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Textural Characterization of Middle Paleocene Sediments from Thar Coalfield Southern Indus Basin Pakistan

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Abstract: The primary objective of the current research was to study the depositional environment of the Bara Formation of the Southern Indus Basin. The present study shows a detailed grain-size analysis of seventy (70) sandstone samples (Core samples from 20 boreholes) from Bara Formation, Thar Coalfield, Southern Indus Basin, Pakistan. The textural analysis shows that most sandstone samples were medium grain size with coarse-grained as a sub-ordinate, and a small amount of fine-grain was associated with minor fractions. The sediments were moderate to poorly sorted, fine skewed to near-symmetrical, and leptokurtic to mesokurtics. They were deposited under fluctuating energy conditions with a fluvial depositional environment predominant. Bivariate graphs indicate that the fluvial/river process was dominant over the deltaic process in (Middle Paleocene) Bara Formation. Passega (C-M) graph specifies that the sediments of Bara Formation transported as bed load and suspension under the current depositional setting. The linear discriminate function (LDF) analysis shows a fluvial-deltaic depositional environment.

Keywords: Middle Paleocene, Bara Formation, Thar Coalfield, Grain size parameters, Southern Indus Basin.

1. INTRODUCTION

Sedimentary rocks contain important information of their sources and hydrologic condition of associated sedimentary basins. The composition, texture, sorting, and grain size of the siliciclastic sedimentary rocks are the fundamental indicators of sedimentary environments. The grain size analysis technique has widely been used to reflect sedimentary rocks' textural properties and depositional settings (Baiyegunhi *et al.*, 2017; Edwards, 2001).The grain size parameters are used to evaluate sedimentary basins' transportation mechanism and depositional environment (Blott *et al.*, 2001). Particle size distribution is essential characteristics features of sediment for the reason that clast sizes of certain sediments indicate their hydrodynamic conditions and transportation history (Baiyegunhi *et al.*, 2020; Blott *et al.*, 2001; Samtio *et al.*, 2020).Therefore, textural analysis indicates significant signatures of transportation media and depositional setting (Baiyegunhi, *et al.*, 2017; Samtio *et al.*, 2021). Western Indus Basin was traditionally proposed as a foreland basin **(Fig.1a)** in response to a collision between the Indian and Asia continents (34-70 Ma). However, both plates remain significantly argued about the collision timing (Hakro *et al.*, 2017). The Southern Indus Basin of Pakistan is dominated by a tertiary sedimentary sequence **(Fig.1a).** The Middle Paleocene's depositional environment will help to understand the tectonic setting of the western margin of the Indus Basin, Pakistan.

Thar Coalfield is more extensively explored from the coal and hydrogeological exploration point of view. But very little has been contributed to sedimentological and geochemical aspects. In this study, we present our detailed fieldwork and new data of grain size analysis of sandstone samples from the Middle Paleocene Bara Formation of the Southern Indus Basin **(Fig.1c)**. In combination with previous results, the depositional processes and setting of the Bara Formation are then discussed based on the textural parameters i.e., mean, sorting, skewness, and kurtosis of sediments.

Geology of the area

The surface geology of Thar Desert comprises dunes in the study area and exposure of Precambrian rocks of igneous and metamorphic origin known as Nagarparkar igneous complex (NPIC), and it is the northern expansion of Indian craton **(Fig.1c).** The district Tharparkar is affluent in natural resources such as, granite, coal, salts, and China clay, but the groundwater is saline. The various exploration studies specify four geological units, **(Fig.2a-b)** present in the Tharparkar area: dune, sub-recent (alluvial deposits),

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Bara Formation of Paleocene, and Igneous rocks of Precambrian age.

Dune Sand consists of sand deposits. The lithological unit contains clay and silt inter bedded with sand. The shallow aquifer occurs at the contact between the base of the Quaternary dune sands and on the Sub-Recent deposits' upper surface and is recharge from monsoon **(Fig. 2a and b).** This groundwater unit is tapped by dug wells and is utilized as a freshwater resource by local populations. Sub-recent Deposits consist of sandstone, siltstone, claystone with slightly to moderate oxidation. Near the contact of the underlying coal zone, sub-recent deposits consist of kaolinitic sandstone beds. Bara Formation consists of carbonaceous claystone, sandstone, coal beds, and sand. Sideritic bands, and granite wash intercalations are present at places. The contact depth of the Bara Formation ranges from 115meter to 230meter. The cumulative thickness of coal seams ranges from 0.5 to 42meter. The basement complex is weathered granite, coarse-grained with alteration of feldspars to kaolin and mafic particles. A basic dyke of doleritic composition has been logged in a drill hole.

Many studies have been conducted by various researchers at different exposures of Bara Formation (Farshori, 1972; Hakro, A.A.D., and Baig, 2013; Shah, 2009; Siddiqui and Shah, 2007) for mapping, Stratigraphic aspects, coal exploration, sedimentology, geochemistry, and mineralogical characteristic. Many researchers have even studied the sub-surface sediments of the Bara Formation in the Thar Coalfield. Mineralogical study (Bulk and Clay mineral composition) was carried out for depositional setting of Bara Formation at Thar Coalfield (Abdallah *et al.,* 1997; Baig, M. A. A and Mujeeb, 2007; Hakro, A.A.A.D. *et al.,* 2015). The spatial variation of sulfur concentration in the middle Paleocene coal deposits of Sindh was studied (Baqri, 1997). A detailed study of coal macerals and palynology was carried out for the depositional setting of the Bara Formation(Ahmad, 2004; Kumar, 2012). Previously Bara Formation at Thar Coal Basin was widely explored for coal and hydrological investigation, but few contributions to sedimentary hydrodynamics have been known.

