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Textural Characteristics and distribution of Coastal Sediments in the northern section of the Syrian continental shelf

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□ ABSTRACT □

Detailed textural study of the Northern section of the Syrian Continental shelf (N35.92991 E35.91785: N35.35752 E35.91542) has been carried out in order to determine the sediment nature and distribution. The sediments are mainly coarse to very fine-grained particles, moderately sorted, negatively skewed to fine skewed and leptokurtic to mesokurtic in nature. Interrelationship of various parameters shows bimodal nature of sediments having dominance of mainly medium to coarse sand. The major part of the sediment fall in coarse to very fine grained category (sand, silt and clay). Based on the CM (Coarser one percentile and Median size values in micron) pattern, the sediment fall in rolling and suspension field. These factors indicate that the sediments discharged from the rivers mixes with offshore sediments and with the sediments eroded from a source rock. Moreover, the wave energy conditions were high enough to disperse the sediments along the shelf and passing it to the open ocean and later dispersing them by littoral currents.

Key words: Grain size analysis, Syrian continental shelf, sorting, Sediment distribution

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دراسة الخصائص النسيجية وتوزع الرسوبيات الساحلية في القطاع الشمالي من الرصيف القاري السوري

الدكتور سامر غدير غدير*

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□ ملخّص □

أجريت دراسة ترسيبية مفصلة للقطاع الشمالي من الرصيف القاري السوري (N35.92991 E35.91785: N35.35752 E35.91542) بغية تحديد طبيعة ، وتوزع وخصائص الرسوبيات البحرية الموزعة على كامل هذا القطاع. أظهرت الدراسة أن الرسوبيات تتراوح بين الخشنة والناعمة جداً، معتدلة الفرز، ذات ميل سلبي إلى متماثل وأخيراً مفرطحه إلى متوسطة التفرطح. أظهرت علاقات الارتباط المختلفة لعدة بارامترات الطبيعة ثنائية الترسيب لرسوبيات المنطقة حيث يغلب الرمل على كافة العينات مع وجود كل من السلت والغضار ولكن بنسب مختلفة. بالاعتماد على مخطط CM، فإن أغلب الرسوبيات قد ترسبت إما عن طريق الدحرجة على القاع أو بشكل مباشر من المعلقات. تشير هذه العوامل إلى أن الرسوبيات قد تم تفريغها من الأنهار ومن ثم اختلطت مع الرسوبيات العميقة والرسوبيات المجواة من الصخور الأم. علاوة على ذلك، كانت طاقة الأمواج عالية بما فيه الكفاية لتشتيت هذه الرواسب على طول الرصيف القاري السوري ومن ثم نقلها إلى الأعماق المفتوحة ليتم تفريقهم بعد ذلك من قبل التيارات الساحلية.

الكلمات المفتاحية: تحاليل الحجم الحبيبي– الرصيف القاري السوري – معامل الفرز – توزع الرسوبيات

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Introduction

Continental shelves are intricate depositional systems where patterns of sediment distribution play a major role in establishing the ecosystems equilibrium (Chen et al., 2003). Sediment supply, deposition and dispersion result from the interaction between continental (e.g., river run-off, erosion) and marine (e.g., waves, tides, storms) forcing agents, functioning at both local and regional scales (Reading, 1996; Nichols, 2009).

A variety of processes involved in the movement of water and its relationship to depositional patterns have attracted the scientists for long time (e.g., Friedman & Sanders, 1978; Baruah et al. 1997; Chaudhri et al.1981; Rao et al. 2005; Anithamary et al. 2011). Waves, tides, currents and freshwater influx cause complicated water movement that transport and modify the properties of particulate matter in coastal regions. Although these regions are geomorphologically different, they have a common feature that suspended matter is carried back and forth, deposited, and eroded many times before it finally settles, either permanently or for a long period. Despite the fact that the problem of the source of the sediments is often very complicated, the process of grain size sorting and selection usually establishes equilibrium between the suspended matter, bottom, and the water.

Granulometric studies of sediments deposited on continental shelves provide valuable information on the fundamental properties of sediments and their depositional environment. The sediment grain size characteristics are influenced by a variety of transporting and depositional agents such as rivers, streams, waves and currents, sea level change, shoreline configuration, storms, and the distance from the source material, distance from the shoreline, nature of the source material and topography of the area (Reading, 1996; Nichols, 2009). Size frequency distribution and textural parameters obtained from grain size analyses have been studied by a variety of sedimentologists (e.g., Folk & Ward, 1957; Folk, 1966; Reddy et al., 2008; Rajani Kumari and Mrutyunjaya Rao, 2009; Manivel et al., 2016), in order to differentiate the sediments of various environments such as fluvial, estuarine and other coastal environments.

Aims

In this study, an attempt has been made to provide grain size data obtained from textural analyses of the northern section of the Syrian continental shelf in order to understand sediment depositional environments, processes and the depositional patterns of the sediments in the study area.

Regional Setting and Study Area

The tectonic regime in the eastern Mediterranean is currently characterized by the convergence of the Arabian, African and Eurasian Plates. The northern portion of the African plate comprises transitional to oceanic lithosphere and constitutes the southern passive margin, which is now preserved in the Levantine Basin (Makris et al., 1983). The Syrian margin, which is located in a particular geodynamic context, is subject to tectonic regimes since the late Tertiary (Manla Al Dakhil, 2009). This passive margin is subject to a complex tectonic regime related to the proximity of major tectonic structures (Robertson, 1998). This situation supports the threat of disturbances of the geological substratum and its recent sedimentary cover including the original disturbance geomorphic shore and instabilities in the marine part of the Syrian coast.

