Sedimentlogical Characteristics, Depositional Environment, and Mode of Transportation of Fayoum Depression Lakes Bottom Sediments

Hassan I. Farhat

Geology Lab., National Institute of Oceanography and Fisheries (NIOF), Cairo, Egypt.
hf_geo@hotmail.com

Abstract The present work was carried out to describe and interpret the distribution pattern of Fayoum depression lakes (Lake Qarun and Wadi El-Rayan lakes) bottom sediments. Grain-size distributions and the derived sedimentological parameters have been studied in order to relate them to the mechanics of transportation, deposition and also as environmental indicators. Fayoum depression lakes bottom sediments consist mainly of sand fraction with variable ratios of gravel and mud fractions. Medium, fine, and very fine sand fractions have wide distribution. Gravel fraction in Lake Qarun is represented by carbonate skeletons, whereas it represented by rock fragments, and Nummulites fauna shells in Wadi El-Rayan Lakes. Mud fractions (silt and clay) have wide distribution west and eastward of lake Qarun, whereas in El-Rayan Lakes were absent at south of two lakes and eastward of first lake with wide distribution at front of El-Wadi drain and middle zone of first lake. Sediments of Lake Qarun show low prominent truncation between traction and saltation, low suspension load, and high truncation between saltation and suspension. Wadi El-Rayan Lakes bottom sediments show a prominent truncation with no traction and saltation except westward of first Lake, and west and eastward of second Lake due to access of gravel fraction, with high truncation between saltation and suspension, and medium suspension load. The C–M patterns of Lake Qarun sediments indicate that mode of transportation was by rolling, while Wadi El-Rayan lakes sediments modes of transportation were by rolling, uniform suspension, and graded suspension. C–M patterns and the multigroup multivariant discriminant functions V_1–V_2 plot indicate that the mechanics of transportation and depositional environment of El-Fayoum depression lakes are generally considered as complex turbidite environments.
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Key words: Fayoum depression; Lake Qarun; Wadi El-Rayan lakes; bottom sediments; sedimentological parameters; mechanics of transportation; depositional environment

1. Introduction

Sedimentation processes are closely related to those of transportation, because deposition results from modification of the process of transportation that causes a decrease in the energy of the transporting agent (Kukal, 1971). The distribution of particles size in sediments is a function of the availability of different sizes of particles in the parent material, and the processes operating where the particles were deposited (Folk & Sanders, 1978).

The problems of a "true size" of skeletal particles and plant remains have been questioned by Folk and Robles (1964). It's also emphasized that in carbonate sediments distributions may not reflect a sorting of grains by hydrodynamic processes (Brailhwaite, 1973). Other workers have determined these parameters and successfully related them with the environment of deposition (Emery *et al.,* 1954; Guilcher, 1965; Friedmn, 1968; Lewis, 1969; Taylor and Lewis, 1970). The grain size distribution of the recent bottom sediments act on the distribution of fauna and flora in the aquatic ecosystem, and affect the distribution of the organic matter content.

Analysis of the grain-size distribution of gravel, sand and silt fractions often provides a basis for the study of other textural features of deposits. The various, sometimes controversial, interpretations of such data have led to numerous discussions (Friedman & Sanders, 1978; Mycielska-Dowgiałło, 2007; Flemming 2007; Hartmann & Flemming, 2007; Szmańda, 2007; Weltje & Prins, 2007).

The study aims to make a comparative study of the sedimentological characteristics and therefore to represent recent bottom sediment samples of El-Faiyoum Depression Lakes (Lake Qarun and Wadi El-Rayan Lakes) in order to determine the grain size distribution, mode of transportation, and origin of the depositional environment.

2. Methods of study

2.1. Study area

El-Faiyoum Depression Lakes are represented by Lake Qarun and Wadi El-Rayan Lakes located south west of Cairo in the Western Desert, Lake Qarun is a closed saline basin located between 30° 24′ & 30° 49′ E and 29° 24′ & 29° 33′N in the lowest part of El-Faiyoum depression, about 80 Km of Cairo. It has an irregular shape of about 40 km length and 6 km mean width. The average area is about 240 km^2, shallow, with mean depth of 4.2m. The water level of the lake fluctuated between 43 to 45 meters below mean sea level (Meshal, 1973). The lake receives the agricultural and sewage drainage water from El-Faiyoum Governorate. Most of the drainage water reaches the lake through two main drains, El-Batts and El-Wadi Drains. Since, 1973 El-Wadi drain partially delivers most of its water into Wadi El-Rayan Lakes to maintain established water level of Lake Qarun (Figure 1 A).

Wadi El-Rayan is a great depression (703 km^2), 40 km southwest of El-Fayum Province. Since 1973 the depression has been used as a water reservoir for agricultural drainage water exceeding the capacity of Lake Qarun. Nowadays, it holds two main lakes, at different elevations, connected by swampy channel. They lie between 30° 20′- 30° 25′ E and 29°05′-29°20′ N. The first lake of Wadi El-Rayan covers an area of about 53 km^2 at 10 m below the sea level and receives frequent effluent of wastewater from El-Wadi Drain (average 200 million cubic meters of agricultural drainage water are transported annually) (El-Shabrawy, 2007). The surplus water from this lake floods to the second one via shallow connecting channel. The 2^{nd} lake is larger than the first one (110 km^2 at 18 m below the sea level) with maximum water depth of 33 m. It is changing all the time, where newly flooded areas are continuously added at the southwestern side of the lake (Figure 1 B). (Abd Ellah, 1999)

2.2. Sampling

During spring, 2011, samples of sediment were taken from twenty stations covering the whole lakes area (Figure 1). Sediments were collected with Ekman dredge sampler the samples were preserved in plastic bags for analysis.

2.3. Analysis

After drying, sediment samples were prepared by using decantation method (Folk, 1974), grain size analysis was done by dry sieving technique (Folk, 1974). Samples containing more than 5% fine fraction (finer than 4ϕ) were analyzed using the pipette method described in Krumbein & Pettijohn (1938), Griffiths (1967) and Carver (1971). The sedimentological parameters were derived. Truncation lines at inflection points of the cumulative curves and C–M diagram have been drawn to bring out the mechanics of transportation (Visher, 1969; Passega and Byramjee, 1969). The depositional environment has been evaluated using multigroup, multivariant linear discriminant functions (Sahu, 1983). The following equations are used for calculating V_1 and V_2 functions, adopting the eigen vector matrices of Sahu (1983):

$$V_1 = 0.48048X_1 + 0.6231X_2 + 0.40602X_3 + 0.44413X_4$$

$$V_2 = 0.24523X_1 - 0.45905X_2 + 0.15715X_3 + 0.83931X_4$$

Where X_1; X_2; X_3 and X_4 are mean size, variance, skewness and kurtosis, respectively.

