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RESEARCH PAPER

Grain Size Analysis as Paleo-environment Indicator of Lower Pliocene Sediments (Bai-Hassan Formation), Garmian Area, Kurdistan Region, NE Iraq

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A B S T R A C T:
Grain size distribution has utilized to determine the paleoenvironment sediments. The study is primarily dependent on the analysis and description of plots and interrelation factors between parameters. Five samples have been collected in the five different facies along (90) m thickness in the outcrop. The grain size is ranging from (Ø -8 to 14), (Boulder to Clay) which has given good attention to such research. Grain size analysis indicated the major of the particles are Gravel and the minor proportion is (Sand and Mud), which shows that the samples are more Gravely (> 80%) except for the sample (5) is less (< 50%). Sediment transport mechanisms indicated that bimodal sources and were moved associated with the bed (rolling, sliding, and salting) based on the force of the flow. The statistical parameters pointed out the obvious results of the sediment environment. The values of Median and Mean were negative which inferred the coarse pebble size, sediments were very poorly sorted, finely skewed, and leptokurtic. Interrelationship factors between the parameters showed a clear interpretation of the Paleoenvironment and streamflow. The indications have shown that the sediment deposits in a river environment, high current energy, accompanied by strong turbulence currents.

KEY WORDS: Keywords: Garmian, Grain size parameter; Paleoenvironment; Fluvial environment, Floods
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1.INTRODUCTION:

Grain size analysis is the fundamental mechanism determining the sediment because of the effectiveness of its techniques to discriminate and classify the sedimentary environment, and also provides significant details about transport history and precipitate conditions (Krumbein, 1938; Folk and Ward, 1957; Friedman, 1979; Tucker and Vacher, 1980; Blott and Pye, 2001). During recent decades, coarse-sized sediments have been greatly developed because of a widened attention in the environmental studies of the sediments, river depositions and surface processes (Lucchitta, 1978; Blair ,1987; Blair and McPherson, 1999).

The unconsolidated deposits are covering large areas in that location, with various grain sizes increasing to coarser in an area and finer in another. The sediments in the study area are a controversial topic, due to the difficulty in distinguishing between Bai Hassan and Mukdadyia formations (Jassim and Goff, 2006). The main aims of the study are; to determine and understanding the type of the Paleoenvironment trait, mechanisms of the sediment transportation, and the source of the materials transport processes by (water, air and land) (López, 2017). The grain size has been previously divided into millimeters (mm) and phi (Ø) units (Udden, 1914; Wentworth, 1922). The scale is divided into the range of the grain sizes from Boulders (Ø > -8) to Clays (Ø <8) as it showed in (Table 1).

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Table (1) Weight retained in sieve mesh, percentage, and the cumulative ratio of taken samples.

Sieve Mesh (mm)	Phi (Ø)	Sampl **1** (gm)	Wt%	Acc . Wt	Sample **2** (gm)	Wt%	Acc. Wt	Sample **3** (gm)	Wt%	Acc. Wt	Sample **4** (gm)	Wt%	Acc. Wt	Sample **5** (gm)	Wt%	Acc. Wt
256	-8	823	15.9	15.9	1190	36.5	36.5	1516	32.2	32.3	1750	33.0	33.0	1043	21.03	21.0
64	-6	941	18.2	34.2	420	12.9	49.5	1909	40.6	72.9	1282	24.2	57.3	534	10.7	31.8
16	-4	2255	43.7	78.0	428	13.1	62.6	203	4.32	77.2	294	5.55	62.8	350	7.06	38.9
4	-2	185	3.59	81.6	190	5.84	68.5	194	4.13	81.3	191	3.61	66.4	142	2.86	41.7
2	-1	240	4.66	86.2	90	4.31	72.8	193	4.11	85.4	207	3.91	70.3	450	9.07	50.8
1	0	170	3.30	89.5	170	5.23	78.0	150	3.19	88.6	380	7.18	77.5	685	13.8	64.6
0.5	1	90	2.72	92.2	180	5.54	83.5	143	3.04	91.7	277	5.23	82.7	490	9.88	74.5
0.25	2	55	1.07	93.3	103	3.17	86.7	114	2.43	94.1	238	4.49	87.2	320	6.45	80.9
0.125	3	108	2.10	95.4	100	3.08	89.8	48	1.02	95.1	170	3.21	90.4	380	7.66	88.6
0.0625	4	56	1.09	96.5	95	2.92	92.7	125	2.66	97.8	214	4.04	94.5	340	6.86	95.5
0.0039	8	143	2.78	99.3	142	4.37	97.1	84	1.79	99.6	188	3.55	98.0	130	2.62	98.1
Clay	14	35	0.68	100	94	2.89	100	20	0.43	100	105	1.98	100	95	1.92	100
Total (Kg)		5,151	100		3,252	100		4,699	100		5,296	100		4,959	100	

Statistical parameters are generally reflecting the grain size distribution data and show insight features of the sediment environment and also can be considered a good proxy of different grain sizes (Folk, 1974). Median and Mean may be easily calculated but they do not represent the extremes of the curve, while the other parameters (Standard deviation, Skewness, and Kurtosis) demonstrate the ratios of dispersion and show a wide range of understanding and interpretation about the environment system (Folk, 1974).

Inman (1949) mentioned three essential modes of particle movement which are rolling, salting and suspension. The sediment particles are rolling connecting the bed and moving intermittent neither steady nor continuous. The coarse-sized particles such as gravels and coarse sands are rolling or sliding, knowing as surface creep or traction load (Visher, 1969). Determination of sedimentary environments, grain size analysis with its parameters have been applied on the various facies of the samples. Most of the selected facies are rich in gravel, however, some are containing varying quantities of sand, silt, and clay. Samples are located in the Garmian area, nearby the Serwan river (Figure 1).