The study area is located along the northern section of the Syrian continental shelf. It extends over a distance of 106 km starts from Alsamra region in the north (N35.92991 E35.91785) to the Jable city in the south (N35.35752 E35.91542) (Fig. 1). Distribution of the Aldefla, Alkendeel, Alkabeer alshemaly and Alssanober are the main rivers flowing in this area, carrying huge amount of sediments to the Mediterranean Sea every year. These sediments tend to stay on the continental shelf or travel away across the shelf via submarine canyons towards deep sea (Gili et al. 2000, Paull et al., 2003).

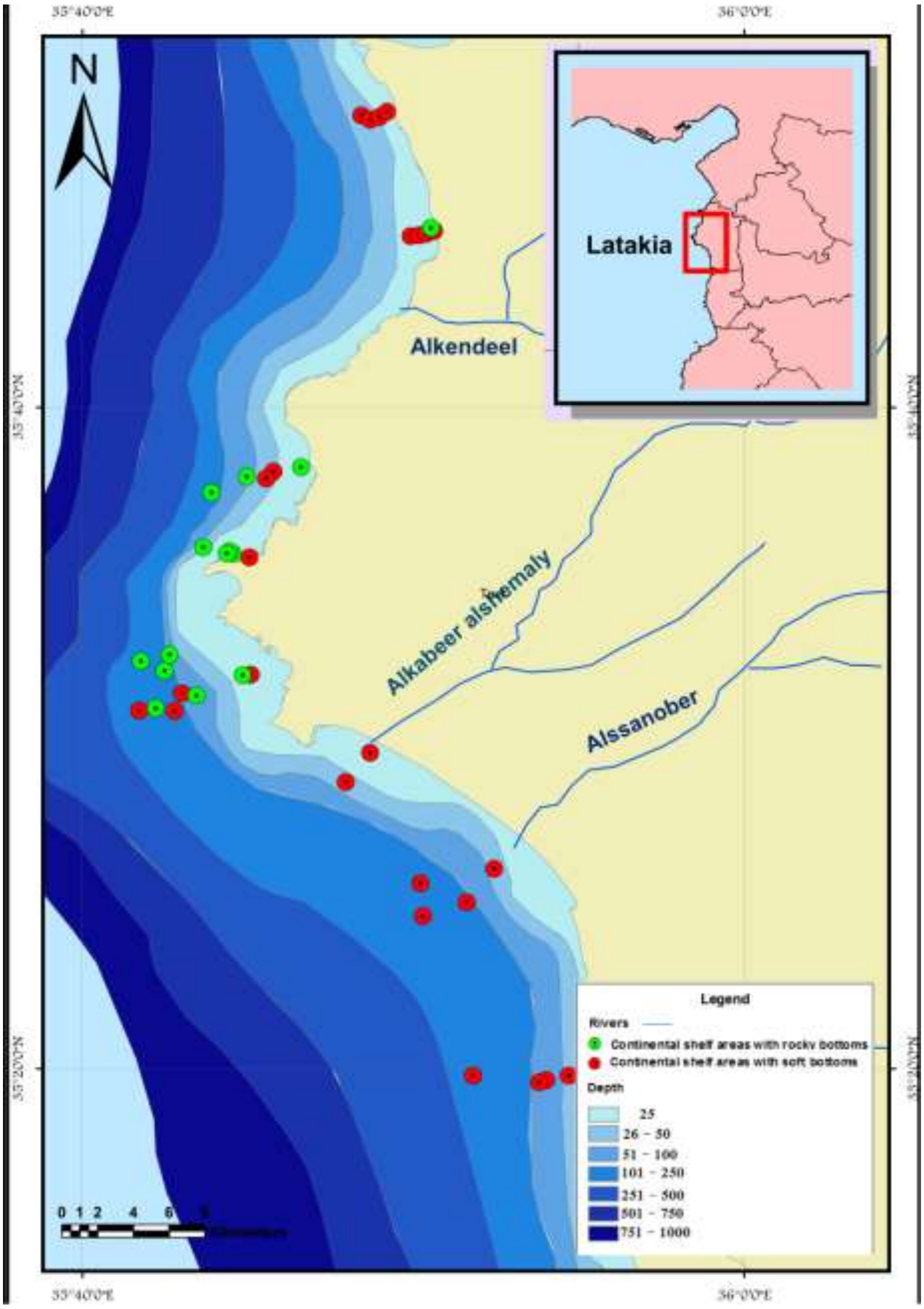

Fig. 1 Location map and sampling of the study area

Material and methods

To study the distribution of superficial sediments in the northern section of the Syrian continental shelf, thirty samples were collected by using Van Veen grab 1/40 m^2 sampler on board hired fishing trawler (Table, 1). The Van Veen grab has also showed the presence of rocky bottoms in some regions of the study area (Table, 2). Soft samples were taken from 10 transects set perpendicular to the coast between 2m and 190m water depth (Fig. 1). The water depth at each sampling point was determined using a Single-beam Echo-sounder. Differential Global Positioning System (DGPS) was used to determine the coordinates of the sampling points. All samples were collected during the research carried out between 27/9/2011 and 27/1/2015, at the High Institute of Marine Research- Tishreen University, under the financial support offered by the Higher Commission for Scientific Research-Syria. Approximately 1 – 2 Kg (wet weight) of sediments was collected at its site; samples were stored in plastic bags with lake water. The sediment samples were dried for at least 24 hours in an oven at 105 C^o to remove the moisture before analysis. From the dried samples, 100 mg was taken by the coning and quartering method. The 100 mg of sample is then subjected to sieve analysis in ASTM sieves at one-phi intervals for about 20 minutes in EFL – 2000/1-sieve shaker. Hydrometer analysis was carried out to compute fine-grained material (>4 Φ). These data were then combined to produce complete grain-size distributions. This basic data i.e. weight percentage frequency data is converted into cumulative weight percentage data, served as basic tool for the generation of other statistical parameters such as mean grain size, sorting coefficient and skewness using USGS GSSTAT and SEDPLOT (Poppe et al., 2004) described herein generates statistics to characterize sediment grain-size distributions and calculates the net sediment transport trend vectors (Gao and Collins, 1992). It is written in Microsoft Visual Basic 6.0 and provides a window to facilitate program execution. The input for the sediment fractions is weight percentages in whole-phi notation (Inman, 1952).