3. Geologic setting

3.1. Stratigraphy of El-Fayoum Depression area

The geological setting of El Fayoum area has been studied by many authors (e.g., Said, 1962; Tamer, 1968; Swedan, 1986). El Fayoum province consists of four main depressions (Nile Valley, El-Fayoum, Hawara and El-Raiyan) surrounded by the limestone plateau of Eocene Age Rock units exposed in El- Fayoum region range from Eocene to Quaternary Ages. The subsurface stratigraphic column is capped by Quaternary sediments that are widely distributed over the entire area of El-Fayoum province and composed of varied grain sizes of sand and gravel intercalated with silt and clay. These deposits directly overly the thick and extensive Eocene Age limestone deposits. The depositional environments and sequence succession of the underlying limestone resulted in the accumulation of thick Quaternary deposits in this region. (Massoud *et al*.,2009). (Table 1).

Wadi El-Rayan is an excavation within the Middle Eocene Rocks of Southern El-Fayoum depression area and the exposed rocks are represented by Muweilih Formation, Midawara Formation, Sath El-Hadid Formation and El-Gharaq Formation. (Iskander, 1943). Muweilih Formation is formed at Gebel Munqar El-Rayan at Early Luteian time, this formation is conformably overlies the Samalut Formation and conformably underlies the Midawara Formation. It inter bedded sandy argillaceous limeston and marl with occasional thin shell beds and Nummulites intercalation (Abu El-Ghar, 1991). Midawara Formation is formed at Gebel Munqar El-Rayan at Middle Luteian time, this formation is conformably overlies the Muweilih Formation and conformably underlies the Sath El- Hadid Formation. It consists from glounitic, highly nummulitic sand stone and siltston with mionr interbeds of marl to the north. The Midawara Formation changed to more calcareous facies. The Sath El- Hadid Formation overlies Midawara Formation and represents the crop of many scarps in southern Fayoum (e.g. Gebel Munqar El-Rayan….etc.) and represents the base of the succession at Gabal El-Mishgigah. Its age is Middle to Late Lutetian. It formed hard white limestone with chert concretions. The Gharaq Formation is conformably overlies the Sath El- Hadid Formation and unconformable the Pliocene sediments in Wadi El-Rayan area. (Abu El-Ghar, 1991). Wadi El-Rayan formation consists of clays, marls and limestone and is mainly exposed in the south of the Fayoum depression. (Strougo, 1970).

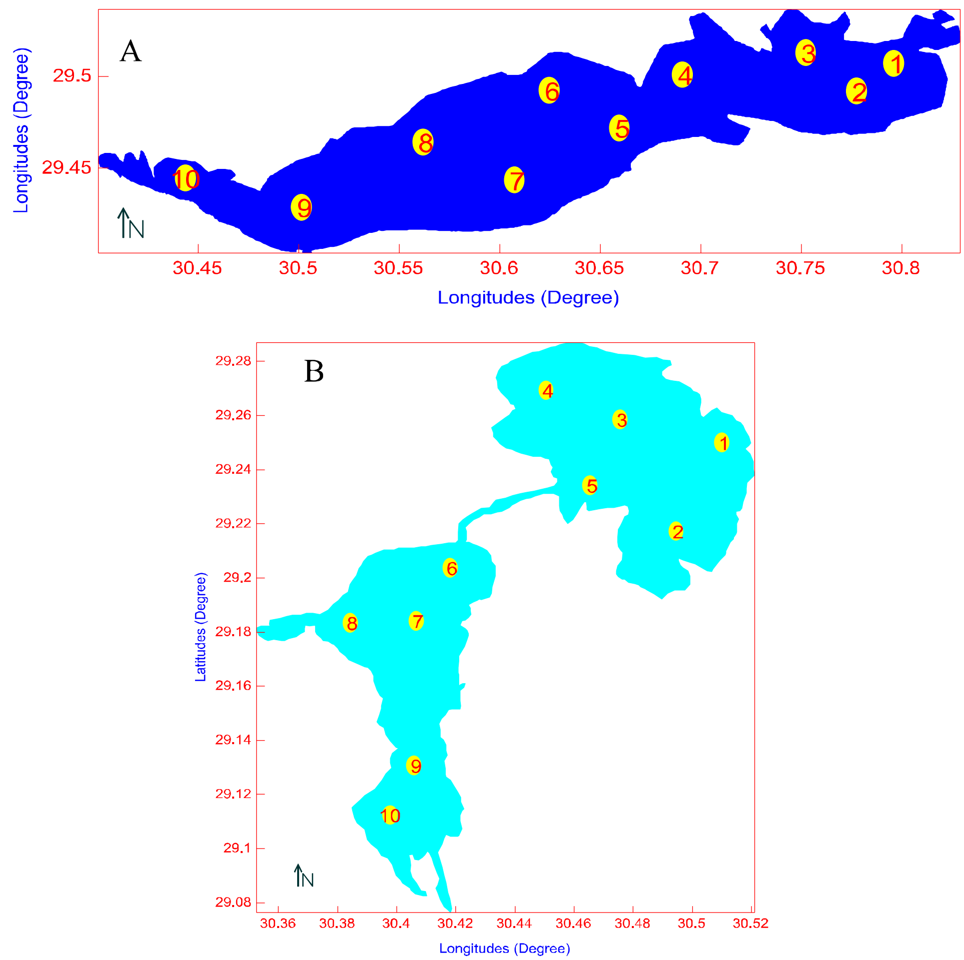

Figure (1): Location map showing sampling sites (A) Lake Qarun, and (B) Wadi El-Rayan Lakes

Table (1): Full description of the surface and subsurface rock units in El-Fayoum area based on direct observation of the Rock exposures. (After Massoud *et al*., 2009)

Age	Formation			Lithological description
Quaternary	Holocene		–	Sand, sandstone, clay, silt
	Pleistocene		–	Sand, gravel, shale, gypsum. clay stone,
				calcareous material intercalated with
				ferruginous sandy silt
Tertiary	Pliocene		–	Sand, gravel, conglomerate
	Miocene		Gebel El Khashab	Sand, gravel
	Oligocene	U.	Widan El Faras	Basaltic flows
		L.	Qatrani	Sand, sandstone with calcareous clay
	Eocene	U.	Qasr El Sagha	Shale, limestone, sand, sandstone
			Birket Qaroun	Clay with calcareous sand
		M.	Gar Gehannam	Shale, marl, limestone, sand
			Wadi El Rayan	Clay, marl, limestone

3.2. Structure of El-Fayoum Depression area

El Fayoum depression has been impacted by a large number of structural features (faults and tectonic subsidence) that are prominent at the edges of the depression. Approximately 49% of these structural features have been generated at the northern edge, 38% generated at the western and southern edges and 13% exists at the eastern side of the Geologic map of El-Fayoum depression (Swedan , 1986; Conoco, 1987; and Massoud *et al*., 2009).