2. GEOLOGICAL SETTING

The study area is located in Garmian area, between latitudes ($34^{o}51'$ 26 – 34^{o} 50' 14"), and longitudes ($45^{o}32'$ 32" – 45^{o} 31 02"), South of Sulaimaniyah Government, North East Iraq (Figure 1). Structurally, it is located in an unstable shelf particularly in the Foothill zone, on Serwan transversal Fault (Jassim and Goff, 2006) (Figure 2). A fault is extending along the Serwan river and prolongs from NE-SW of Iraq. The area is full of deep synclines filled with Pliocene deposits in coarse molasses type such as conglomerates.

Geologically, the sediments in the area are including between recent sediments, Bai-Hassan and Mukdadyia formations (Lower Pliocene), Injana Formation (Upper Miocene), and Fatah (Lower Fars) formation (Middle-Lower Miocene) Figure (2). Quaternary sediments are adjacent Serwan river and covering the floodplain and riverbank. These formations are often composing of gravel, sand, and clays. The study area has not studied yet and is not easy to distinguish between two main formations in the same range of age, which are Bai- Hassan and Mukdadyia formations. These two formations have the same compositions sway between cycles of gravel, gravely sandstone, sandstone, and mudstone, however, they can be recognized by their distribution in the Foothill zone and high folded zone (Jassim and Goff, 2006).

According to Jassim and Goff (2006), during Late Miocene-Pliocene, the Arabian plate collided the Iranian plate led to lifting areas, by its role, formed High folded zones, north Iraq. During the Late Miocene-Pliocene, conglomerate and sand-sized grains have been settled down as a result of weathering and the uplift occurred later in Pliocene. The study area consists of conglomerate, sandstone and clays. Distribution of geological depositions and different types of faults. It is particularly appearing Foothill zone sediments, north Iraq (Figure 2).

3. METHODOLOGY

The samples have collected in an outcrop beside the Serwan river, approximately (90 m) thickness, which appeared its exposure to erosion (Figure 1). One site has selected among six different locations that previously visited, about (5Kg) were collected for each sample (Table 1).

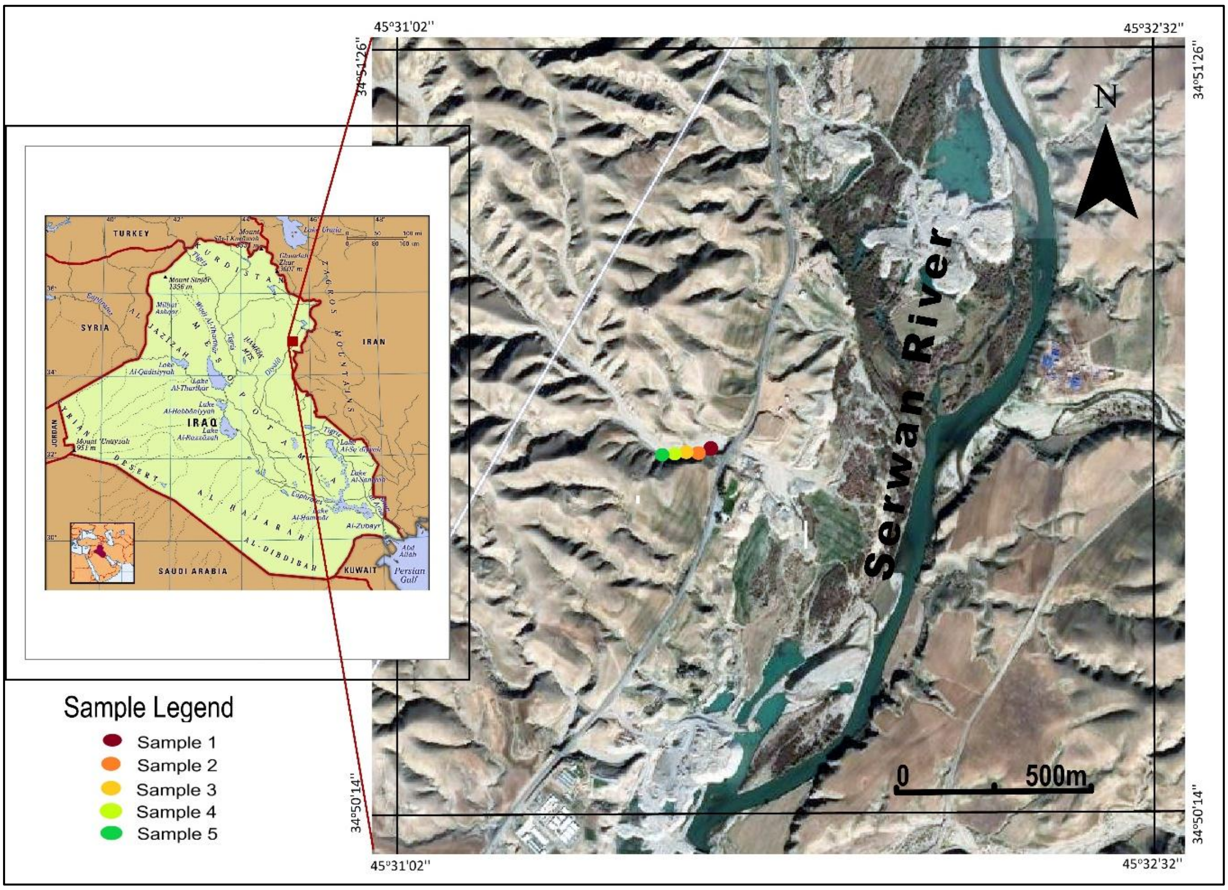


Figure 1: Google Map of the study area (Garmian, NE Iraq) explaining the sample locations.