Results and discussion

Grain size analysis

The comparative study of the histograms of retained fractions of sieve and hydrometer analysis shows most of samples ranged from coarse to very fine-grained particles (Fig. 2; Table, 3). Similarly, most of the cumulative curves show almost similar trend. In the near shore zone, most of the samples show a moderately to well sorted grains. This is because of the dominance of coarse to medium sand size sediments in relatively high wave energy where wave action could remove finer material by winnowing and transporting it down the shelf. In the transition and offshore zone, the dominance of medium to fine grained sediments is may be due to limited inputs and weak wave energy conditions (Fig. 3).

Table 1 Areas of the continental shelf showing sampling points and their geographical coordinates.

0-20 m		20-50 m		50-100 m		100-200 m		Sampling stations
Coordinates	Depth (m)	Coordinates	Depth (m)	Coordinates	Depth (m)	Coordinates	Depth (m)	
N35.81718 E35.82000	13	N35.81552 E35.81593	26	N35.81385 E35.81109	70	N35.81522 E35.80745	145	Assanker - Basset
N35.75579 E35.84064	7	N35.75420 E35.83607	33	N35.75376 E35.83372	78.5	N35.75326 E35.83001	145	Aum attoyur - Alkendeel
N35.65347 E35.77184	13	N35.39725 E35.45876	30					Derasat
		N35.63551 E35.76209	30.7	N35.63258 E35.75839	78	N35.63224 E35.75830	126	Rass alfasoury
N35.59133 E35.75135	1.6							Almaahad
N35.53325 E35.75135	16.8	N35.52460 E35.71744	44	N35.51662 E35.71354	64	N35.51760 E35.69623	103	Almadena
N35.47974 E35.79960 N35.43643 E35.87345	17.3 18	N35.43115 E35.83790	32	N35.42067 E35.85970	79	N35.41479 E35.83818	122	Shokefat
N 35.32410 E 35.91285	17	N 35.32260 E 35.90103	40	N 35.32168 E 35.89882	83	N 35.32603 E 35.86491	190	Jable

Table 2 Areas of the continental shelf with rocky bottoms and their geographical coordinates.

0-20 m		20-50 m		50-100 m		100-200 m		Sampling stations
Coordinates	Depth (m)	Coordinates	Depth (m)	Coordinates	Depth (m)	Coordinates	Depth (m)	
N35.75772 E35.83933	15							Aum attoyur - Alkendeel
		N35.63808 E35.77689	22	N35.67227 E35.67741	55	N35.63224 E35.75830	126	Rass alfasoury
N35.53332 E35.74745	7.6	N35.53588 E35.70833 N35.62488 E35.72915 N35.54385 E35.70976 N35.52368 E35.72547	26.7 27.2 22.5 33.5	N35.54110 E35.69640 N35.51854 E35.70435	56.5 75.1			Almadena
N35.59370 E35.74158 N35.59458 E35.73971 N35.59373 E35.73854 N35.59344 E35.74742	9.6 12.7 12 2	N35.59701 E35.72574	39.9					Protected zone