Structural trends are observed in the E-W, ENE-WSW, NNW-SSE and NW-SE directions, of which the NW-SE is the most dominant trend in El-Fayoum province. Figure (2).

Wadi El-Rayan depression is an isolated natural depression (about 10 Km width and 15Km length). It is one of three depressions constituting Fayoum area. These depressions are Wadi El-Muweilih at the extreme south, Wadi El-Rayan in the middle and Birket Qarun to the north (Said, 1960).

The origin of Wadi El-Rayan depression is a matter of different opinions. Out of them, Ball (1927), Ibrahim (1956), El-Shafei (1957), and Said (1960) stated that western desert depressions (e.g. Wadi El-Rayan, El-Qattara….etc.) are originated as a natural subsidence and the wind has been the main excavating agency. On the otherhand, Tamer (1968) viewed that Wadi El-Rayan depression has complicated origin, including the tectonic and the weathering processes.

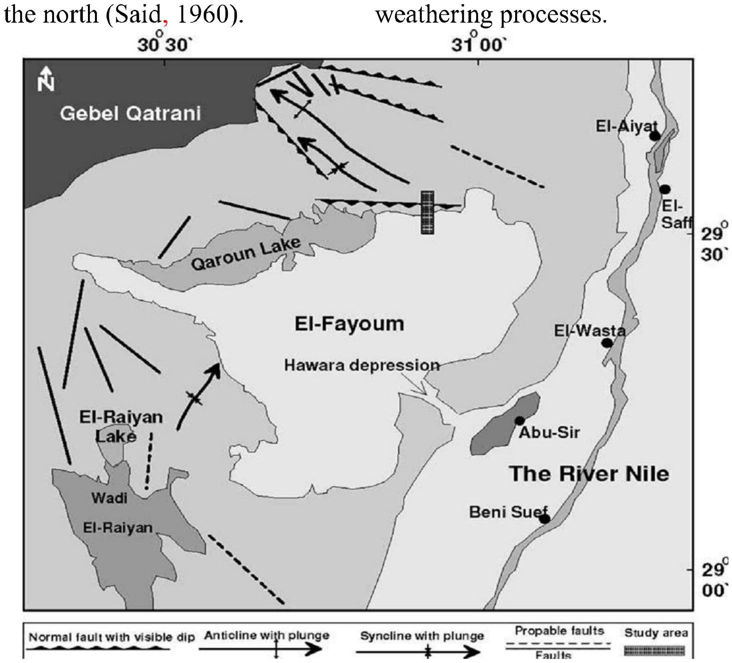

Figure (2): Structural map of El-Fayoum depression area. (After Massoud *et al*., 2009)

Abd El-Bakki (1972) stated that Wadi El-Rayan depression is divided into three geomorphologic units namely; a- Depression edges are bounded by high lands, which are characterized by lake of vegetation and absence of drainage lines, b- Depression floor is organized topographically into a number of depressions; the lowest point is – 64 m below sea level. The floor of depression is characterized by gentle slop toward lowest portion and covered with sand, and c- Sand duns are typically take the shape of longitudinal and parallel dunes (20m to 30m height) extending along the direction of prevailing wind (NNW) and continuing for distance. These sand dunes are probably formed within Holocene Time.

There is a ridge of about 15Km long and 10Km wide between El-Fayoum depression and Wadi El- Rayan depression. This ridge formed from fissured Eocene limeston with surficial gravelly layer (Beadnell, 1905).

4. Grain-size Analysis

4.1. Grain-size distribution

Principal fractions composing sediments were represented in distribution maps (Figure 3 and Table 2). The maps are based on the data derived from grain size analysis according to Folk (1974). Maps showed that sand fraction is the dominant fraction with variable ratios of gravel and mud fractions. Sand fraction records (28.47 % - 92.39 %) in Lake Qarun, while records (32.17% - near 100%) in El-Rayan Lakes. Gravel fraction records (1.13 % - 51.97%) in lake Qarun; represented by carbonate skeletons which are exceed northward of El-Qarn island, while records (zero % - 67.83 %) in El-Rayan Lakes; represented by rock fragments eastward of first lake near Baqarat hills due to physical weathering, and eastward and westward of second lake due to the excess of shells of Nummulites. Mud fraction (silt and clay) records (zero % - 70.40%) in Lake Qarun, while records (zero % - 45.26%) in El-Rayan Lakes.

Table (2): Sediment fractions percent and sediment textural classes of El-Fayoum Depression Lakes bottom sediment.

Fraction name		Grave l	V.C. Sand	C. Sand	M. Sand	F. Sand	V.F. Sand	C. Silt	M. Silt	F. Silt	V.F. Silt	Clay	Gravel %	Sand %	Mud %	Sediment textural classes
Lake Qarun																
	1	4.97	0	0	0	21.14	28.34	11.97	15.81	6.84	4.01	6.92	4.97	49.48	45.55	Gravelly muddy sand
	2	5.54	0	0	0	11.17	47.71	20.96	7.28	2.97	1.32	3.04	5.54	58.88	35.58	Gravelly muddy sand
	3	10.77	0	0	0	30.82	26.69	11.49	10.78	4.21	1.53	3.7	10.77	57.51	31.72	Gravelly muddy sand
	4	30.13	0	0	0	18	27.21	13.95	4.58	1.68	0.57	3.9	30.13	45.21	24.67	Muddy gravelly sand
	5	6.8	0	0	38.96	48.57	4.86	****	****	****	****	****	6.8	92.39	0.81	Gravelly sand
	6	51.97	16.4	19.37	12.26	0	0	****	****	****	****	****	51.97	48.03	0	Sandy gravel
	7	28.67	0	0	5.13	23.25	21.5	8.58	4.16	2.41	1.52	4.77	28.67	49.88	21.45	Muddy gravelly sand
	8	10.01	0	0	0	26.17	38.91	12.72	4.67	2.73	0.63	4.15	10.01	65.08	24.91	Gravelly muddy sand
	9	6.98	0	0	0	33.16	26.06	7.91	10.41	5.87	2.33	7.28	6.98	59.22	33.8	Gravelly muddy sand
	10	1.13	0	0	0	0	28.47	27.39	11.87	5.5	7.41	18.24	1.13	28.47	70.4	Gravelly sandy mud
Wadi El-Ryan Lakes																
First Lake	1	0	0	0	11.55	35.77	43.25	2.16	3.29	1.5	0.66	1.82	0	90.57	9.43	Muddy sand
	2	0	0	0	0	0	54.74	8.92	10.46	6.27	5.66	13.94	0	54.74	45.26	Muddy sand
	3	0	0	0	0	31.95	36.94	4.73	5.15	4.24	3.47	13.51	0	68.9	31.1	Muddy sand
	4	67.83	19.06	8.76	4.34	0	0	****	****	****	****	****	67.83	32.17	0	Sandy gravel
	5	0	0	11.01	28.97	30.31	20.66	****	****	****	****	****	0	90.95	9.05	Muddy sand
Second Lake	6	0	0	0	0	13.91	46.54	15.73	4.64	1.84	2.55	14.79	0	60.45	39.55	Muddy sand
	7	10.05	0	0	0	26.78	27.02	3.24	4.88	4.57	3.63	19.82	10.05	53.8	36.15	Gravelly muddy sand
	8	2.57	3.77	11.24	64.12	13.05	4.31	****	****	****	****	****	2.57	96.49	0.94	Gravelly sand
	9	0	0	0	26.87	68.01	4.46	****	****	****	****	****	0	99.33	0.67	Sand
	10	0	0	0	40.25	46.24	13.3	****	****	****	****	****	0	99.8	0.2	Sand