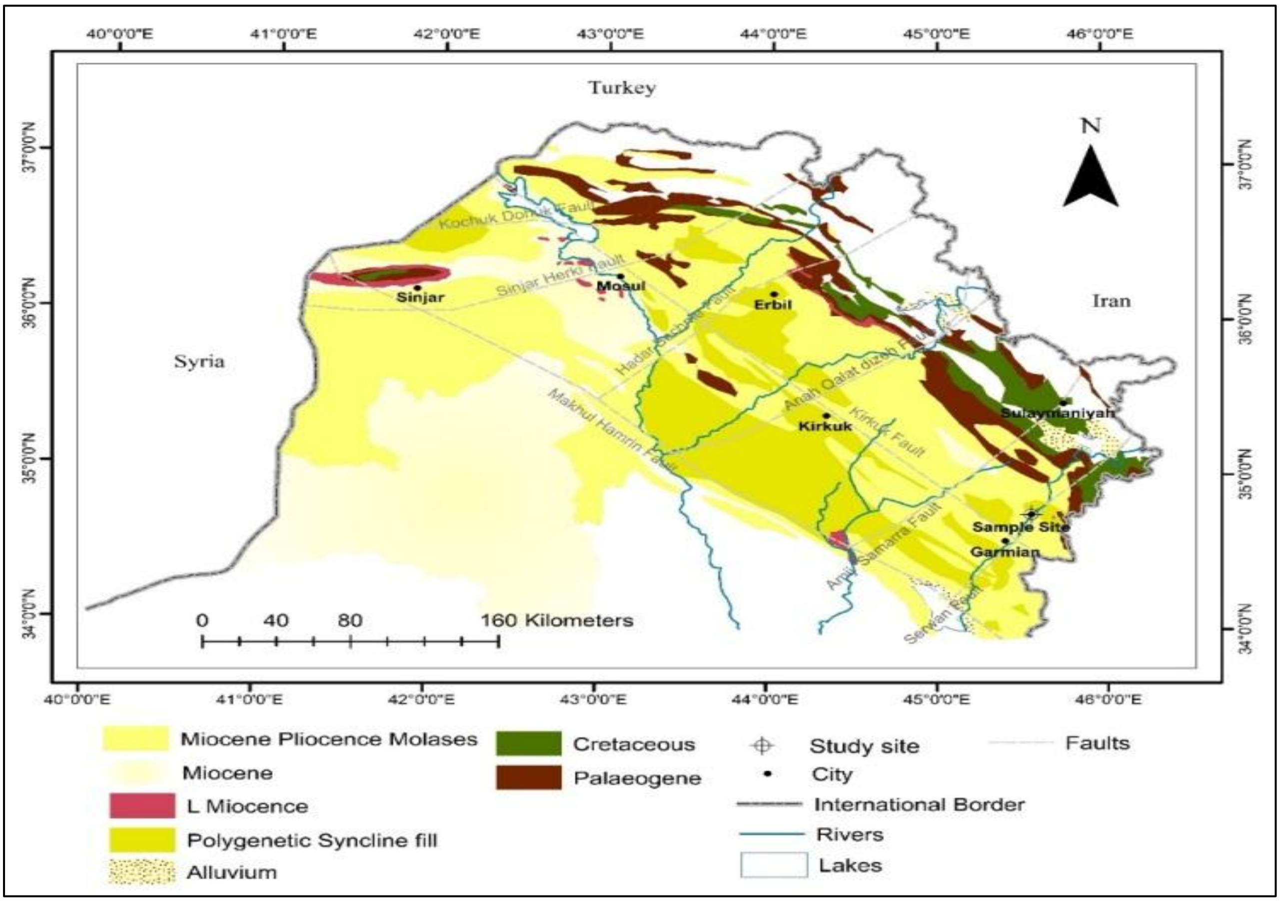


Figure 2: Geological map of North Iraq, showing the samples site and the main faults (normal and reverse) (after Jassim and Goff, 2006).

The study built upon two main methods which are: direct description in the field interpretation by grain situation, graduation and orientation based on the sedimentary structure such as packing grains, and also Lab analysis of the samples. Aggregate samples have been dealt chemically and physically to break up into particles. Samples analyzed in Garmian Engineering Testing Laboratory (GETL) using American Society for Testing and Materials (ASTM) Sieves, Vibrator and weight-sensitive balance.

Folk's grain size parameters still have a wide range of use among the geological milieus, as shown in the equations and been applied in (Table 2 and 3). The equations are:

Table (2) Percentage proportion of gravel, sand, and mud of the samples.

Sample No.	Gravel %	Sand %	Mud %	USDA
1.	86.2	10.3	3.5	Muddy Sandy Gravel
2.	72.8	19.9	7.3	Muddy Sandy Gravel
3.	85.5	12.3	2.2	Muddy Sandy Gravel
4.	70.4	24.1	5.5	Muddy Sandy Gravel
5.	50.8	44.7	4.5	Sandy Gravel

Percentage Retained (%): — 100…… (*Equation-1*)

Where, *Ws* denotes weight retained in a sieve, *Wt* the total weight. The percentage ratio for gravel, sand and clay, separately calculated for each sample (Table 2) and was applied to the Folk's Triangular plot (Figure 3). The plot showed that the grain size distributed between gravel, sandy gravel, and muddy sandy gravel.

$M_d = Ø_{50}$ ……………………………….… (*Equation-2*) (Folk, 1974).

The equation built upon the idea half of the particles is coarser by weight than the Median, and half is finer.

Mean (Mz)

(*Mz*) = ———— …………… (*Equation-3*) (Folk, 1974).