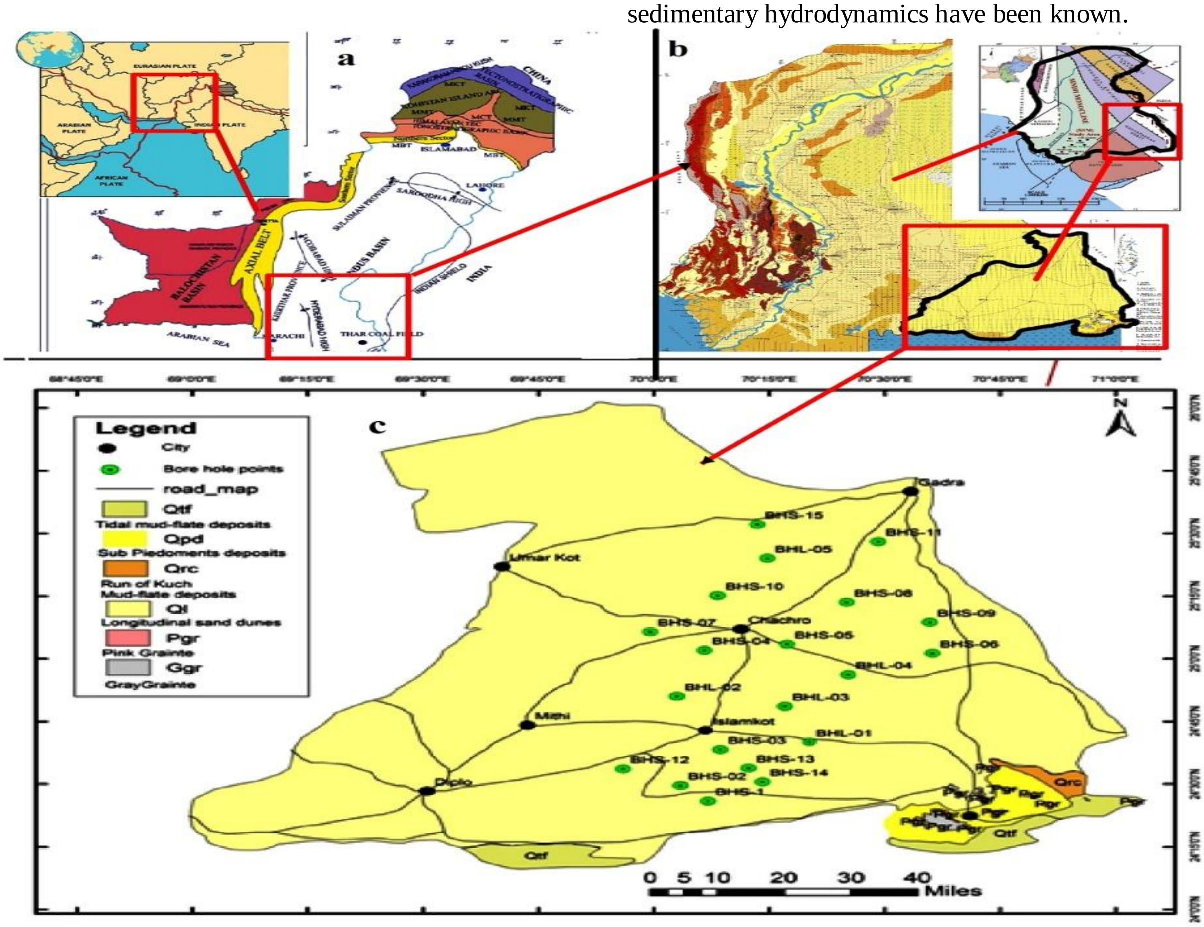

Fig. 1 (a) shows the location of the study area with respect to the Indian Plate and Sedimentary basin of Pakistan, (b) Location of study are with respect to Geology of Sindh, C) Geology of the study area marked with sample locations.

2. MATERIALS AND METHODS

Twenty borehole lactations in Thar Coalfield **(Fig.1c)** were selected for the sample collection. Seventy (70) unconsolidated representative samples were collected from these borehole locations for textural analysis. (Folk and Ward, 1957) was followed for a standard sieving method to classify clast sizes into various classes. The individual unconsolidated sediments were crumbled, and from each sample, 100 gram was used for the textural analysis. On a white paper sheet from each sample, a 100gram amount was disintegrated into individual grains gradually and carefully with hands and fingers. Each unconsolidated sample was mixed by picking corners of papers. The standard sieve stack of -2, -1, 0, 1, 2, 3, and 4 phi was utilized for Clasts size analysis. An electrically powered vibrator machine vibrated the stack of mesh sizes for about the recommended time of vibration to properly separate each class of clast size. The Clast size analysis was completed with an electrical vibrator (digital octagon machine) at the Geology Department, University of Sindh, Jamshoro. The particle size in millimeter(mm) transferred into phi (Krumbein) measurement scale(Krumbein, 1934).

$\emptyset = -\log_2 D$,

Here ∅ represent phi scale, and D represents grain's dia in mm.

Frequency and cumulative frequency curves were drawn based on wt% and cumulative wt%, which effectively calculate textural grain size parameters **(Fig. 3a and b).** From **Figure 3c**, selected percentile (5,16,25,50,75,84 and 95) percentile values noted down from the point where the line of these percentile values cross with the cumulative frequency curve **(Fig.3c)**. These frequency curves were also utilized to compute various grain size variables recommended by (Sahu, 1964). The drawing of a two-component scatter plot in which statistical parameters are plotted against one another was suggested by (Friedman, 1967). Various interpretation diagrams have been used to recognize the Bara Formation sandstone's depositional environment. Linear discriminate function (Sahu, 1964) was used to understand and differentiate the depositional environment. C-M plot (Passega, 1964) was used to realize distinct depositional mechanisms, sedimentation, and the transport medium's energy level.

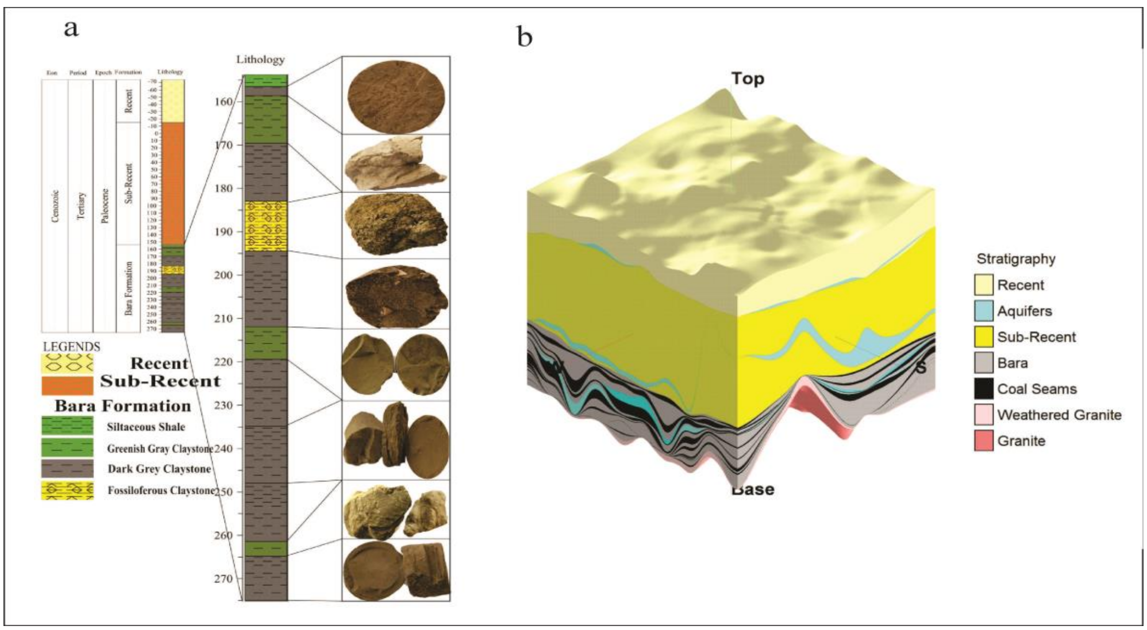

Fig. 2. a) Shows the general litho log of borehole and b) shows the 3D geological model of Thar Coalfield.