****: samples with mud fraction less than 5%

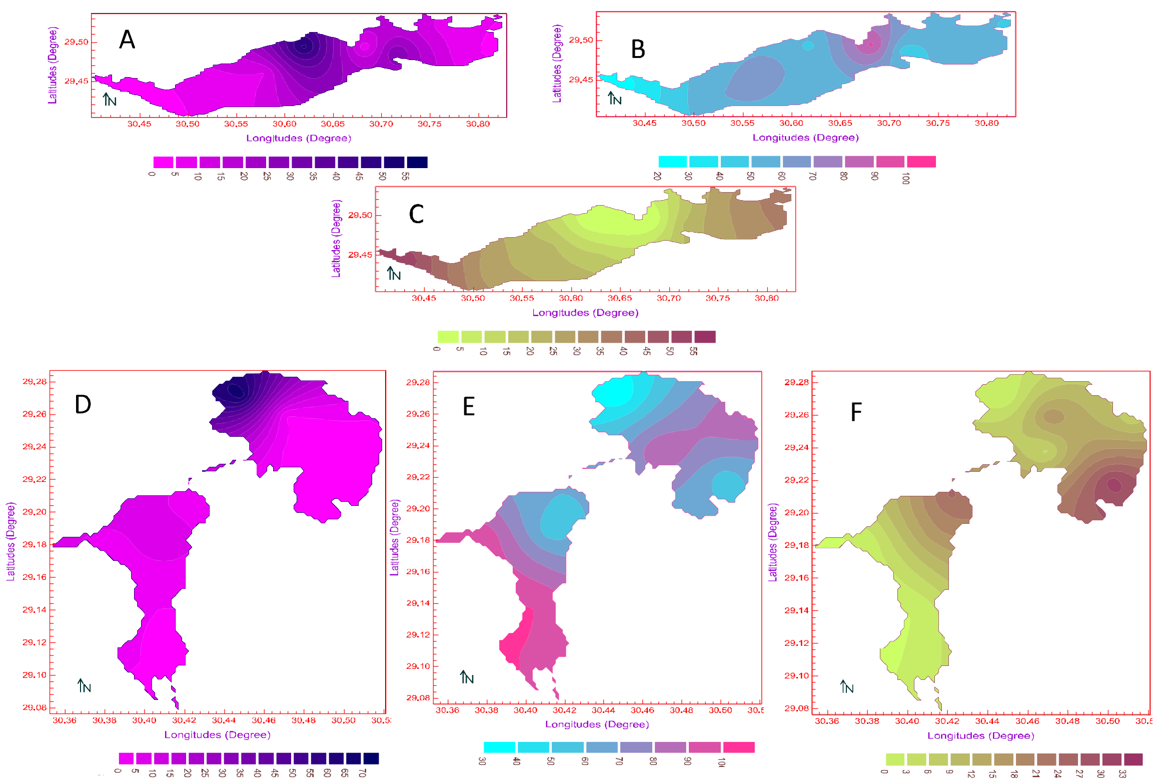

Figure (3): Distribution of grain size fractions of El-Fayoum Depression Lakes bottom sediment (A, B, and C gravel, sand, and mud fractions of Lake Qarun, respectively) and (D, E, and F gravel, sand, and mud fractions of Wadi El-Rayan Lakes, respectively).

Sediment textural classes (Figure 4) are deduced according to Folk (1980), Qarun sediments were gravelly muddy sand westward, sandy gravel northward, and gravelly sandy mud at end of western zone, while sediment of Wadi El-Rayan Lakes were muddy sand in first lake except westward was sandy gravel, and sediments of second lake was sand southward, muddy sand northward, gravelly muddy sand eastward, and gravelly sand westward.

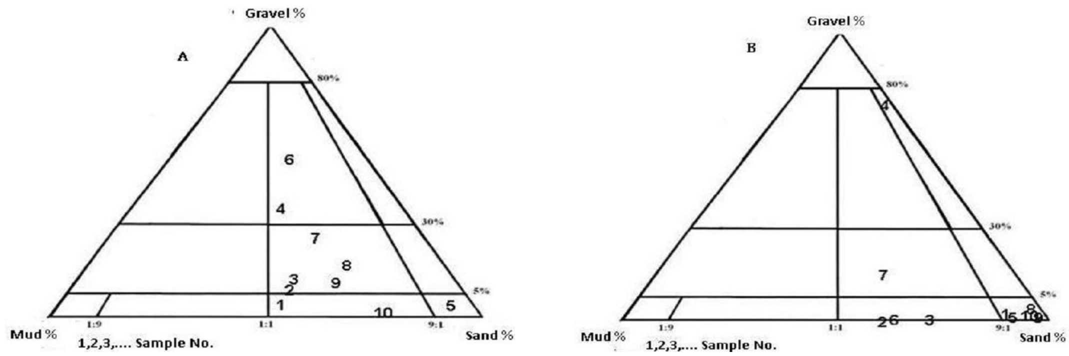

Figure (4): Sediment textural classes distribution for the bottom sediments of El-Fayoum Depression Lakes according to the ternary plots of Folk, (1980), (A) Lake Qarun, (B) Wadi El-Rayan Lakes.