Inclusive Graphic Standard Deviation (Sorting) (σ_1)

(σ_1) ——— ——— ……… (*Equation-4*)
(Folk and Ward, 1974)

< Ø 0.35 Very well sorted
Ø 0.35 to Ø 0.5 Well sorted
Ø 0.50 to Ø 0.71 Moderately well sorted
Ø 0.71 to Ø1.0 Moderately sorted
Ø 1.0 to Ø 2.0 Poorly sorted
Ø 2.0 to Ø 4.0 Very poorly sorted
> Ø 4.0 Extremely poorly sorted

Inclusive Graphic Skewness (SK_1)

(SK_1) =———— ————…… (*Equation-5*)
(Folk, 1974)

Ø 1.0 to Ø 0.3 Very fine skewed
Ø 0.3 to Ø 0.1 Fine skewed
Ø 0.1 to Ø -0.1 Near symmetrical
Ø -0.1 to Ø -0.3 Coarse-skewed
Ø -0.3 to Ø -1.0 Very coarse skewed

The Graphic Kurtosis (KG_1)

(KG_1) =—————………. (*Equation-6*)
(Folk, 1974)

< Ø 0.67 Very Platykurtic
Ø 0.67 to Ø 0.90 Platykurtic
Ø 0.90 to Ø 1.11 Mesokurtic
Ø 1.11 to Ø 1.50 Leptokurtic
Ø 1.50 to Ø 3.00 Very leptokurtic
> Ø 3.00 Extremely leptokurtic

These equations undergo to mathematical and statistical processes to be presented later on graphs and plots. The mean is illustrating grain size distribution of the materials and also reveals the stream energy, depending on the velocity and turbulence of the transporting medium (Folk, 1980). Sorting is a function of the grain size range of the sediments and reflects the amount of energy, and flow velocity by its role, steadiness in the current energy, in somewhat, states a good sorting (Al-Miamary, 2000). Skewness and kurtosis show how closely the grain-size distribution approaches the normal Gaussian probability curve, and the more extreme values, the curve will be non-normal (Folk, 1974).

4. RESULTS AND DISCUSSIONS

The research is used different types of plots, graphs, and statistical parameters to come into precise results. To be fairly explained, it requires extra details. Therefore, the discussion examined three main results which are frequency curves, grain size parameters, and interrelationship factors between the parameters.

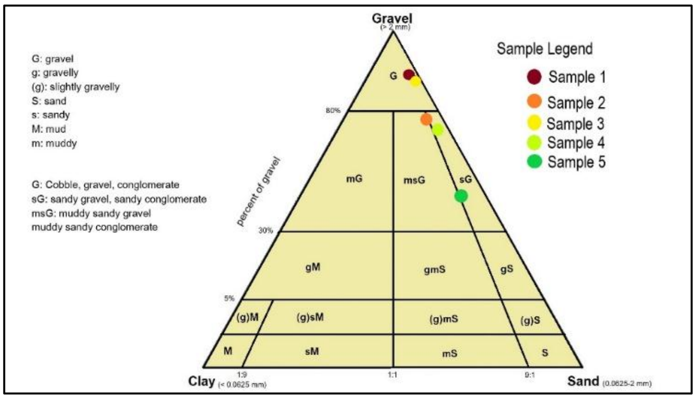


Figure 3: Triangular diagram showing the sieve analysis of the samples (Folk, 1980).

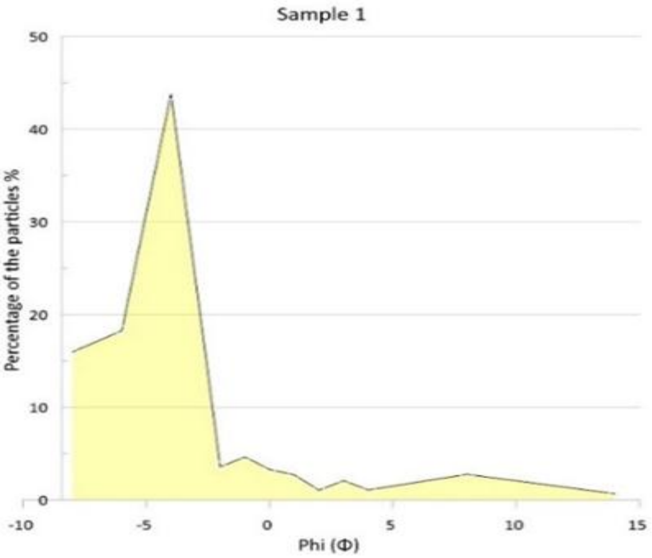
4.1 Frequency Curves

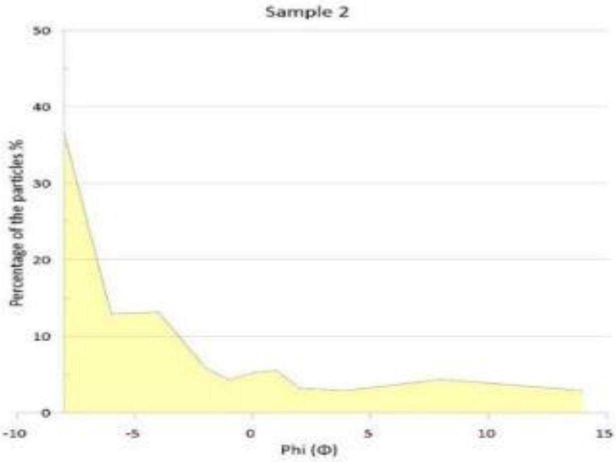
Twenhofel and Tyler (1941) importantly mentioned the statistical processes for grain size allowing immediate and easy comparison of coarse-sized sediments and implies the similarities and differences in terms of sediment environmental conditions. The percentage ratio of grains has calculated for each sample (Table 2) by (*Equation* 1). The Folk's ternary diagram revealing distributed between Gravel (>70%), Sand (<20%), and Mud (<5%) (Figure 3). The ternary diagram illustrated that the common particles are cobble, conglomerate, sandy conglomerate, and muddy sandy conglomerate. The proportion of cobble and gravel states the high flow velocity of the stream at the sedimentation.