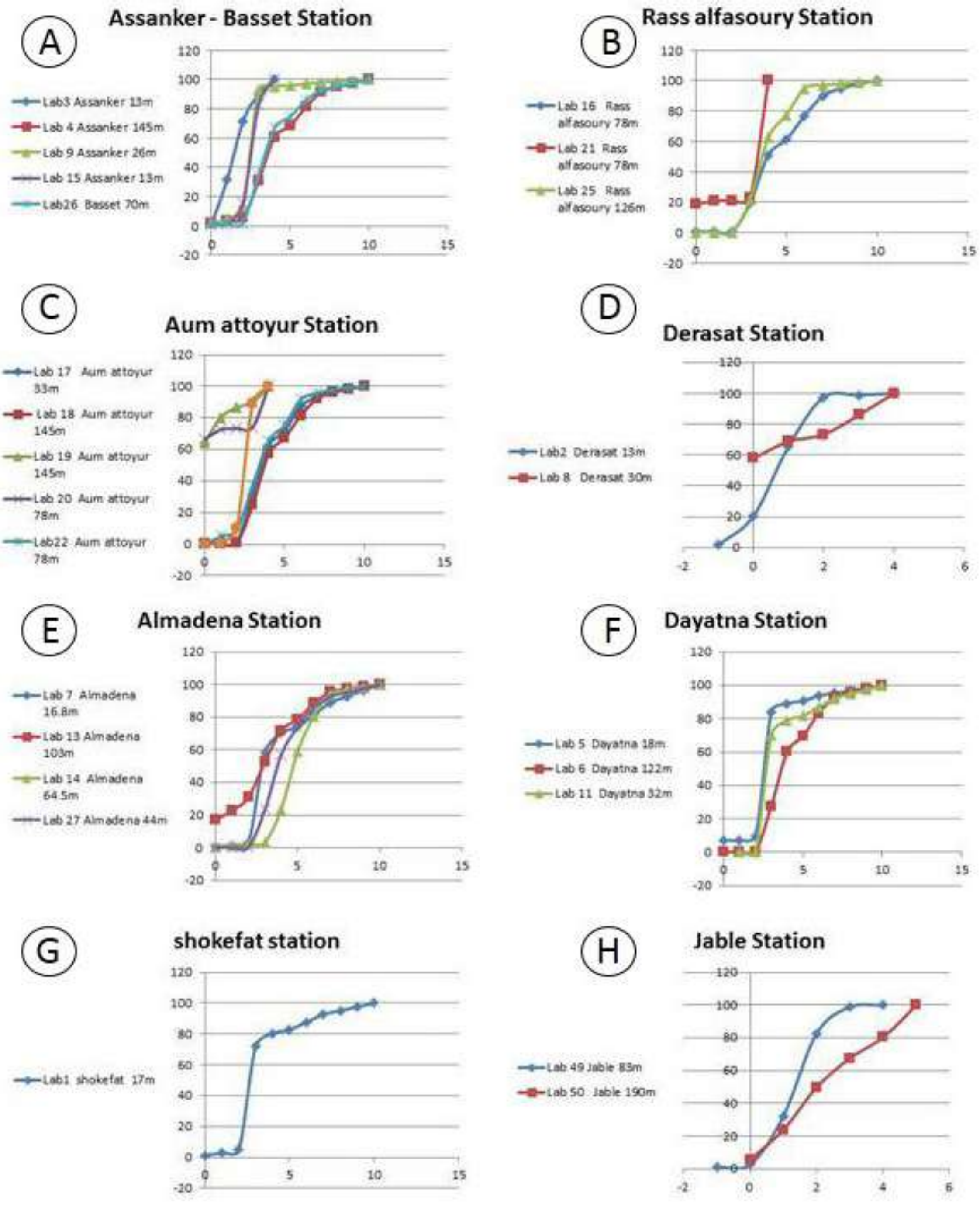

Fig. 2 Cumulative curves showing the trends of all the samples at different stations along the north section of the Syrian continental shelf [X-axis: grain size (Φ), Y-axis: weight (%)].

Statistical parameters

Mean size (MZ)

Phi mean size (Mz) is a measure of central tendency, which is calculated by the formula (Φ 16 + Φ 50 + Φ 84)/3 and mainly an index of energy conditions. The mean grain size of the study area sediments varies from-0.25 ф to 8.95 ф (Table 3) with an average of 2.66 ф (Fig. 3A) and thus falls in the Fine Sand category. The variations in ϕ mean size reveal the differential energy conditions resulting in their deposition (Karuna et.al., 2013). The range of mean (i.e. fine to coarse) indicates low discharge and proximity to source and hence limited transport of sediments (Joseph, et.al., 1997). The variation in mean size is a reflection of the changes in energy condition of the depositing media and indicates average kinetic energy of the depositing agent (Sahu, 1964). According to the mean size results in the studied stations (Table 3), it appears that the energy conditions was decreased from the shore line towards offshore transition and offshore except some stations such as Almadena station where there is a kind of turbulence in the wave energy condition.

Standard deviation (бi)

Inclusive graphic standard deviation is the measure of sorting or uniformity of particles size distribution. It is calculated by the formula (Φ 84 - Φ 16) / 4 + (Φ 95 - Φ 5) / 6.6 and mainly indicates the difference in kinetic energy associated with these modes of deposition. It is an important parameter in sediment analysis because it reflects the energy conditions of depositional environment but it does not necessarily measure the degree to which the sediment has been mixed (Joseph, et.al., 1997). Sorting has an inverse relation with standard deviation. The standard deviation of the study area sediments varies from well sorted to extremely poorly sorted (0.44 Φ to 8.62 Φ) (Table 3) with an average of 1 Φ (Fig. 3B) and falls in the moderately sorted category. The variations in the sorting values are likely due to continuous addition of coarser or finer materials in differential proportions.

Skewness (Sk)

The graphic skewness measures the systematic of the distribution or predominance of coarse or fine-sediments and is calculated by the formula (Φ 84 + Φ 16 – 2 Φ 50) / 2 (Φ 84 - Φ 16) + (Φ 95 + Φ 5 – 2 Φ 50) / 2 (Φ 95 – Φ 5). The positive value represents more fine material in the fine tail i.e., fine-skewed, whereas, the negative value denotes coarser material in coarser-tail i.e., coarse skewed. Skewness value ranges in between -0.60 (very coarse skewed) to 0.90 (very fine skewed) (Table 3) with an average of -0.24 (coarse skewed) (Fig. 3C). Very coarse skewed to coarse skewed sediments indicate deposition at high-energy environments, whereas fine skewness of sediments indicates the deposition of the sediments in sheltered low energy environments (Reddy et al., 2008).

Kurtosis (KG)

The graphic kurtosis is a quantitative measure used to describe the departure from normality of distribution. It is a ratio between the sorting in the tails and central portion of the curve and is calculated by the formula (Φ 95 - Φ 5) / 2.44 (Φ 75 - Φ 25). If the tails are better sorted than the central portion, then it is termed as leptokurtic, whereas, it is platykurtic in opposite case. If both are equally sorted then mesokurtic condition prevails. The kurtosis value of the study area sediments ranges from 0.66 (very platykurtic) to 1.39 (leptokurtic) (Table 3) with an average of 0.90 (mesokurtic) (Fig. 3D). Majority of the samples fall under platykurtic type. Friedman (1967) suggested that extreme high or low values of kurtosis imply that part of the sediment achieved its sorting elsewhere in a high-energy environment. The variation in the kurtosis values is a reflection of the flow characteristics of the depositing medium (Sahu, 1964).