4.2. Grain-size parameters

The grain size parameters of studied samples of El-Fayoum Depression Lakes bottom sediments (mean size, sorting, skewness, and kurtosis) were calculated from cumulative curves according to Folk and Ward (1957) and given in Table (3) and Figure (5). The results revealed that mean size of Qarun bottom sediment varied between -0.45 and 4.23 phi (i.e. very coarse sand to coarse silt), while Wadi El-Rayan bottom sediments varied between -0.85 and 5.07 phi (i.e. very coarse sand to medium silt). concerning, sorting distribution of Qarun bottom sediment varied between 0.89 and 2.64 phi (i.e. moderately sorted to very poorly sorted), while Wadi El-Rayan bottom sediments varied between 0.41 and 3.28 phi (i.e. well sorted to very poorly sorted). The skewness of Qarun bottom sediment varied between -0.38 and 0.7 (i.e. strongly coarse skewed to strongly fine skewed), while Wadi El-Rayan bottom sediments varied between 0.00 and 0.82 (i.e. symmetrical to strongly fine-skewed). The calculated statistical parameters revealed that the kurtosis of Qarun bottom sediment varied between 0.67 and3.51 (i.e. platykurtic to extremely lepto-kurtic), while Wadi El-Rayan bottom sediments varied between0.82 and 2.19 (i.e. platy-kurtic to very lepto-kurtic). Median of Qarun bottom sediment varied between -1.1 and 4.80 phi (i.e. median is displaced towards the finer grain size in the mean except northward median is displaced towards the coarser grain size), while Wadi El-Rayan bottom sediments varied between -1.2 and 3.9 phi (i.e. median is displaced towards the finer grain size in the mean except westward of first lake is displaced towards the coarser grain size).

5. Mode of transportation and sediment Origin

5.1. Characteristic of truncation lines at inflection points of cumulative lines

Table (4) giving results obtained by truncation lines drawn at the inflection points of cumulative curves of El-Fayoum Depression Lakes (Lake Qarun and Wadi El-Rayan Lakes) bottom sediments corresponding to the separation of the traction/saltation and saltation/suspension (Visher, 1969).

Most of analyzed samples of Lake Qarun show a prominent truction between traction and saltation at range of -1.4 ± 0.2 Ø with accounts ranged between 0.2 and 18% except at sample 8 at start of western zone was 1.2 Ø with account of 3% due to access of gravel fraction. Truncation between saltation and suspension was more than 4 Ø which ranged between 4.0 and 6.8 Ø with account ranged between 60 and 99.8 % except at sample 6 at northward of El-Qarn island was 1.9 Ø with account of 95 % due to the excess of gravel fraction. Suspension load ranged between zero and 32 %.

Wadi El-Rayan Lakes bottom sediments show no prominent truction between traction and saltation except westward at first lake was -1.2 Ø with account for 48% due to excess of gravel fraction. West and eastward of second lake was -1.2 and -1.5 Ø with account of 3.5 and 0.15% respectively due to access of gravel fraction. Truncation between saltation and suspension was 4 ± 0.2 Ø with account ranged between 52 and 99.8 %, and suspension load ranged between zero and 46 %.

Table (3): Sedimentlogical parameters of El-Fayoum Depression Lakes bottom sediment according to Folk & Ward, 1957.

Sample		Median	Mean size (Mz)		Sorting (σ_I)		Skewness (SK_I)		Kurtosis (K_G)	
		Value(Ø)	Value(Ø)	Type	Value(Ø)	Type	Value	Type	Value	Type
Lake Qarun										
1		3.5	4.23	Coarse silt	1.98	Poorly sorted	0.37	Strongly fine-skewed	1.16	Lepto-kurtic
2		3.8	3.87	Very fine sand	1.67	Poorly sorted	-0.09	Near symmetrical	3.51	Extremly lepto-kurtic
3		3.5	3.40	Very fine sand	1.83	Moderately sorted	0.04	Near symmetrical	1.55	Very lepto-kurtic
4		3.1	2.20	Fine sand	2.64	very poorly sorted	-0.29	Coarse-skewed	0.67	Platy-kurtic
5		2.1	2.00	Fine sand	0.96	Moderately sorted	-0.38	Strongly coarse-skewed	1.91	Very lepto-kurtic
6		-1.1	-0.45	Very coarse sand	0.89	Moderately sorted	0.70	Strongly fine-skewed	0.71	Platy-kurtic
7		2.7	2.07	Fine sand	2.79	very poorly sorted	-0.11	Coarse-skewed	0.80	Platy-kurtic
8		3.4	3.43	Very fine sand	1.76	Poorly sorted	-0.06	Near symmetrical	2.46	Very lepto-kurtic
9		3.4	4.03	Coarse silt	2.60	very poorly sorted	0.33	Strongly fine-skewed	1.19	Lepto-kurtic
10		4.8	5.77	Medium silt	2.16	very poorly sorted	0.57	Strongly fine-skewed	0.77	Platy-kurtic
Wadi El-Rayan Lakes										
First Lake	1	3.1	3.03	Very fine sand	0.96	Moderately sorted	0.11	Fine –skewed	1.38	Lepto-kurtic
	2	3.9	5.07	Medium silt	1.85	Poorly sorted	0.82	Strongly fine-skewed	1.09	Meso-kurtic
	3	3.5	4.55	Coarse silt	2.09	very poorly sorted	0.72	Strongly fine-skewed	1.10	Meso-kurtic
	4	-1.2	-0.85	Very coarse sand	0.61	Medium well sorted	0.73	Strongly fine-skewed	1.71	Very lepto-kurtic
	5	2.3	2.38	Fine sand	1.07	Poorly sorted	0.12	Fine –skewed	0.82	Platy-kurtic
Second Lake	6	3.8	4.80	Coarse silt	2.10	very poorly sorted	0.66	Strongly fine-skewed	1.69	Very lepto-kurtic
	7	3.5	4.97	Coarse silt	3.28	very poorly sorted	0.38	Strongly fine-skewed	1.09	Meso-kurtic
	8	1.5	1.50	Medium sand	0.78	Medium well sorted	0.00	Symmetrical	2.19	Very lepto-kurtic
	9	2.3	2.30	Fine sand	0.41	Well sorted	0.07	Near symmetrical	0.96	Meso-kurtic
	10	2.1	2.30	Fine sand	0.53	Medium well sorted	0.28	Strongly fine-skewed	0.82	Platy-kurtic

5.2 C-M patterns

C-M patterns diagram was firstly introduced by Passega (1957) plotting C (one percentile in µm) against M (median in µm) on a logarithmic paper. He distinguished between two types of bottom currents available for transporting sediments. These are tractive currents capable for transporting their load either by rolling or in suspension and turbidity currents in which their load is entirely a suspension one. Passega (1964) divided this C-M diagram into six segments namely N, O, P, Q, R and S. Further more Passega and Byramjee (1969) subdivided the diagram into nine classes namely *I*, *II*, *III* and *IV* where the mode of transportation is by rolling, while sedimentation of classes *V*, *VII* & *VIII* are transported by uniform suspension, and for class VI the graded suspension is the main agent of transportation, whereas for class IX sediments are transported by pelagic suspension. Mycielska-Dowgiałło & Ludwikowska-Kędzia (2011) stated that Passega (1964) diagram may thus still be useful for the investigation of fluvial deposits, although it was elaborated originally for the marine environment.