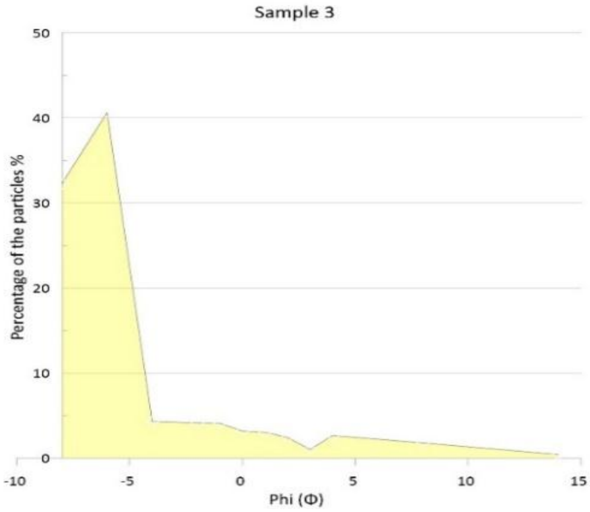
The size-frequency curve denotes the natural distribution of sediment and providing more details on the sorting, symmetry, and modality index (Friedman and Johnson, 1982). The frequency curve indicates that the sediment modality is a bimodal distribution attributing that it is derived from more than a source, and irregular kinetic energies in the depositional environment (Figure 4). However, it can be assumed that there are some changes in kinetic energy. The changes are not limited to the sediment environment, but rather extend to the movement of particles during the flood (Folk and Ward, 1957). In addition to the presence of variation in the grain size, there are sudden changes have been occurred, perhaps because of branching and converging river channels (Aghwan and Al-Fattah, 2005).

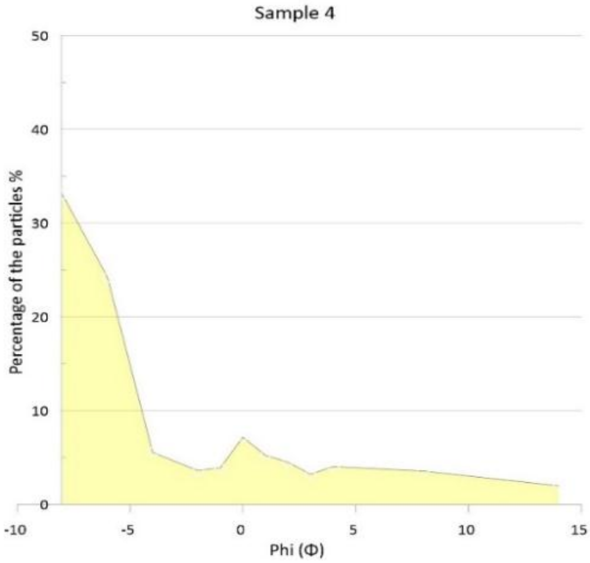
Einstein *et al*., (1940) used the relationship between grain size diameter (Phi) and the accumulative weight of the grain size in which explains the transport mechanism of the sediments. The total sediment load is divided into bed material load and washload (Konodolf and Piegay, 2016).

The bed material load derived from Coarse-Sized Grains and the washload typically derived from Fine-Sized Grains, both of which have flushed into the stream from the upland sources. Based on the figure (5), most of the sediments are considered bedload materials which including cobble, pebble, and coarse sand grains. By mode of transport, the sediment load is often moving in attaching along the bed, whether rolling, sliding, or salting (samples 1, 2, 3). However, some of the particles are seemed as washload materials and transported in the mode of suspended which dispersed in the flow by turbulence and carried suspending from long distances (samples 4, 5). The movement of the particles can be classified:









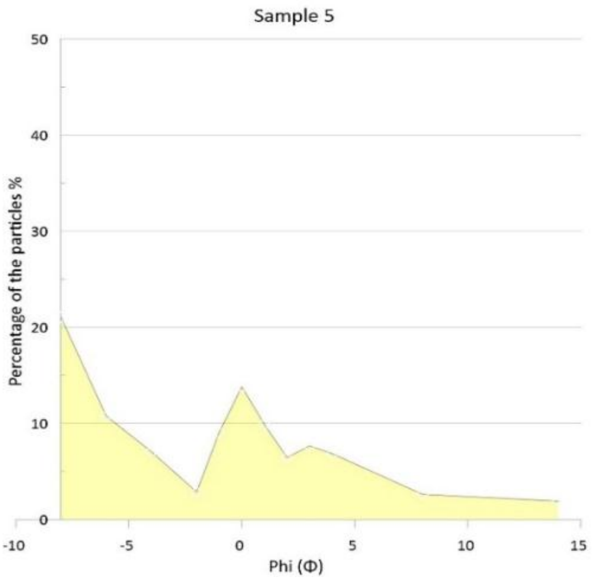
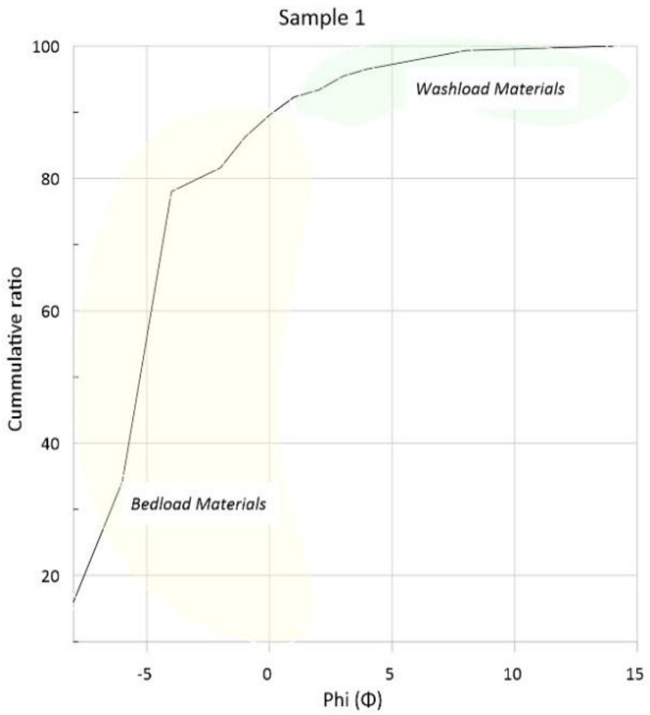
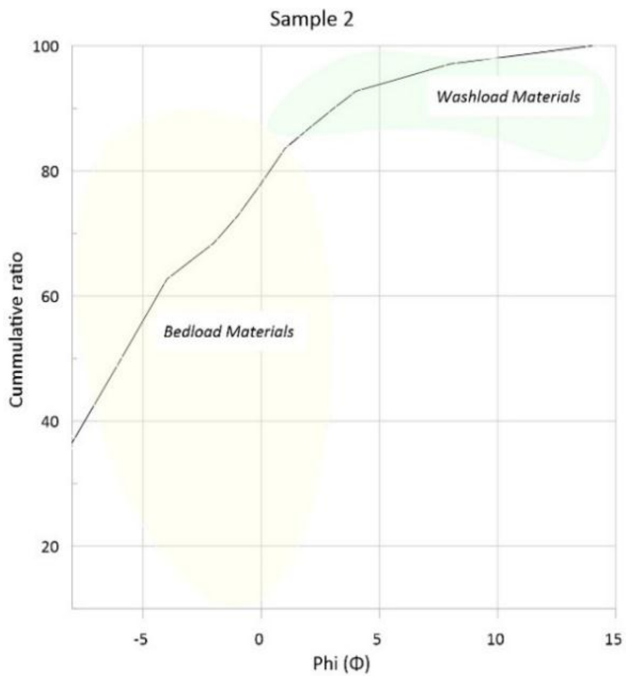