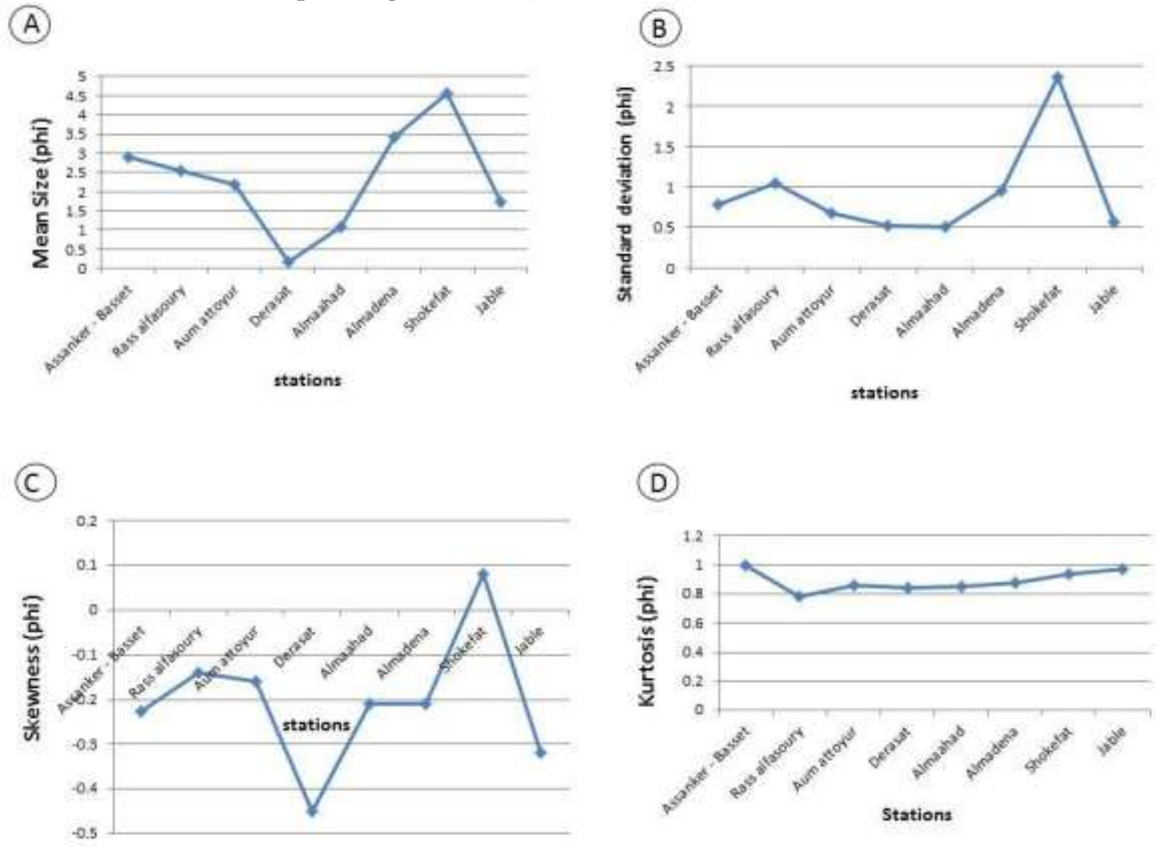

Fig. 3 Cumulative histograms of all samples showing the average of: A: Mean, B: Standard deviation, C: Skewness and D: Kurtosis in all studied stations.

Bivariate Plots

Bivariate plots between certain parameters are also helpful to interpret various aspects of depositional environment, as the textural parameters of the sediment are often environmentally sensitive (Folk and Ward, 1957; Passega, 1957; Friedman, 1967). The bivariate plot between Mean size and Standard deviation (Fig. 4A) of the study area samples shows that the nature of the sediments are dominantly bimodal, of which, the dominant constituent is sand. The silt and clay are subordinate; making the admixture moderately well sorted to moderately sorted. The higher energy level permits deposition of coarser sediments as well as transportation of a much wider range of fine sediments (Brayant, 1982). The bivariate plot between Mean size and Skewness (Fig.4B) clearly brings out the values, which fall mostly in the negativelty-skewed area, with a mean size range from coarse sand to coarse silt. This is due to the mixture of two or three size classes of sediments. In general, the ideal fractions are nearly symmetrical but the mixing produces either positive or negative skewness depending upon the proportions of size-classes in the admixture. The present values were mostly falling in the negative skewed zone of the graph; however, a few samples are positively skewed, in the mean-size range. It clearly indicates the nature of sediments with higher percentage of sand and subordinate silt and clay. The negative skewed indicates excess of coarser tail represents the depletion of the finer sediments indicates a depositional tendency (Duane, 1964). The sediments with positive skewness lie in low energy environments while; sediments of negative skewness occur in high energy environments. The plot between Standard deviation and Skewness (Fig.4C) shows almost moderately sorted and negatively skewed sediments. The plot shows clustering of grains in 0.50 Φ to 1.0 Φ sector, which establishes two conditions i.e. either unimodal samples with good sorting or equal mixture of two modes. The relation between mean-size and kurtosis is complex and theoretical (Fig.4D). The plot denotes the mixing of two or more size-classes of sediments, which basically affect the sorting in peak and tails i.e. index of kurtosis. It shows that the sediment-admixture is dominated by coarse-sand to fine-sand including silt with clay. The plot between standard deviation and kurtosis, shows most of the samples falls in mesokurtic to platykurtic and moderately sorted to moderately well sorted because of the dominance of medium to fine sand-size sediments (Fig.4E).