The C–M patterns (Passega and Byramjee, 1969) drawn separately for El-Fayoum Depression Lakes samples are shown in Table (4) and Figure (6); Lake Qarun sediments fall in the ranges of *I, II,* and *III* classes which means that the sediments mode of transportation was by rolling, while Wadi El-Rayan lakes sediments fall in *I*, *III*, also *IV*, *V* , and *VI* ranges which means that modes of transportation were by rolling, uniform suspension, and graded suspension respectively.

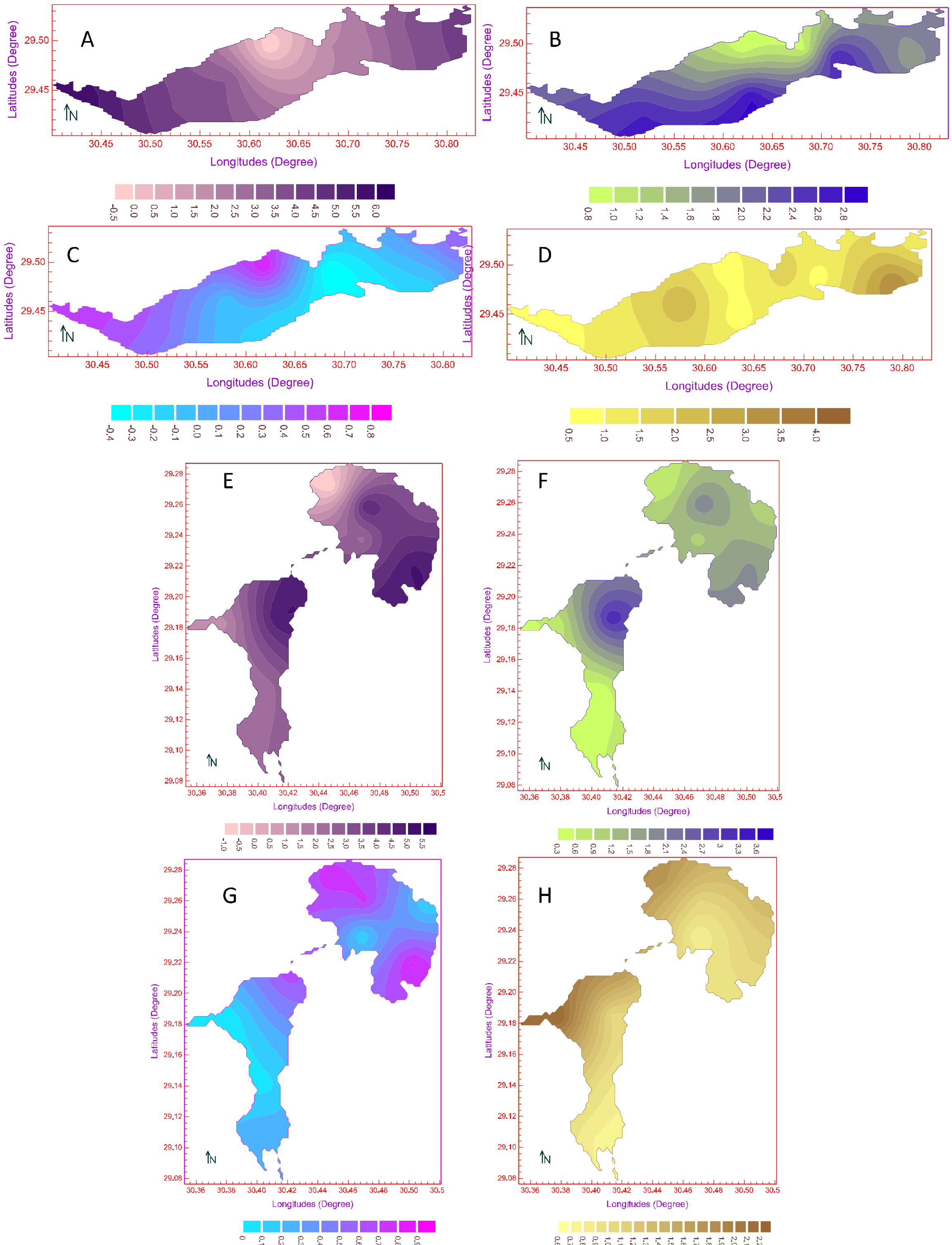

Figure (5): Distribution of statistical parameters of El-Fayoum Depression Lakes bottom sediment (A, B, C, and D mean size, sorting, skewness, and kurtosis of Lake Qarun, respectively) and (E, F, G, and H mean size, sorting, skewness, and kurtosis of Wadi El-Rayan Lakes, respectively).

