and tourmaline indicate granitic source of Bara Formation sediments. The plotting of modal analysis data on QFT and QmFLt discriminatory diagrams suggested the cratonic interior to recycled orogen tectonic setting. The abundance of quartz and lack of lithic fragments and feldspars suggest possible derivation from relatively low lying granitoid source (Indian craton) along with the influx of sediments from recycled sands from associated platform or passive margin basins.

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