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Textural Characteristics and Depositional Processes of Sediments from a 47 km Transect in the Niger Delta, Southern Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. The first author designed the study, the second author took active part in the field and data acquisition process while the third author drafted the first manuscript. The forth author managed the literature searches and the computations. All authors read and approved the final manuscript.

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ABSTRACT

120 sediment samples collected along a 47 km transect from Ikot Abasi to Eket, Akwa Ibom State were subjected to granulometric analysis to determine their textural characteristics and depositional processes. Standard sedimentological methods involving sieve analysis were utilized to determine the various size distributions for each sample. This was further subjected to statistical treatment (mean size, sorting, kurtosis, skewness, bivariate and multivariate analyses). Results show that the samples were very fine to pebbly (3.23 to -1.53) Ø diameter in size and varies from very poorly sorted to very well sorted (2.069 to 0.294) Ø with about 86% of the samples being poorly sorted. The sediments are predominantly leptokurtic (91%), with only few (9 samples) being platykurtic (range 8.148 to -1.082) Ø and are coarse to very fine skewed in nature. The dominant modes of transportation reflected by these sediments are saltation and surface creep attributed mostly to

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current and channel action. Bivariate analysis revealed that most of the sediments are associated with fluvial processes of deposition with beach processes being subordinate. Multivariate analysis showed that shallow marine agitated environment mostly characterized the sediments of this study area. CM pattern for the sediments reveal deposition was mainly by graded suspension to bottom suspension and rolling. These features characterize sediments deposited by fluvial processes dominated by tractive current patterns in a shallow marine depositional environment.

Keywords: Granulometric analysis; skewness; kurtosis; graded suspension.

1. INTRODUCTION

The area under investigation is a 47km transect in the southern part of Akwa Ibom State Nigeria between Eket and Ikot Abasi (Fig. 1). It is drained by two notable rivers, the Imo and Qua-Iboe rivers. In between these two rivers are three major creeks (Essene, Jaja and Awa creeks) which are tidal and constitute the main source of water that feed the swamps in most part of the area. To date, no systematic study has been carried out on sediments from this area. Grain size analysis has been a significant tool for relating textual characteristic of sediments to their depositional processes [1-2]. The size distribution is a reflection of the fluidity factor of the depositing medium and the energy factor of the environment of deposition. Several works have been carried out to distinguish depositional environment based on their textural characteristics [3-6].

This study was undertaken to describe the textural characteristics of about 120 samples collected across the Ikot Abasi - Eket transect in order to understand the depositional processes (energy and transport mechanism) and paleoenvironment of deposition.

2. GEOLOGIC SETTING

The study area lies between latitude 4° 30' – 4°45' and longitude 7°35' – 7°53'E covering about 47 km stretch within the southern part of Nigeria. It falls within the Niger delta basin and overlies the location of the Rift-Rift-Rift triple junction associated with the separation of Africa and South American continents. It is an ocean-ward continuation of the Gulf of Guinea [7]. It is bordered to the northeast by the Calabar hinge line which separates it from the Calabar Flank and to the north and northwest by the Benin hinge line and the Anambra basin respectively.

Regionally, the Niger Delta trends in the northwest-southeast direction. The sediments of the Niger Delta are Paleogene (Eocene) to Recent in age and is represented by a thick wedge of clastic deposits covering an area of about 105,000 km^2 [8]. Studies on the geology of this petroliferous basin have been documented by earlier workers in the area [7-14].

Its evolution is controlled by pre- and syn-sedimentary tectonics and is associated with the third megatectonic phase of the development of southern Nigeria sedimentary basins as described by [11,12,15]. Of significance in the development of the Niger delta was the shape of the Cretaceous coastline, which was progressively being re-shaped as the delta grew [16]. Climatic variations and the proximity and nature of sediment source areas also contributed to the factors that controlled the growth of the Niger Delta. The various stages of growth of the delta marks the delimitation of the five (5) depobelts that characterizes the Niger Delta.

Stratigraphically, the Niger Delta is made up of three main formations. These include the Akata, Agbada and Benin Formations. The Akata Formation is characterized predominantly of shales [17]. The shales are dark grey, silty and uncompacted and represent the pro-deltaic sediments of the basin. They contain several lenses of abnormally high pressures siltstones/ fine grain sandstones [8].

The Agbada Formation consist of intercalations of sandstones and shales of the delta front deposit, distributary channel and delta plain origin [8]. The alternation of sandstone-shale sequence has been interpreted as a cyclic marine-fluvial sequence during deposition of the Agbada Formation [18]. The sands are fairly clean, locally calcareous and glauconitic. The shales are dark grey, hard, silty in places and locally glauconitic. The Benin Formation was first described by [19] and expanded upon by [10] who erected a type section for this formation at Elele – 1 well, 34 km northwest of Port Harcourt. It consists predominantly of massive, highly porous, freshwater bearing sandstones, with some shale interbeds which are considered to be of braided stream origin [8].