3. RESULTSAND DISCUSSION

Statistics of Grain sizes parameters

Frequency and cumulative frequency curves of unconsolidated and friable sandstone sample from Bara Formation at Thar Coalfield formulated in **(Fig.3a and b).** The frequency curves infer that most samples were uni-modal, with peaks ranging from 1 to 3phi. Thus, the Unimodality of the Bara Formation unconsolidated sediments specify the controlled environment of the depositional mechanism.

Particle size Statistical Parameters

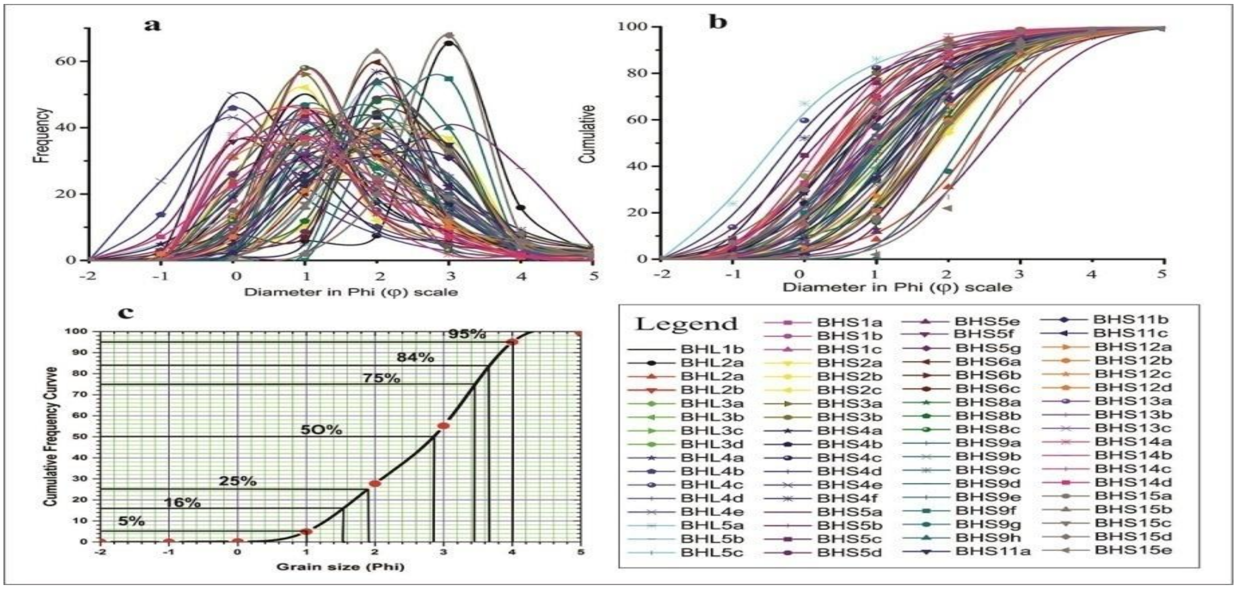

Fig. 3(a) Frequency (b) Cumulative frequency curves for (70) samples showing the particle size trends of studied samples from the Bara Formation, Thar Coalfield (C) represents the procedure of calculating the percentile values.

Particle-size parameters, i.e., Graphic mean, Sorting, Graphic Skewness, and Graphic Kurtosis, computed from percentile values using mathematical expression as proposed (Folk and Ward, 1957) **(Table 1).** Statistical parameters were utilized to point out variation in the clast-size characterization of sandstone and listed in **(Table 2)** and standard values of statistical parameters are present in Table 2.

Interpretation by Graphic mean (Mz)

Mzis an essential statistical factor that specifies general grain size, denoted by Mz (phi) sizes, and implies the index of energy conditions (Passega, 1964). Mz value ranges -0.28φ to 2.55φ. Results indicated sixty percent (60%) medium sand, (33%) coarse sand, (06%) fine sand, and one percent (01%) samples were very fine sand **(Fig.4a and 5b)**. The majority of medium grain sediments with subordinate coarse-grained sediments indicated moderately high energy conditions (Boggs, 2009).

Interpretation by Graphic skewness (SKI)

Skewness result varies b/w -0.16 to 0.42φ (nearly symmetrical to fine skewed). The skewness result indicated (47%) near-symmetrical, (05%) coarse skewed, (44%) fine skewed, (4%) strongly fine skewed One percent (01%) sample from the Bara Formation was placed in the excellent skewed boundary **(Fig.5a, 7a, and 8a)** and revealed the variable energy conditions during which sediments were deposited.

Interpretation by Standard Deviation

Inclusive standard deviation or sorting of unconsolidated sediments varies between 0.67 to 1.45phi. Sorting or standard deviation results indicated that fifty seven percent (57%) poorly sorted, thirty-three percent (33%) were moderately sorted, and three percent (03%) samples were moderately well sorted **(Fig.7a.).** Sediment's moderately well-sorted characteristics are common because of fractional winnowing action (Baiyegunhi *et al.*, 2017).

Interpretation by Graphic kurtosis (KG)

Kurtosis results of sediments vary from 0.75 to 1.84φ. Kurtosis result reveals that (4%) very leptokurtic, (30%) leptokurtic, (17%) platykurtic, and (49%) mesokurtic **(Fig.4a and 8a).** The differences in kurtosis amount are caused by fluctuations in flow characteristics of the medium (Hanamgond and Chavadi, 1998). Fine sand-sized platykurtic-mesokurtic clast and clast roundness influence attributed to sand maturity. This can be a characteristic feature of fine sand in a main marine depositional setting (Ramanathan *et al.*, 2009). Lower KG values and moderately to poorly sorted sediments could be attributed to some of the unconsolidated sediments acquiring their sorting in a high energy depositional setting.

Interpretation by discriminate diagrams

The statistical parameters, i.e., Graphic mean (Mz), Graphic Kurtosis (KG), Inclusive Standard Deviation or Sorting, Graphic Skewness (SKI), reveals the energy variation of transporting and depositional medium. Furthermore, the particle size distribution indicates that the energy conditions of media prevail. The matching of numerous textural components by producing interpretation diagrams have been utilized to discriminate deposition environment (Friedman, 1967).