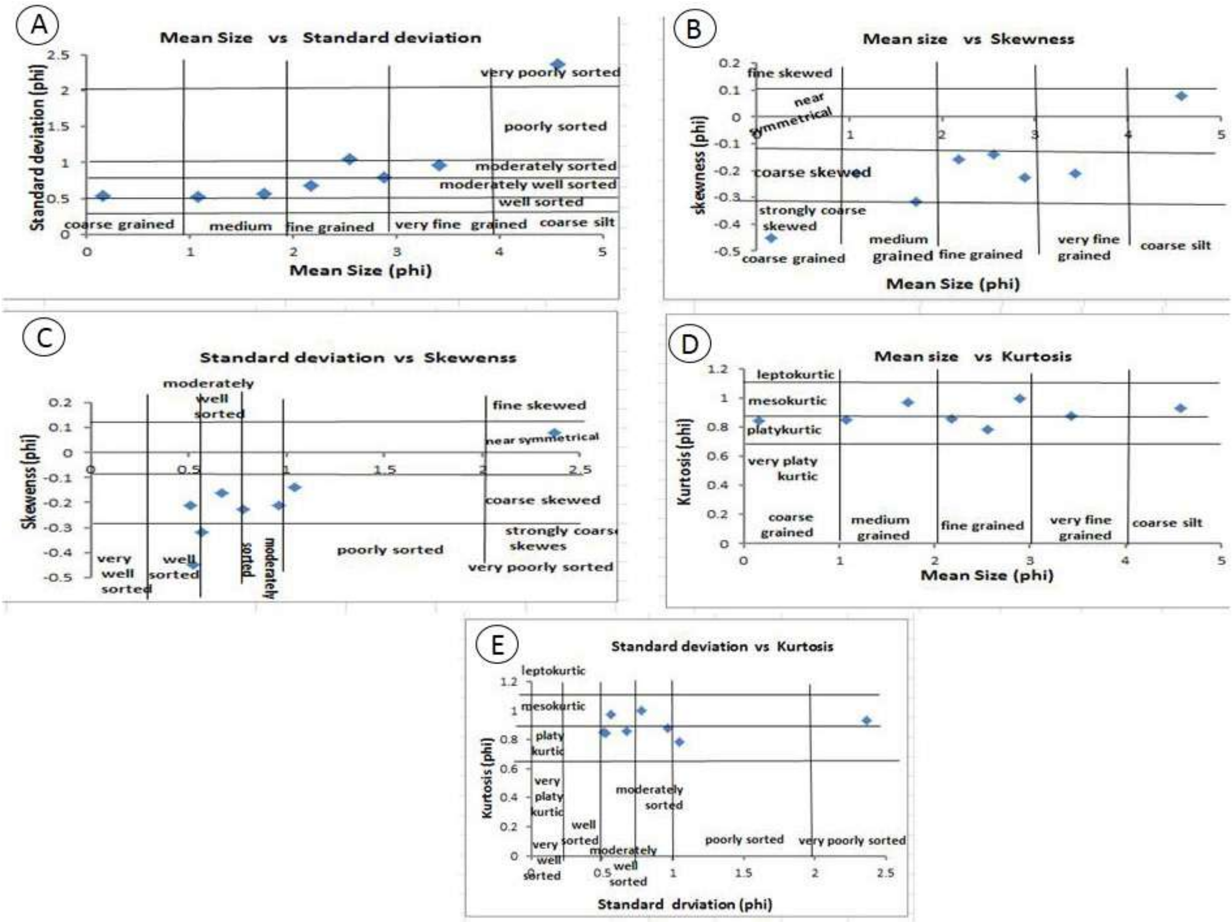

Fig. 4 Bivariate plots showing: A: Mean Vs Standard deviation, B: Mean Vs Skewness, C: Standard deviation Vs Skewness, D: Mean Vs Kurtosis and E: Standard deviation Vs Kurtosis of all studied stations.

Triangular diagram

One of the most common methods used by sedimentologists is to plot the basic gravel, sand, silt, and clay percentages on equilateral triangular diagrams. This means the presenting data will be simple and facilitates quick classification of sediments and comparison of samples (Poppe and Eliason, 2008). This study reveals that most of the coastal sediments of northern section of the Syrian continental shelf fall in the sandy mud category (Fig. 5). This means that the wave energy conditions were high enough to disperse the sediments along the shelf and passing it to the open ocean and later dispersing them by littoral currents.