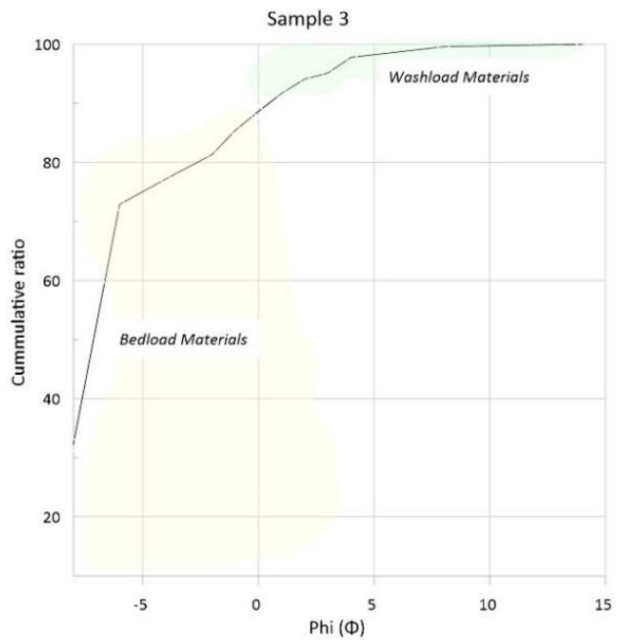
Figure 4: Frequency Curve distribution of the Samples (Folk, 1980)

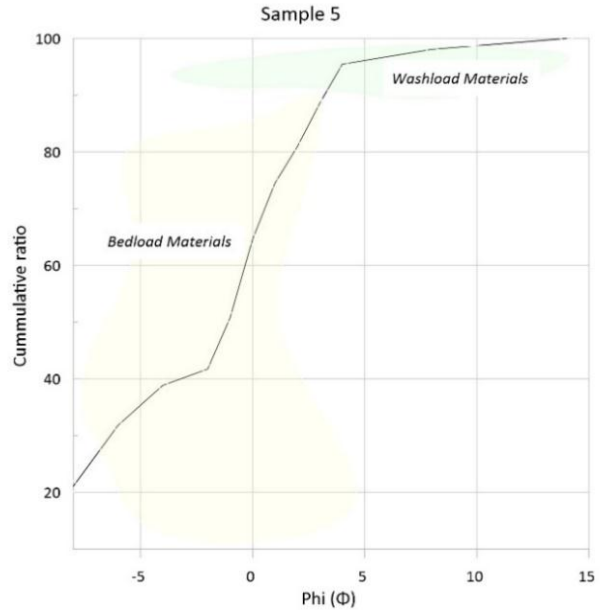
a. *Rolling transport:* appearing within the coarse- sized material ranging (Ø -8 to -4) in most of the samples, except sample (5). This states the sediment movement (rolling or creeping), which often occurs because of variation pressure on the grain, reverse to the stream direction (Passega and Byramjee, 1969) (Figure 5).
b. *Saltation transport*: included from (Ø -4 to 4), it takes a long inclined crouch in the curve (Figure 5). This type of movement may occur in the flash flood and represents the movement of the graded bed and exists above bedload materials (Passega and Byramjee, 1969).
c. *Suspension movement*: including the fine-sized materials, ranging between (Ø 4 to 14) which is covering (very fine sand, silt, and clay) by less than 5% of the total percentage and appear as a straight line in the curve (Figure 5). However, this class is representing the equilibrium status between the forces that generate turbidity against the stability directions of the grains (Sagoe and Visher, 1977).

The presence of grains is ranging between phi (Ø -8 to 0) which might indicate high kinetic energy, flooding successions, and the fluvial environment. Certain changes have appeared in the cumulative frequency curve, particularly (sample 5), which can be considered turbid currents or disturbances in the current energy during sedimentation.