Scatter plots were constructed to assume that grain size parameters suggest variation during hydrodynamic of unconsolidated sediments (Sutherl and Lee, 1994). To discriminate between depositional settings, SKI and KG were the best statistical parameters proposed by many geoscientists.

Mean (Mz) versus kurtosis (KG)

The Bivariate graph KG vs Mz indicates that Bara sediments were Platykurtic to Very leptokurtic **(Fig.4a).** Mesokurtic (0.90φ-1.11φ) category dominants followed through platykurtic (0.67φ-0.90φ) and leptokurtic (1.11φ-1.5φ) respectively. The mean versus kurtosis plot indicates the dispersion of samples close to the base in and around the standard Kg curve (mesokurtic category) area (Folk and Ward, 1957) **(Fig.4b).** It could be inferred from the model plot **(Fig.4b)** that the distribution of particle sizes leads to intermixing of clast size classes, which affected sorting of unconsolidated sediments at peak and tail in the frequency curves. The variable proportion of coarse grain unconsolidated sediments blended with the leading medium sand grain mode reduces the sorting degree, especially in the tails of frequency curves.

Mean (Mz) versus skewness (SKI)

Bivariate SKI against Mz plots reveals that most of the Bara sediments were medium to coarse grain and nearly symmetrical to fine skewed **(Fig.5a).** However, three (03) samples clustered in strongly fine skewed and coarse skewed region, respectively, and samples no 14 and 3, 32, 50, 70 were clustered in coarse and fine sand class **(Fig.5a)** (background graph of (Moila and Weiser 1968) reveals that the inland dune was dominant over the beach sand. The model plot indicates a clustering of values close to the defined pattern's sinusoidal curve as suggested (Folk and Ward, 1957), which also shows a narrower grain size variety **(Fig.5b).** The sediments studied' sinusoidal nature is due to the deposit's two size classes being proportionately mixed, i.e., medium sand and coarse sand. The unimodal sediments are generally almost symmetrical, but perhaps the mixing generates whether positively or negatively skewness probably depends on the size-class proportions in the admixture.

Table.1. Formula for calculations of statistical parameters.

Statistical Parameter	Formula (after Folk, 1968)
Graphic Mean	Mz= (16φ+ 50φ+ 84φ)/3
Median	(MD = 50φ)
Standard Deviation	SD = (84φ-16φ)/4+ (95φ-5φ)/6.6
Graphic Skewness	SKI= 84φ+ 16φ -2(50φ)/2(84φ-16φ)+ 95φ + 5φ -2 (50φ)/ 2(95φ-5φ)
Graphic Kurtosis	KG = (95φ - 5φ) (75φ - 25φ)/2.44

Table 2. Summary of Grain size parameters i.e. Mean(Mz), Median(MD), Sorting(SD), Skewness(SKI), Kurtosis(KG)

S. No	Sample Name	MD	Mz	Verbal limits	SD	Verbal Limit	SKI	Verbal Limits	KG	Verbal Limits
1	BHL-1a	0.93	1.1	MS	0.97	MS	0.23	FS	0.96	MK
2	BHL-1b	0.68	0.81	CS	1.04	PS	0.225	FS	1.23	LK
3	BHL-2a	2.52	2.56	FS	0.81	MS	-0.067	NS	1.84	VLK
4	BHL-2b	0.40	0.47	CS	1.01	PS	0.15	FS	1.19	MK
5	BHL-3a	0.60	0.68	CS	1.23	PS	0.16	FS	0.84	PK
6	BHL-3b	1.33	1.35	MS	1.2	PS	0.046	NS	1.1	MK
7	BHL-3c	1.12	1.14	MS	1.002	PS	0.07	NS	1.04	MK
8	BHL-3d	1.03	1.1	MS	1.07	PS	0.133	FS	1.07	MK
9	BHL-4a	0.97	1.17	MS	1.45	PS	0.234	FS	0.98	MK
10	BHL-4b	1.36	1.41	MS	1.1	PS	0.13	FS	1.08	MK
11	BHL-4c	-0.21	0.027	CS	1.18	PS	0.32	SFS	1.20	LK
12	BHL-4d	0.58	0.76	CS	1.24	PS	0.27	FS	1.10	MK
13	BHL-4e	0.96	1	CS	1.21	PS	0.06	NS	0.91	MK
14	BHL-5a	-0.4	-0.28	VCS	1.18	PS	0.24	FS	1.18	LK
15	BHL-5b	1.45	1.5	MS	0.93	MS	0.104	FS	1.35	LK
16	BHL-5c	1.04	1.06	MS	1.27	PS	-0.01	NS	0.98	MK
17	BHS-1a	-0.07	0.14	CS	1.06	PS	0.42	SFS	1.13	LK
18	BHS-1b	0.9	1.01	MS	1.3	PS	0.15	FS	0.94	MK
19	BHS-1c	0.7	0.73	CS	0.89	MS	0.01	NS	0.92	MK
20	BHS-2a	1.13	1.22	MS	0.9	MS	0.18	FS	0.86	PK
21	BHS-2b	1.83	1.71	MS	1.13	PS	-0.11	CS	0.93	MK