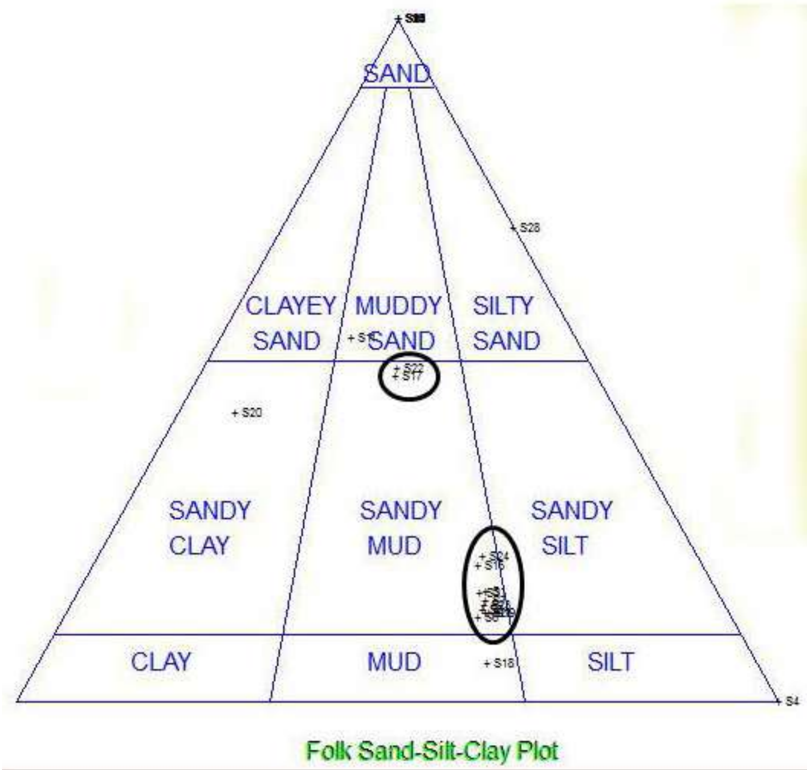

Fig. 5 Triangular diagram showing distribution of study area sediments.

CM plot

The CM patterns of the sedimentary environment determine processes that are responsible for the formation of clastic deposits. It also helps in analyzing depositional environment, transportation mechanism with respect to size and energy level of transportation. Passega (1957) introduced C-M plot to evaluate the hydrodynamic forces working during the deposition of the sediments by plotting coarsest first percentile grain size (C) and the median size (M) of sediment samples on a double log paper (Fig. 6). The present plot is made and interpreted following Passega (1957, 1964). Most of the samples of the study area scattered within class V and IV while the rest fall in the VI class. This means that the load type of studied samples can be designated as suspension and rolling for the samples of class V, rolling for the samples of class IV, and uniform suspension for the samples scattered within class VI.

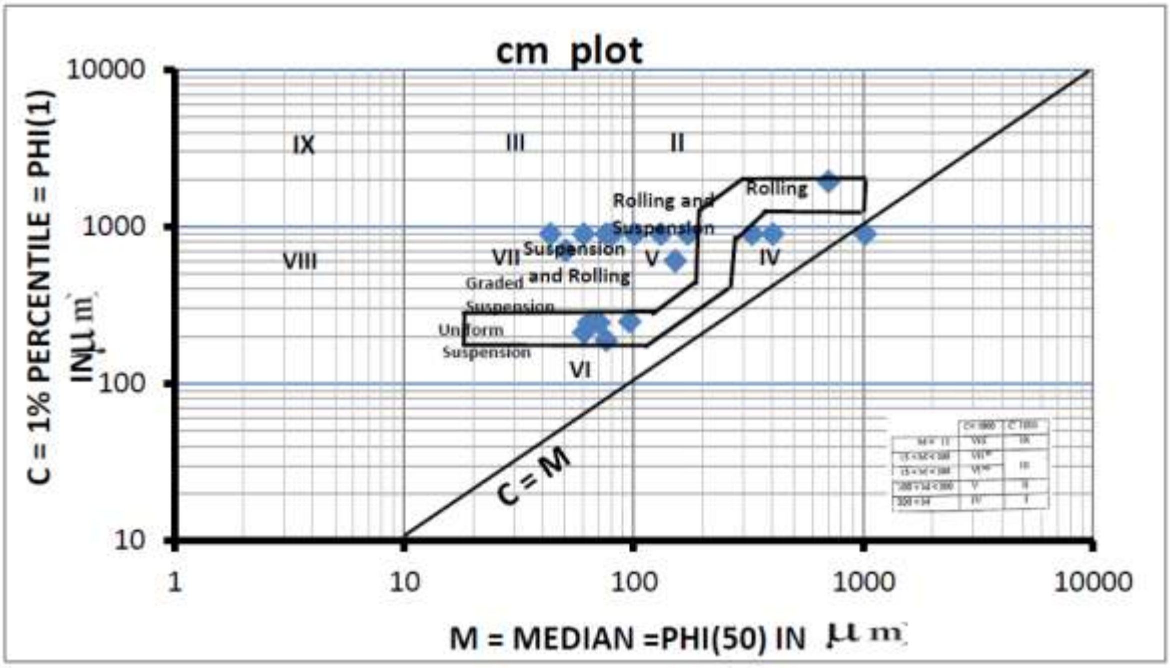

Fig. 6 C-M plot showing distribution of sediment samples. Samples fall in V sector indicates suspended sediments with less rolling; samples fall in IV sector indicates rolled sediments; while samples fall in VI and VII sector denotes uniform suspension.

Conclusions

The following conclusions are made:

- The textural parameters indicate that the sediments are coarse to very fine-grained particles, moderately sorted, negatively skewed and deposited under high to low energy conditions with dominant rolling and suspension mechanisms.
- The variations in mean size indicate differential energy conditions at different locations. Whereas, the variation in the sorting values are likely due to continuous addition of coarser or finer materials in varying proportions at different locations.
- Cumulative Curves and bivariate plots drawn between different textural parameters clearly established that the sediments are mostly bimodal and composed of mainly medium sand with subordinate silt and clay. These are moderately sorted and of fine sand size.
- Various bivariate plots between mean, skewness, kurtosis and standard deviation explain the dynamic process operating in the region together with the influence of climatic changes.
- Triangular diagram reveals that most of the coastal sediments of northern section of the Syrian continental shelf fall in the sandy mud category.
- The CM plots indicate that the Latakia coast sediments underwent the rolling and suspension under tractive current; however, a few samples showing uniform suspension mode only.