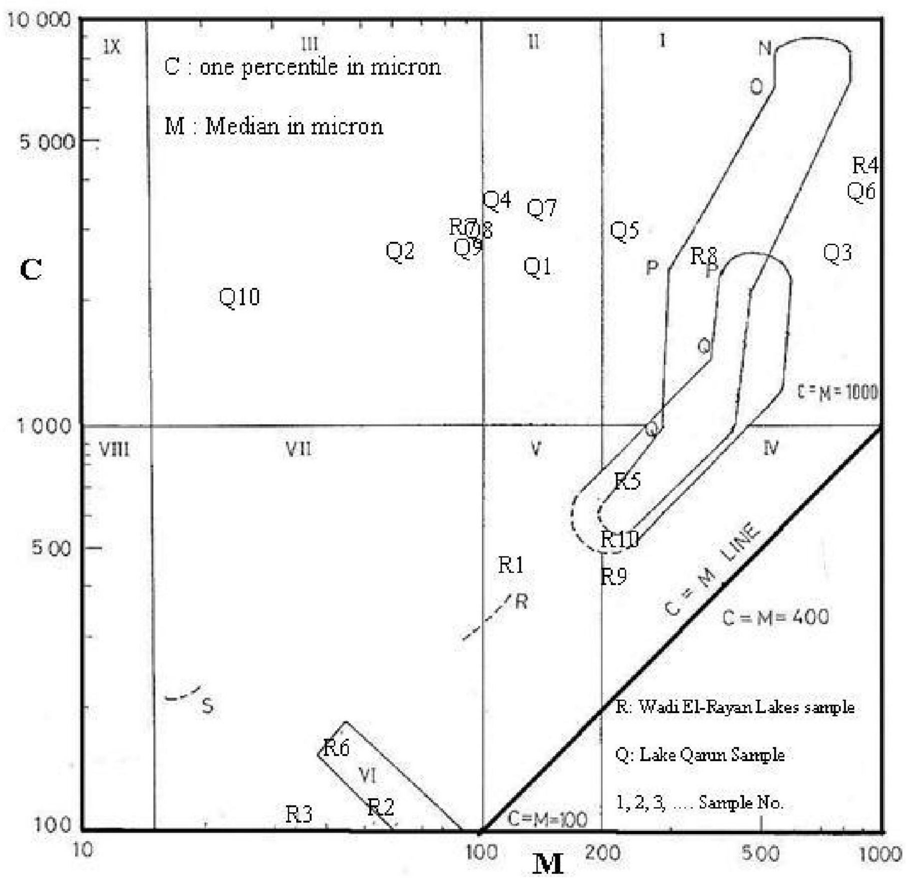

Figure (6): C-M pattern diagram of El-Fayoum Depression Lakes bottom sediment.

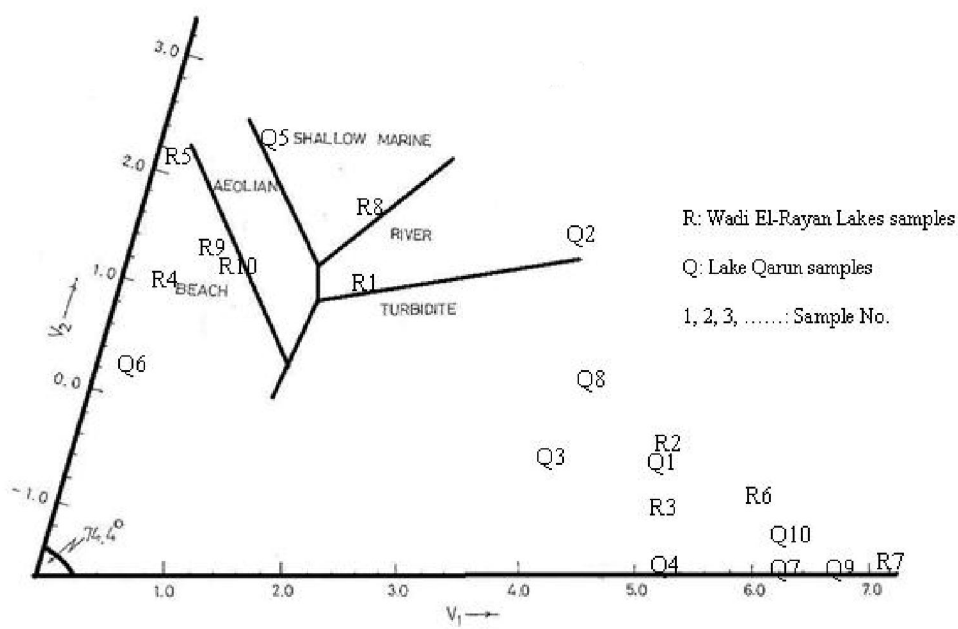

Figure (7): Multigroup, multivariant discriminant functions V_1-V_2 plot of El-Fayoum Depression Lakes bottom sediments.

5.2 Multigroup multivariant discriminant functions $V_1 - V_2$ plot

A rigorous statistical method of multigroup, multivariant linear discriminant functions proposed by Sahu (1983) was applied for discriminating the depositional environment of El-Fayoum Depression Lakes bottom sediment. When the values of the discriminant functions of V_1 and V_2 (Table 4) were plotted on the multigroup multivariant discriminant diagram Figure (7), only two samples one from Lake Qarun (eastward) and one from Wadi El-Rayan Lakes (at the front of connecting canal) fall in the field of the river environment; Most of Lake Qarun samples (sample no. 3, 4, 7, 8, 9, and 10) and four samples from Wadi El-Rayan Lakes (samples no. 2, 3, 6, and 7) fall in the field of turbidite deposition. One sample (sample no. 5) in Lake Qarun and Wadi El-Rayan Lakes (sample no. 8) falls in the field of shallow marine depositional environment. The other four samples; in Wadi El-Rayan Lakes (samples no. 4, 5, 8 and 9); and one in Lake Qarun (sample no.6) fall in beach depositional environment.

Table (4): Characteristics of truncation lines, C-M classes, and Discriminant functions V_1 and V_2 values of El-Fayoum Depression Lakes bottom sediment.

Sample No.		Traction/Saltation		Saltation/Suspension		Suspension	C-M	Discriminant functions	
		Ø	Wt%	ø	Wt%	Wt%	Classes	V_1	V_2
Lake Qarun									
1		-1.40	1.80	6.80	85.20	13.00	*II*	5.13	0.28
2		-1.20	2.50	6.40	90.00	7.50	*III*	5.11	2.60
3		-1.20	4.00	4.80	78.00	18.00	*I*	4.43	0.60
4		-1.20	18.00	5.10	72.00	10.00	*II*	5.57	-2.14
5		-1.40	0.20	4.00	99.80	0.00	*I*	2.23	1.61
6		-1.50	5.00	1.90	95.00	0.00	*I*	0.88	0.23
7		-1.30	17.00	4.80	60.00	23.00	*II*	6.15	-2.41
8		1.20	3.00	5.20	85.00	12.00	*III*	4.64	1.48
9		-1.30	1.80	4.20	64.20	34.00	*III*	6.80	-1.05
10		-1.50	0.15	6.30	67.85	32.00	*III*	6.25	0.01
Wadi El-Rayan Lakes									
First Lake	1	0.00	0.00	3.90	89.00	11.00	*V*	2.69	1.50
	2	0.00	0.00	4.20	54.00	46.00	*VI*	5.38	0.72
	3	0.00	0.00	3.90	68.00	3.20	*VII*	5.69	0.15
	4	1.20	48.00	4.00	52.00	0.00	*I*	0.88	1.17
	5	0.00	0.00	4.00	92.00	8.00	*IV*	2.27	0.76
Second Lake	6	0.00	0.00	4.20	74.00	28.00	*VI*	6.07	0.68
	7	-1.20	3.50	4.10	60.50	36.00	*III*	9.71	-2.73
	8	-1.50	0.15	4.00	99.55	0.30	*I*	2.08	1.92
	9	0.00	0.00	4.00	99.30	0.70	*IV*	1.66	1.30
	10	0.00	0.00	4.00	99.80	0.20	*IV*	1.76	1.17

6. Discussion

Grain-size distribution of sediments and the derived sedimentological parameters have been studied in order to relate them to the mechanics of transportation, deposition and also as environmental indicators. Many sedimentologists (Pettijohn, 1975; Reineck and Sing, 1975; Selley, 1976) have also stressed the need to take into account the geological setting of the basin, sedimentary structures, etc. while inferring the depositional environment from grain size parameters. The results of the present study from the application of three methods truncation lines, C–M patterns, and discriminant functions have a bearing on the interpretation of the mechanics of transportation and depositional environment of El-Fayoum Depression Lakes bottom sediments.