22	BHS-2c	1.85	1.88	MS	1.04	PS	0.012	NS	1.2	LK
23	BHS-3a	0.5	0.56	CS	1.02	PS	0.18	FS	1.49	LK
24	BHS-3b	0.48	0.46	CS	0.85	MS	0.043	NS	1.38	LK
25	BHS-4a	1.79	1.84	MS	0.87	MS	0.06	NS	1.02	MK
26	BHS-4b	0.53	0.64	CS	1.15	PS	0.18	FS	1.23	LK
27	BHS-4c	1.32	1.34	MS	0.901	MS	0.08	NS	0.95	MK
28	BHS-4d	1.12	1.21	MS	1.27	PS	0.134	FS	1.12	LK
29	BHS-4e	1.12	1.15	MS	1.003	PS	0.03	NS	1.08	MK
30	BHS-4f	-0.07	0.14	CS	1.06	PS	0.42	SFS	1.13	LK
31	BHS-5a	1.8	1.95	MS	0.92	MS	0.29	FS	1.1	MK
32	BHS-5b	2.53	2.55	FS	0.96	MS	0	NS	0.89	PK
33	BHS-5c	0.8	0.53	CS	1.29	PS	-0.16	CS	1.26	LK
34	BHS-5d	0.85	0.95	CS	0.995	MS	0.15	FS	1.14	LK
35	BHS-5e	1.8	1.87	MS	0.75	MS	0.13	FS	0.83	PK
36	BHS-5f	1.6	1.71	MS	0.904	MS	0.17	FS	1.24	LK
37	BHS-5g	0.95	0.96	CS	1.03	PS	-0.002	NS	1.06	MK
38	BHS-6a	0.65	0.76	CS	1.24	PS	0.15	FS	0.86	PK
39	BHS-6b	1.48	1.47	MS	0.86	MS	0.07	NS	1.52	VLK
40	BHS-6c	1.44	1.49	MS	1.28	PS	0.08	NS	1.05	MK
41	BHS-8a	1.73	1.79	MS	1.005	PS	-0.074	NS	1.27	LK
42	BHS-8b	1.5	1.48	MS	1.17	PS	-0.01	NS	0.96	MK
43	BHS-8c	1.7p	1.77	MS	0.82	MS	-0.01	NS	1.02	MK
44	BHS-9a	0.63	0.76	CS	0.77	MS	0.16	FS	1.16	LK
45	BHS-9b	1.05	1.22	MS	1.2	PS	0.25	FS	1.12	LK
46	BHS-9c	1	1.2	MS	1.16	PS	0.27	FS	1.07	MK
47	BHS-9d	1.6	1.6	MS	0.97	MS	0.043	NS	1.05	MK
48	BHS-9e	1.3	1.26	MS	0.96	MS	0.123	FS	1.21	LK
49	BHS-9f	0.8	1.04	MS	1.31	PS	0.272	FS	0.97	MK
50	BHS-9g	2.2	2.16	FS	0.72	MS	0.01	NS	1	MK
51	BHS-9h	1.02	1.22	MS	0.94	MS	0.31	SFS	0.803	PK
52	BHS-11a	1.9	1.94	MS	0.67	MWS	0.099	NS	0.75	PK
53	BHS-11b	1.61	1.55	MS	1.06	PS	-0.14	CS	0.83	PK
54	BHS-11c	1.7	1.67	MS	1.11	PS	0.028	NS	0.89	PK
55	BHS-12a	1.58	1.63	MS	1.15	PS	0.12	FS	0.99	MK
56	BHS-12b	1.75	1.76	MS	0.98	MS	0.044	NS	1	MK
57	BHS-12c	0.50	0.58	CS	1.15	PS	0.16	FS	0.96	MK
58	BHS-12d	1	1.12	MS	1.23	PS	0.20	FS	1.18	LK
59	BHS-13a	0.95	1.04	MS	0.93	MS	0.17	FS	0.98	MK
60	BHS-13b	1.2	1.27	MS	1.08	PS	0.056	NS	0.99	MK
61	BHS-13c	1.5	1.51	MS	1	MS	0.021	NS	0.825	PK
62	BHS-14a	0.43	0.48	CS	0.93	MS	0.09	FS	0.94	MK
63	BHS-14b	0.25	0.25	CS	0.84	MS	0.09	NS	0.93	MK
64	BHS-14c	0.7	0.87	CS	0.885	MS	0.29	FS	1.16	LK
65	BHS-14e	0.48	0.56	CS	1.1	PS	0.17	FS	0.95	MK
66	BHS-15a	0.62	0.54	CS	1.15	PS	-0.06	NS	1.04	MK
67	BHS-15b	1	1.17	MS	1.19	PS	0.16	FS	0.90	MK
68	BHS-15c	1.53	1.62	MS	0.81	MS	0.21	FS	1.51	VLK
69	BHS-15e	1.80	1.84	MS	0.96	MS	0.073	NS	1.10	MK
70	BHS-15f	2.42	2.35	FS	0.69	MWS	-0.088	NS	1.39	LK

Note: FS=Fine sand, MS=Medium Sand, CS=Coarse Sand, VCS=Very Coarse Sand, PS=Poorly Sorted, MS=Moderately sorted, MWS=Moderately Well Sorted, NS=Nearly symmetrical, FS=Fine Skewed, SFS=Strongly fine Skewed, CS=Coarse Skewed, PK= Platykurtic, MS= Mesokurtic, LK= Leptokurtic, VLK= Very Leptokurtic

Table 3. Grain size parameters and their verbal limits

Standard Deviation		Graphic Skewness		Graphic Kurtosis	
Ranges	**Verb Sorting**	**Ranges**	**Verbal Skewness**	**Ranges**	**Verbal Kurtosis**
<0.35	Very well Sorted	>+0.30	Strongly Fine skewed	<0.67	Very Platykurtic
0.35-0.5	Well Sorted	+0.30-+0.10	Fine skewed	0.67-0.90	Platykurtic
0.5-0.71	Moderately Well Sorted	+0.10—0.10	Nearly Symmetrical	0.90-1.11	Mesokurtic
0.71-1.0	Moderately Sorted	-0.10- -0.30	Coarse skewed	1.11-1.50	Lepokurtic
1.0-2.0	Poorly Sorted	<-0.30	Strongly Coarse skewed	1.50-3.0	Very Lepokurtic
2.0-4.0	Very Poorly Sorted			>3.00	Extremely Lepokurtic
>4.0	Extremely Poorly Sorted				

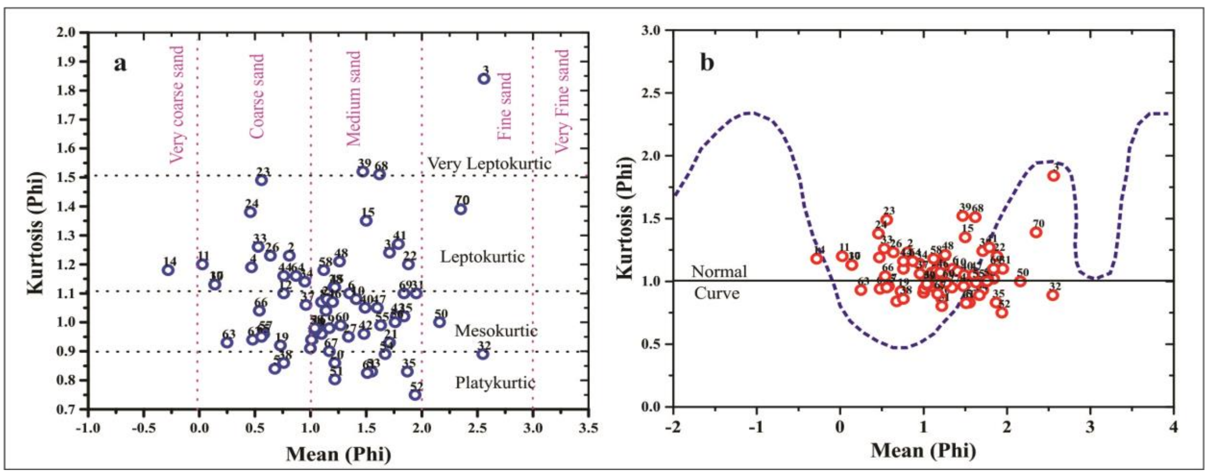

Fig. 4 (a) Bivariate plot of graphic kurtosis against mean. (b) Bivariate plot of graphic kurtosis versus mean showing the placement of Bara Formation samples in the model plot as proposed by (Folk and Ward, 1957).