Table 3 Grain size parameters and interpretation of the north coast of Syrian continental shelf samples.

Location	Depth (m)	Sediment Type	Gravel %	Sand %	Silt %	Clay %	Median	Mean (Mz)	Sorting (σ1)	Skewness (S_k)	Kurtosis (k_G)
Assanker - Basset	70	Sandy Mud	0	16.22	53.44	30.33	4.28	4.22 CSi	1.09 PS	-0.11 NS_k	0.80 PKg
	13	Sand	0	100	0	0	1.30	1.23 MS	0.53 MWS	-0.24 NS_k	0.86 PKg
	145	Sandy Mud	0	16.03	52.89	31.11	3.66	3.58 CSi	0.93 MS	-0.22 NS_k	0.97 MKg
	26	Sand	0	0.001	99.99	0.001	2.60	2.54 FS	0.57 MWS	-0.33 NS_k	1.36 LKg
Rass alfasoury	78	Sand	0	100	-	-	1.51	1.46 MS	1.38 PS	-0.09 Sy	0.66 VPKg
	78	Sandy Mud	0	12.25	54.40	33.34	3.71	3.65 VFS	0.71 MS	-0.19 NS_k	0.91 MKg
Aum attoyur - Alkendeel	33	Sandy Mud	0	14.84	54.26	30.90	4.02	3.98 VFS	0.92 MS	-0.11 NS_k	0.81 PKg
	145	Sandy Mud	0	13.56	54.39	32.04	4.05	4.01 CSi	0.90 MS	-0.13 NS_k	0.83 PKg
	145	Sand	0	100	0	0	-0.21	-0.23 VCS	0.45 WS	-0.07 Sy	0.73 PKg
	78	Sand	0	100	0	0	-0.24	-0.25 VCS	0.45 WS	-0.03 Sy	0.73 PKg
	78	Muddy Sand	0	53.29	17.237	29.466	3.34	3.23 VFS	0.87 MS	-0.29 NS_k	1.03 MKg
	7	Sand	0	100	0	0	3.43	2.36 FS	0.44 WS	-0.33 VNS_k	1.02 MKg
Derasat	13	Slightly Gravelly Sand	0.54	99.46	0	0	0.53	0.44 CS	0.55 MWS	-0.30 NS_k	0.95 MKg
	30	Sand	0	100	0	0	-0.12	-0.12 VCS	0.50 WS	-0.60 VNS_k	0.74 PKg
Almaahad	1.6	Sand	0	100	0	0	1.13	1.08 MS	0.51 MWS	-0.21 NS_k	0.85 PKg
Almadena	16.8	Sandy Mud	0	20.08	50.45	29.45	3.92	3.92 VFS	1.09 PS	-0.04 Sy	0.74 PKg
	103	Sandy Mud	0	47.75	25.89	26.35	1.67	1.45 MS	1.15 PS	-0.30 VNS_k	0.78 PKg
	64.5	Mud	0	5.74	58.89	35.37	4.59	4.48 CSi	0.83 MS	-0.34 VNS_k	1.13 LKg
	44	Sandy Mud	0	12.92	55.50	31.57	3.92	3.86 VFS	0.77 MS	-0.16 NS_k	0.85 PKg
Shokefat	17	Sandy Clay	0	42,37	7.76	50.13	3.30	8.95 C	8.62 EPS	0.90 VPS_k	0.81 PKg
	79	Sandy Mud	0	12.92	55.13	31.94	3.85	3.80 VFS	0.77 MS	-0.15 NS_k	0.87 PKg
	18	Sandy Mud	0	48.85	25.56	25.73	2.89	2.89 FS	0.90 MS	-0.22 NS_k	1.39 LKg
	122	Sandy Mud	0	14.17	54.31	31.51	3.75	3.75 VFS	0.76 MS	-0.14 NS_k	0.85 PKg
	32	Sandy Mud	0	21.32	50.58	28.09	3.44	3.46 VFS	0.79 MS	0.01 Sy	0.75 PKg
Jable	17.5	sand	0	100	0	0	1.17	1.09 MS	0.52 MWS	-0.30 NS_k	0.91MKg
	40	sand	0	100	0	0	3.40	3.32 VFS	0.48MWS	-0.39 VNS_k	1.15LKg
	83	sand	0.38	99.616	0	0	1.22	1.13MS	0.53 MWS	-0.31 VNS_k	0.92MKg
	190	Silty Sand	0	69.46	30.54	0	1.47	1.36 MS	0.73 MS	-0.27 NS_k	0.90 MKg

Note: C-Clay, Csi-Coarse silt, VCS-Very Coarse Sand, VFS- Very Fine Sand, FS-Fine Sand, CS-Coarse Sand, MS-Medium Sand, EPS-Extremely Poorly Sorted, MS-Medium Sorted, MWS- Moderately Well Sorted, PS-Poorly Sorted, WS-Well Sorted, VPSk-Very Positively Skewed, NSk-Negatively Skewed, SY-Symmetrical, VNSk-Very Negatively Skewed, NSk-Negatively Skewed, MKg-Mesokurtic, PKg-Platykurtic, VPKg-Very Platykurtic, LKg-Leptokurtic, VLKg-Very Leptokurtic

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