Sand fraction is the dominant fraction with variable ratios of gravel and mud fractions. Fine and very fine sand fractions have wide distribution in Lake Qarun, while in El-Rayan lakes medium, fine, and very fine sand fractions have wide distribution. Gravel fraction in lake Qarun are represented by carbonate skeletons which are exceed northward of El-Qarn island, whereas represented by rock fragments eastward of first lake near Baqarat hills due to physical weathering, and eastward and westward of second lake due to the excess of shells of Nummulites fauna in Wadi El-Rayan Lakes. Mud fractions (silt and clay) have wide distribution west and eastward of Lake Qarun, whereas in El-Rayan Lakes were absent at south of two lakes and eastward of first lake with wide distribution at front of El-Wadi drain due to siltation of suspended fines entrance with drain's water and middle zone of first lake due to great depths which allow to the suspended fines to precipitate. Sediment textural classes of Qarun sediments were mainly gravelly muddy sand, while sediment of Wadi El-Rayan Lakes was mainly muddy sand. Statistical parameters; mean size, sorting, skewness, and kurtosis of Qarun bottom sediment varies between coarse silt to very coarse sand, very poorly to moderately sorted, strongly fine skewed to strongly coarse skewed, and extremely lepto-kurtic to platy-kurtic respectively, whereas Wadi El-Rayan bottom sediments were medium silt to very coarse sand, very poorly sorted to well sorted, strongly fine-skewed to symmetrical, and very lepto-kurtic to platy-kurtic respectively. These results were in agreement with those obtained by Lotfy (1997), and El-Badry (2001), while disagreed with Salem (2006) because he ignores carbonate shells. The obtained data is agreed with opinion of El-Wakeel (1963) who stated that sediments are in average normally sorted - infect, considerably areas are covered with poorly and unsorted sediments, due to the presence of large amounts of carbonate shells and fragments of shells in the sand fractions higher than 2mm in diameter. The well - sorted and normally sorted sediment is generally located either along or near the shores of the lake, except in areas where the main drains enter the lake.

The characteristics of the individual grain size distribution curves provide a basis for an environmental classification. Precise limits for the slopes, truncation points, and percentages of each of the three basic populations for individual environments probably is impossible certain guidelines. Because of variations in provenance, post-depositional processes, and improper sampling, any single grain size distribution curve may not fit into a unique category Visher (1969).

Visher (1969) elaborated the ideas of Inman (1949) on three fundamental modes of transport of sediment (surface creep (traction), saltation and suspension) by associating the grain-size sub-populations marked by the truncation lines at the inflections on the cumulative curves. It can be noted that sediments of Lake Qarun show a prominent truction between traction and saltation with accounts reached to 18%, while truncation between saltation and suspension was more than 4 Ø with account reached to 99.8 %, and suspension load reached to 32 %. Wadi El-Rayan Lakes bottom sediments show a prominent truction with no traction and saltation except westward at first lake was 48% due to access of gravel fraction, and west and eastward of second lake was -1.2 and -1.5 Ø with account for 3.5 and 0.15% respectively due to access of gravel fraction, while truncation between saltation and suspension with account reached to 99.8 %, and suspension load reached to 46 %.

Using of C-M diagram for interpret possibilities of the results of granulometric analyses can be tremendously enhanced if the analysis of the grain-size distribution of the transported sediments (Flemming, 1988) is accompanied by studies of other textural features (Friedman *et al.,* 1992; Mycielska-Dowgiałło, 1992, 1993, 2001; Izmaiłow, 2001; Mycielska-Dowgiałło & Woronko 2004; Mycielska-Dowgiałło, 1988; Mycielska-Dowgiałło *et al.,* 1995, 2007; and Cichosz-Kostecka *et al.,* 1991; Elsner, 1992; Mycielska-Dowgiałło, 2001, 2007). The interpretative possibilities also increase if the analysis covers not only the deposits under study but also the deposits which constitute their potential source material (Folk, 1971; Flemming, 1988; Mycielska-Dowgiałło, 2007).

The C–M patterns of the sediments (Passega, 1957, 1964; Passega and Byramjee, 1969) reveal the relative dominance of the mechanics of sediment transport involving rolling (traction), graded suspension (saltation) or suspension. In addition, deposits of various environments give characteristic patterns. The C–M patterns of Lake Qarun sediments indicate that mode of transportation was by rolling, while Wadi El-Rayan lakes sediments modes of transportation were by rolling, uniform suspension, and graded suspension. These results were disagreeing with those obtained by Lotfy (1997), El-Badry (2001), and Salem (2006) because they use other simple applications.

The multigroup multivariant discriminant functions V_1–V_2 plot (Sahu, 1983) is based on rigorous statistical treatment of the sedimentological parameters in order to relate them to the depositional environments of the sediments. Most of El-Fayoum Depression Lakes sediments fall in the field of the turbidite depositional environment. Few samples fall in the field of shallow marine depositional environment, little samples fall in the field of beach and river depositional environment. Lakes bottom sediments are generally considered to have been deposited in complex turbidite environments. River environment appeared at mouth of both of El-Batts drain in Lake Qarun and connecting canal at second Lake of Wadi El-Rayan due to siltation of suspended fines come with wastewater. Beach environment appeared south ward of second Lake of Wadi El-Rayan due to regression of water (personal observation) leading to appear beach processes.

7. Conclusion

Fayoum Depression Lakes bottom sediments consist mainly of sand fraction with variable ratios of gravel and mud fractions. Gravel fraction in Lake Qarun is represented by carbonate skeletons, whereas represented by rock fragments, and Nummulites fauna shells in Wadi El-Rayan Lakes. Mud fractions (silt and clay) have wide distribution west and eastward of

Lake Qarun, whereas in El-Rayan Lakes were wide distribution at front of El-Wadi drain and middle zone of first lake. Lake Qarun sediments transportation mode was by rolling, while Wadi El-Rayan lakes sediments were by rolling, uniform suspension, and graded suspension. The mechanics of transportation and depositional environment of El-Fayoum depression lakes are generally considered as complex turbidite environments.

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