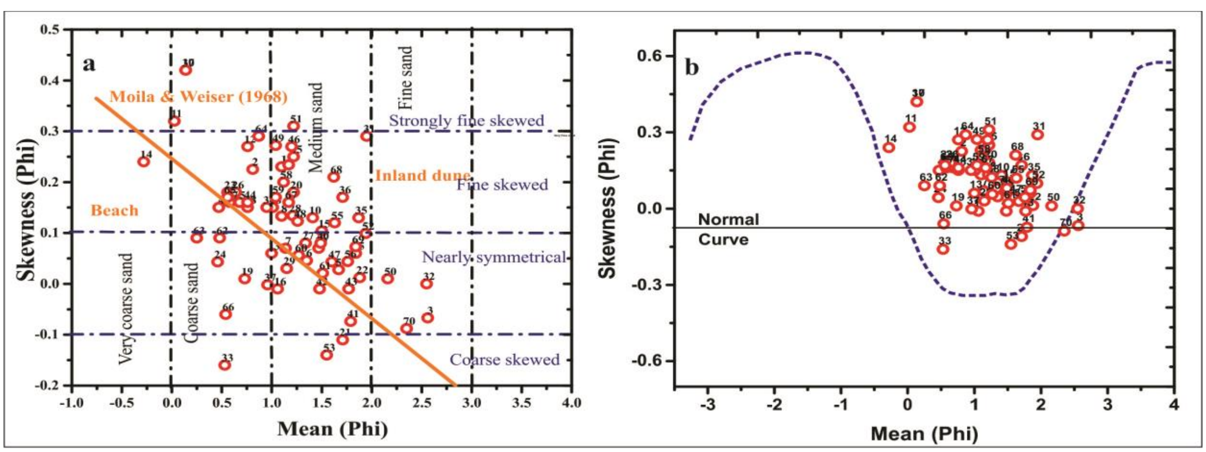

Fig.5 (a) Bivariate plot of graphic mean versus graphic skewness. (b) Bivariate plot of skewness versus mean showing the placement of Bara Formation samples in the model plot as proposed by Folk 1957. (a) Bivariate plot of graphic skewness versus graphic mean as proposed by (Moila and Weiser, 1968).

Stewart Diagram (1958)

(Stewart, 1958) has produced a model graph to differentiate between river, wave, and quiet water field by plotting the SD, and SKI vs MD. In this study, the most Bara Formation sandstone samples were clustered in the River field. However, sample no 3, 32, 50 and 70 falls in wave field **(Fig.6b).** The scatter graph of MD vs SD reveals that most Bara sediments clustered in river field and sample no 3, 32, 50 and 70 falls in wave field **(Fig.6a).** The Stewart energy diagram reveals that river depositional environment was dominant over the wave process.

Skewness (SKI) versus standard deviation (SD)

The discriminate diagram of SD vs SKI reveals that most Bara sediments were moderate to poorly sorted, with few samples moderately well sorted **(Fig.7a)**. Furthermore, the diagram also specifies that most of the samples were fine skewed to near-symmetrical, with three (03) samples fall in the field of strongly fine skewed and coarse skewed, respectively **(Fig.7a)**. Moreover, **Figure 10a** background graph (Friedman, 1967) reveals that river depositional setting was dominant over the beach environment. Finally, the modified modal diagram of (Folk and Ward, 1957), **Figure 7b** indicates that samples that fall mainly in the sector reveal unimodality of sediments.

Skewness (SKI) versus kurtosis (KG)

(Friedman, 1967) stated that the discriminate diagram of KG vs SKI was used for differentiating among deposition settings. The interpretation diagram of KG against SKI demonstrates that the Bara sediments were Platykurtic to leptokurtic. Furthermore, the graph also reveals that the sediments were mostly near symmetrical to fine skewed **(Fig.8a).** Moreover, **Figure 8a**, in terms of depositional setting, indicates that river depositional setting was the dominant influence over the beach environment. The discriminate diagram of KG against SKI **(Fig.8b)** tracks a steady path of the sinusoidal array as the mean size changes and is dependent on two modes (Folk and Ward, 1957). Generally, the Bara Formation sandstone samples fall in the normal curve shaded area, characterized by a nearly pure sand plot (Folk and Ward, 1957).

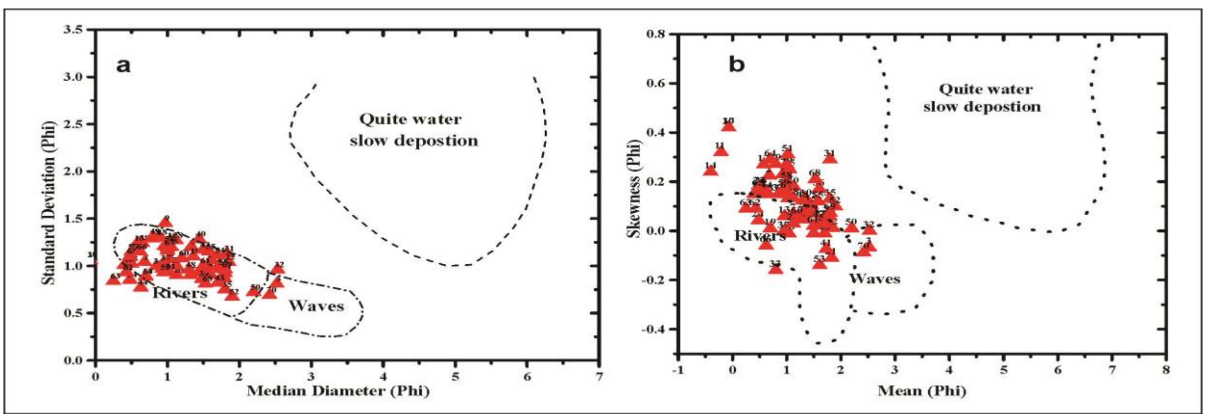

Fig. 6 (a) Bivariate plot of graphic median versus standard deviation. (b) Bivariate plot of skewness versus median showing the placement of Bara Formation samples in the model plot as proposed by Stewart 1958.