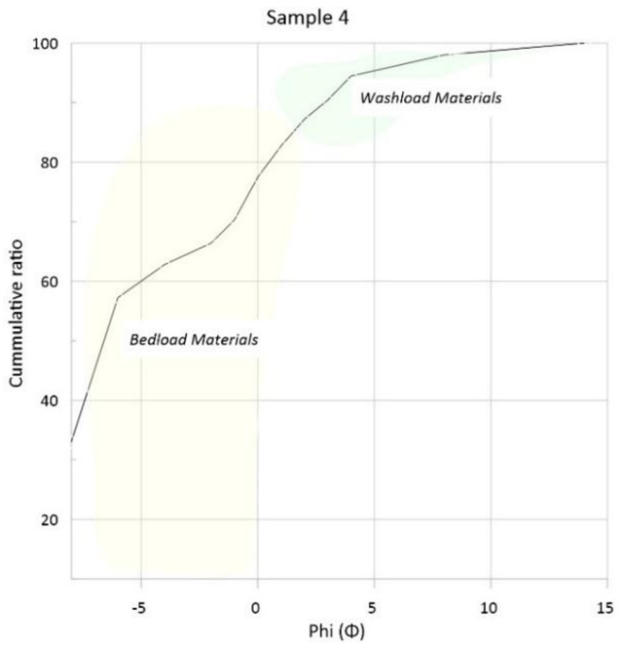


Figure 5: Cumulative Frequency Curve distribution of the Samples (Folk, 1980)

4.2 Grain Size Parameters

These parameters are more accurate and attain satisfying results including:

1. *Median (Md)*

   The median is the relative value separating the fine part from the coarse part (Folk, 1974). The median values varied in the study ranging (Ø-1.2 to – 7.2), (equation 2), on average (Ø-5.2) giving humble results on the relative coarse-sized grain of the samples (Table 3).

2. *Mean (Mz)*

   It is a function of primary grain size for the source rocks giving the ability of average deposit in the sediment (Pettijohn *et al*., 1973). and an important factor of depositional environments (Friedman, 1967) Mean's result is more accurate than the median because the mean depends on three points of grain size measurements and gives a preferable portrait of the sediments (Folk, 1980). The mean has shown (Ø-3 to -4.9), (Equation 3) on average (Ø -4.2) and the biggest assemblage values at (Ø -4) (Table 3). This indicates that the grains are ranging from (Pebble to Granule) which concluding the sediments are transported from relatively the near distances, and to some extent lead to an increase of particle size near the source. It is evidence of high current energy and a characteristic of floods and fluvial sediments (Reinck and Singh, 1980).

3. *Standard Deviation (Sorting)* (σ_1)

Sorting referred to the degree of concentration or dispersion between the grains. In the fluvial sediments, sorting is the process by which grains of a given size are populated. Well-Sorted means the grains are in identical sizes but poor-sorted presents the grains are in different sizes (Konodolf and Piegay, 2016). Standard deviation measures the sorting of sediment displaying the changes in the kinetic energy condition. When the sediments are reflecting different modes, the standard deviation is recording the variation in the kinetic energy, turbulence measures of poorly sorted sediments (Sahu, 1964). The standard deviation (σ1) results are between (2.9-4.4), (equation 4) on average (3.8) that means most of the samples are very poorly sorted to extremely poorly sorted, the most frequency value of sorting is extremely poorly sorted while the average value focusing on very poorly sorted (Table 3). The kinetic energy of the river can be overall considered irregular and high-velocity flow.

4. *Skewness (Sk1)*

It is used to measure the asymmetry of the frequency distributions and the position of the mean concerning the median (Sahu, 1964). Once the value of skewness is positive the sample is considering fine-skewed, which the Mean tends to the finer side of the Median. When the value of skewness is negative, the sample is coarse-skewed, and the mean tends to be the coarser side of the median (Sahu, 1964). Its significance came when it measures the environmental factor (Hills, 1967). The Skewness values are positive except sample (5), (Table 3). These results are demonstrating that the skewness values are very fine-skewed with average fine skewed. (Brambati, 1969) in (Maity and Maiti, 2018) explaining the positive skewness values is an indication of a one-directional of the streamflow. Mentioned (Valia and Cameron 1977) that the positive value is an indicator of the transportability factor and unidirectional flow.

5. *Kurtosis (KGi)*

It is considered a sensitive measurement of the nature of grain size distribution, and it defines as a measurement of peakedness of the distribution (Folk and Ward, 1957). The Kurtosis values of the samples ranged between (0.588-2.869), (Equation 6), (very platykurtic to very leptokurtic) in an average of (1.433), (leptokurtic), (Table 3). It can be said that the changes in the values of kurtosis are closely related to the determination of the origin of the sediments by identifying their models, and most of the sediments have one source and this matches the interpretations of the frequency curve (Cronan, 1972).

4.3 Interrelationship Factors

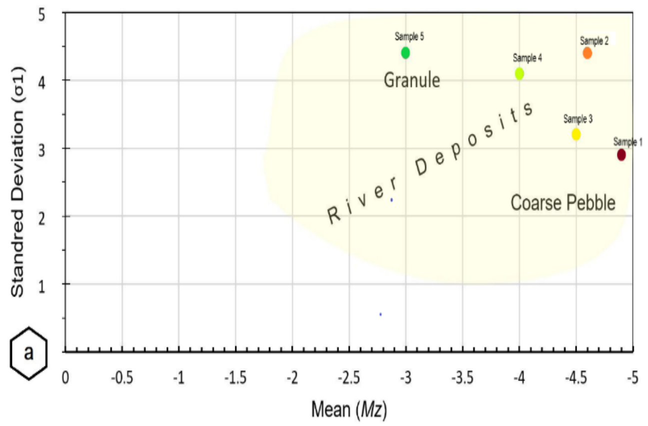
Using different statistical parameters gives a specific conception of the sediment environments, as well as the reflection of the transportation processes with the flow conditions that surrounded by the sediment environment (McLaren and Bowels 1985; Ghosh and Chatterjee 1994). Parameter values are indicating the nature of the current energy and flow condition of the sediment environment. Positive skewness represents the unidirectional flow of the stream (Brambati, 1969). Baruah *et al*. (1997) pointed out that high or low values of kurtosis reveal that part of the deposition is sorted in a high energy environment.