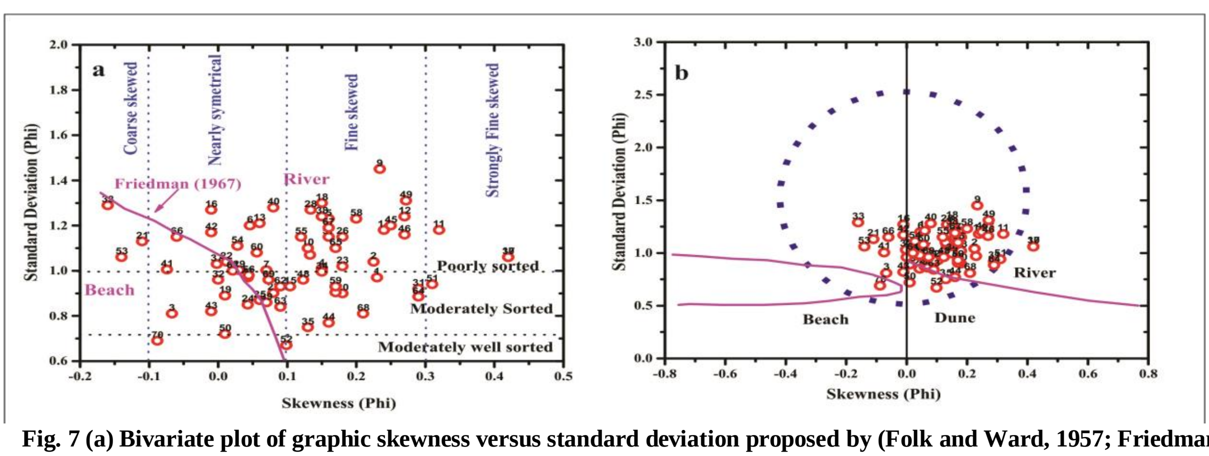

Fig. 7 (a) Bivariate plot of graphic skewness versus standard deviation proposed by (Folk and Ward, 1957; Friedman, 1967). (b) Bivariate plot of skewness versus standard deviation showing the placement of Bara Formation samples in the model plot as proposed by (Folk and Ward, 1957).

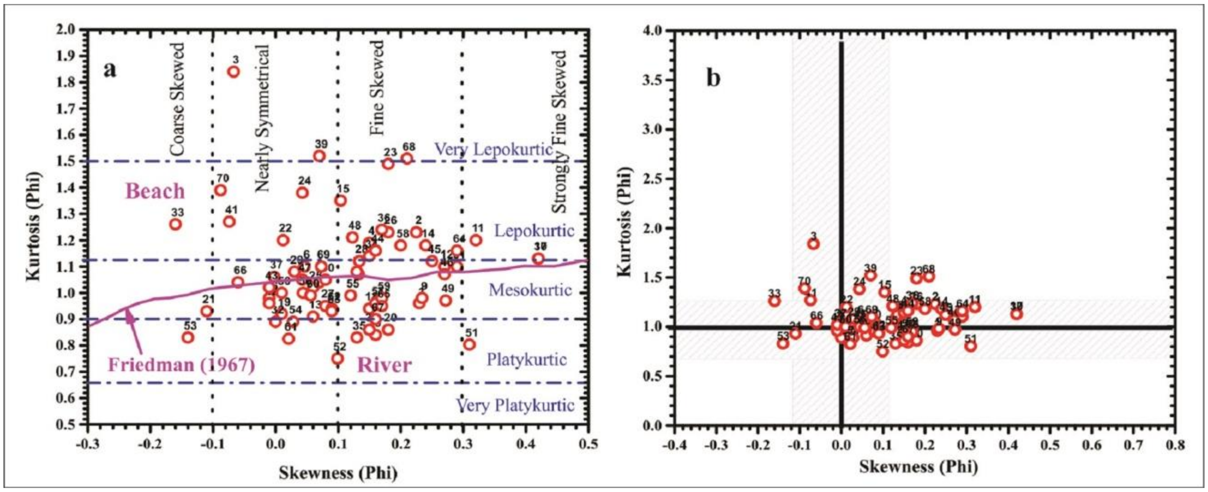

Fig. 8 (a) Bivariate plot of graphic kurtosis versus skewness proposed by (Folk and Ward, 1957; Friedman, 1967). (b) Bivariate plot of graphic kurtosis versus skewness showing the placement of Bara Formation samples in the model plot as proposed by (Folk and Ward, 1957),

LINEAR DISCRIMINATE FUNCTION (LDF)

Textural parameters statistical analysis was applied to be used to identify hydrodynamic conditions throughout the sedimentary processes. It seems to have a perfect relationship to different depositional settings (Sahu, 1964). Sohu, in 1964 produce and formulated the function known as linear discriminate functions (LDF) Y1, Y2, Y3, and Y4. LDF functions were used to discriminate among deposition mechanisms.To differentiate among shallow agitated water (SA) and beach (B), the below mathematical expression (I) was utilized.

$$Y1 = -3.5688M + 3.7016r^2 - 2.0766SK + 3.1135KG \quad (I)$$

"SA" is dominant If values of Y1 were <−2.7411, and the depositional setting is "B" if the values were >−2.7411,

To distinguish b/w "B" and "SM" depositional settings, mathematical expression (II) applied. SM represents Shallow marine

$$Y2 = 15.6534M + 65.7091r^2 + 18.1071SK + 18.5043KG \quad (II)$$

If value of Y2 was <−63.3650, depositional setting is "B" and if the values were>−63.3650, depositional setting was "SM".

To differentiate depositional setting b/w SM and D or L, mathematical expression (III) was utilized.

$$Y3 = 0.2852M - 8.7604r^2 - 4.8932SK + 0.0482KG \quad (III)$$

If values of Y3 were>−7.4190, the depositional setting was "SM," and if values of Y3 were <−7.4190, depositional setting was "D or L" Here D represent Deltaic and L represent Lacustrine depositional setting. To make a distinction b/w "D" and "TC", mathematical expression (IV) was applied.

$$Y4 = 0.7215M - 0.4030r^2 + 6.7322SK + 5.2927KG \quad (IV)$$

If values of Y4 <9.8433, reveals TC deposition setting, and if values of Y4 was >9.8433, reflects the deltaic depositional setting. Here TC represent the Turbidity Current depositional setting.

Where M, R, S.K, and K.G represent Graphic mean, sorting, Graphic kurtosis, and Graphic skewness. Sohu 1964 functions LDF were computed from the calculated textural parameters Bara sediments. As a result, the calculated values of LDF Functions i.e Y1, Y2, Y3, Y4 vary from −2.92 to −8.52, 83.95 to 148.07, −13.58 to −4.99, and 5.30 to 8.84, respectively.

The scatter graph Y3 vs Y2 proposed by (Sahu, 1964) **(Fig.9a)** reveals that most of the Bara Formation sediments falls in the field of Fluvial/Agitated environments. Moreover, five samples were clustered in the field of Shallow marine/Agitated depositional setting domain. The bivariate graph of Y4 vs Y3 **(Fig.9b)** shows that most Bara sediments clustered in the field of Fluvial/Turbidity current depositional setting; Moreover, five samples fall in Turbidity currents/Shallow marine environment. This reveals that the sediments are deposited in a fluvial depositional environment with the influence of shallow marine environments.

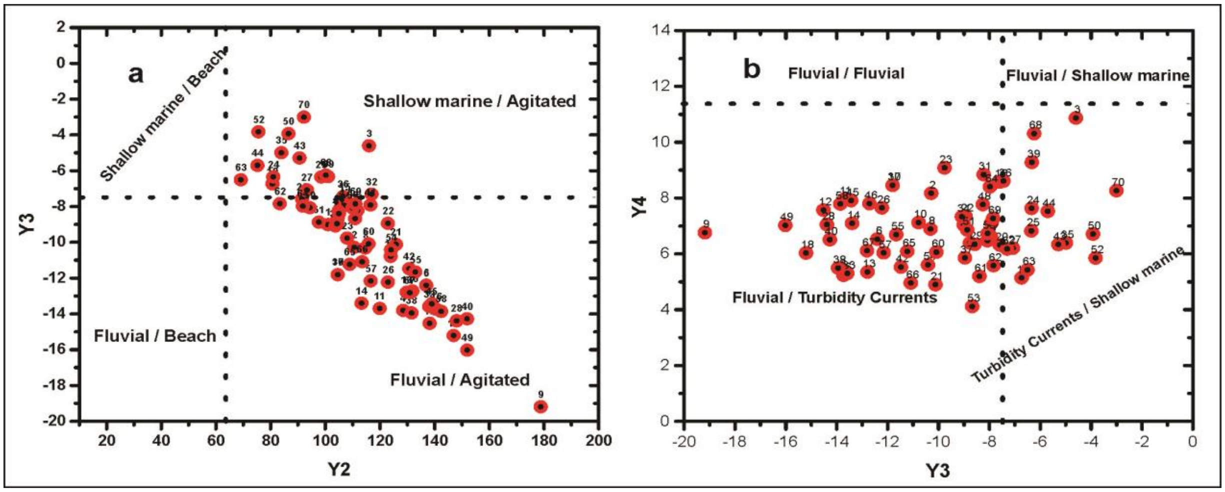

Fig. 9 (a) Discrimination of environments based on Linear Discrimination functions (LDF) plot of Y2 against Y3, (b) Discrimination of environments based on Linear Discrimination functions (LDF) plot of Y3 against Y4, showing the placement of Bara Formation samples in the model plot as proposed by (Sohu 1964).

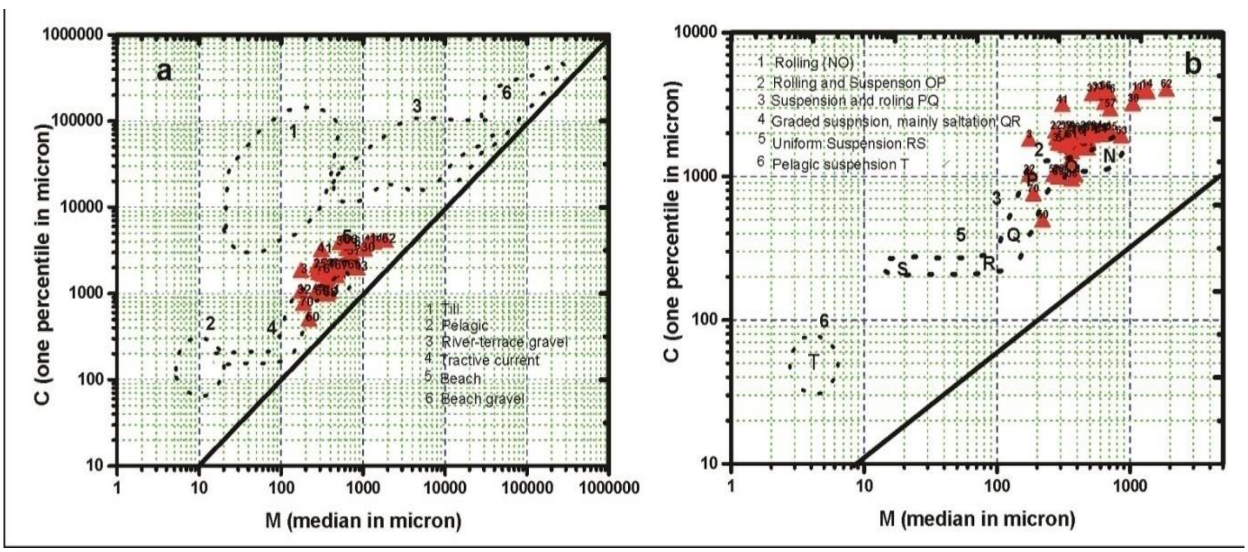

Fig. 10 (a) C-M plot showing the transporting mechanism of the Bara sediments (Passega, 1964), (b) C-M plot showing the transporting mechanism of the Bara sediments (Passega, 1964)

C-M PASSEGA DIAGRAM

(Passega, 1964)produces a famous C-M graph to understand the energy condition that existed during the sedimentation and transportation process. Here C represents the value of coarser one-percentile (C) in micron and M represents the values of median (MD) in micron on a log-log scale. The interrelationship b/w C and M is related to various sediment types and energy conditions of transportations media (Passega, 1964; Visher, 1969). The Passega illustration described in **(Fig.10a)** represents various fields 1, 2, 3, 4, 5, and 6 linked to various transportation and depositional settings. Graph of C vs M values on the Passega diagram(Fig.10b)suggests that most of the Bara sediment falls in the rolling and suspension domain (NO) field. However, few Bara sediments fall in rolling, and rest (OP) and very few samples lie in between the rolling (PQ) field.

The basic C-M pattern diagram (Passega, 1964) has been subdivided into six major groups (1, 2, 3, 4, 5, and 6) till pelagic, river-terrace gravel, tractive current, beach, and beach gravel, respectively. Few samples from the Bara Formations are scattered above the (NO) sections. The C-M showing the depositional setting **(Fig.10a)** indicates that tractive currents and beaches deposited the Bara Formation sediments.

4. CONCLUSIONS

The results of the study area indicates that Bara Formation sandstones are dominated by medium-grained with sub-ordinate coarse particles with a poorly to moderately sorting and fine skewed to nearly symmetrical. They have a platykurtic, mesokurtic, and leptokurtic nature showing transitional maturity. Grain size analyzed results demonstrate that the Bara Formation sandstones deposited in the fluvial-deltaic environment as bedload and suspended load mode of transportation during Middle Paleocene.

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