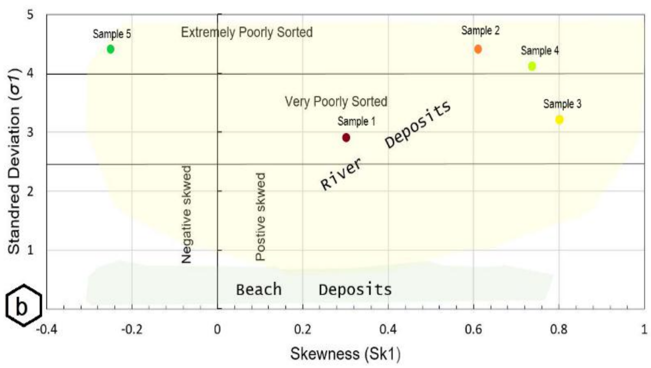
In order to come to delicate indications on the transport process, flow condition, and sedimentation, interrelation factors between available parameters have been applied. These factors are a good way to recognize such various facies to reach sedimentation conditions. (Figure 6.a) illustrating the relationship between Mean and Standard Deviation. The studies have mentioned such a relationship as an indicator between sediment environments (fluvial system, beach, and aeolian deposits) (Friedman, 1961, 1967; Moiola and Weiser, 1968; Folk, 1966, 1980; McLaren and Bowels, 1985; Al Rashedi and Siad, 2016). The relationship is shown that all the samples are ranged between a coarse pebble and granule grain size, within the scope of the river or fluvial sediments that reinforcing the previous analysis.

The relationship between Skewness and Standard Deviation (Figure 6.b) implies the fluvial environment of the samples. The plot is previously studied (Moiola and Weiser, 1968; Folk, 1966, 1980; Camerlenghi *at. el.*, 1995; Blott and Pye, 2001; Saeed and Siad, 2016), and came out to that all the samples distributed between extremely poorly sorted and very poorly sorted that situated within the fluvial environment outline.

Table (3) Results of the different parameters applying on the standard measurements

Sample No.	Median (Md)	Mean (Mz)	Standard deviation ($\sigma 1$)	Skewness (Sk1)	Kurtosis (KGi)	Mean	Standard Deviation	Skewness	Kurtosis
1.	-5.2	-4.9	2.9	0.303	1.581	Coarse Pebble	Very Poorly Sorted	Very Fine Skewed	Very Leptokurtic
2.	-6.0	-4.6	4.4	0.613	2.869	Coarse Pebble	Extremely Poorly Sorted	Very Fine Skewed	Very Leptokurtic
3.	-7.2	-4.5	3.2	0.804	1.448	Coarse Pebble	Very Poorly Sorted	Very Fine Skewed	Leptokurtic
4.	-6.5	-4.0	4.1	0.738	0.681	Coarse Pebble	Extremely Poorly Sorted	Very Fine Skewed	Platykurtic
5.	-1.2	-3.0	4.4	-0.248	0.588	Granule	Extremely Poorly Sorted	Coarse-Skewed	Very Platykurtic
Average	-5.2	-4.2	3.8	0.248	1.433	Coarse Pebble	Very Poorly Sorted	Fine Skewed	Leptokurtic





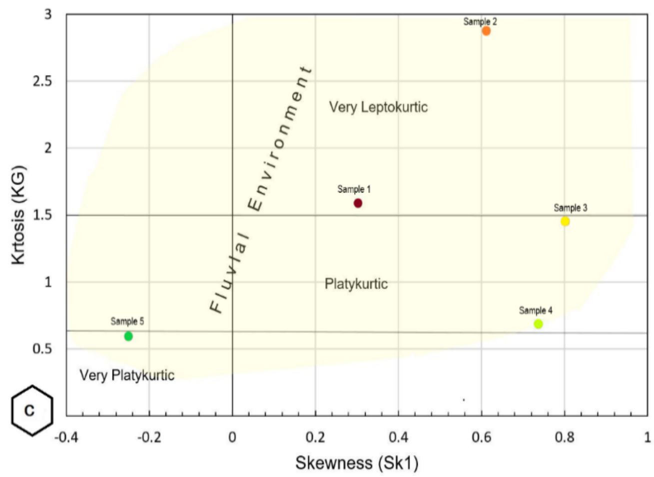


Figure 6: Interrelationship between different parameters showing the sediment environment. (a) the relationship between Standard Deviation and Mean. (b) the relationship between Standard Deviation and Skewness. (c) the relationship between Kurtosis and skewness (Maity and Maiti, 2018).

Demonstrating the relationship between Skewness and Kurtosis (Figure (6.c)), might be used as an indicator of the environment. The samples positively skewed except for (sample 5). On the other side, the samples ranged within very leptokurtic to very Platykurtic ranges. The results referred that the sediment accumulated in the foredeep basin coming from the high folded zone and thrust belt through several sudden progressions. The settling has come from the disparity in topography and sediment load which observed the visualize of the Bai Hassan formation environment is fluvial condition and far away from other environments such as Delta and Beach.

5. CONCLUSIONS

The study dealt with a few sedimentary aspects regarding paleoenvironmental determination using grain size analysis. Various statistical parameters have used such as Median, Mean, Standard Deviation, Skewness, and Kurtosis with their interrelation factors. The study came out that the sediments deposited in the fluvial environment during rapidly flooded transgressions, associated with high current energy and turbulence, uni-streamflow direction, and bimodal sediment. Deposition materials filled the synclines during the rapid advances and catastrophic floods during the lower pliocene.

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