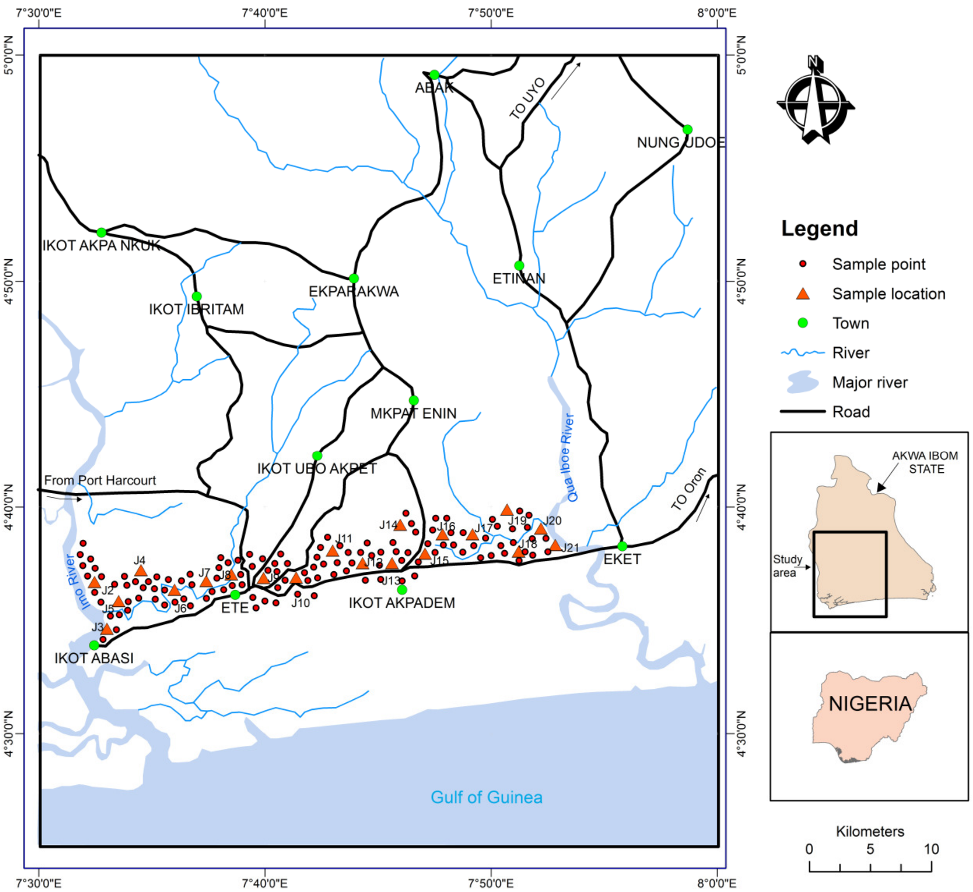


Fig. 1. Map of the study area showing the sample location points

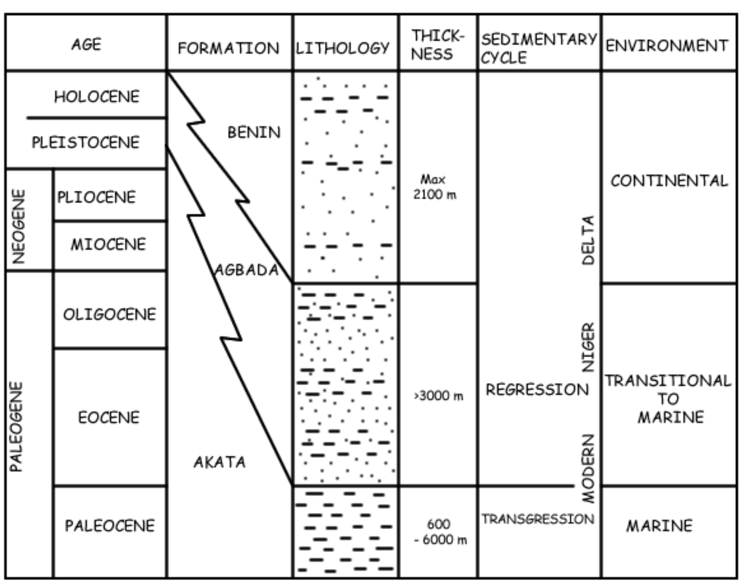


Fig. 2. Generalized lithostratigraphic chart of the Niger Delta (after Nwangwu [17])

The present study area belongs to the coastal swamp depobelt of the Niger Delta [7] and fall within the Benin Formation with some Quaternary (Alluvial) sedimentary deposits. These alluviums are made up of silts and sandy materials within the flood plain, swamps and tidal inlets are high grey – dark carbonaceous muds and clays [20]. The Benin Formation underlies the Quaternary sediments and is characterized by sands with shales and lenses of lignite in certain areas.

The area under study is generally flat and low lying with alluvial plains, sand ridges and rolling sandy plains as the principal features [21] and characterized by creeks and estuarine processes shaping it consistently in different areas. Notable creeks within the area include the Jaja, Essene and Awo creeks. Two major rivers that influence the area under investigation are the Imo and Qua Iboe rivers, with large network of tributaries, streams, creeks, rivulets and tidal inlets [21].

3. METHODOLOGY

A total of 120 sediment samples were collected across southern Nigeria along a 47 km transect from Ikot-Abasi to Eket in Akwa Ibom state. This area falls within the Nigeria's Niger Delta sedimentary basin. Sediment samples were collected in polyethene bags for laboratory analysis. During this process, biases was avoided by collecting samples that were fresh and devoid of contamination from nearby engineering structures. In the laboratory, the dried samples were subjected to coning and quartering. The samples were then subjected to sieve analysis using a Ro-tap sieve shaker for a period of 15 mins for each sample. The measurement of the weight retained was carried out and tabulated accordingly. Cumulative curves were plotted and statistical parameters such as mean, median, standard deviation, skewness, and kurtosis were all computed following the technique proposed by [3]. Log – plots were prepared in order to characterize the various transport and depositional mechanisms and compared with the findings of [1]. Bivariate and linear discriminate function (multivariate) analyses were also carried out to properly characterize the sediments and determine the variation in energy and fluidity factors [4] which seems to have excellent correlation with different process in terms of mode of deposition. The first percentile of about 95 samples were plotted against median diameter (mm) according to [22] method and used characterize the transportation mechanism for the sediments.

4. RESULTS AND DISCUSSION

4.1 Grainsize Parameters

The result of textural analysis of the samples was used to determine the statistical parameters and is presented in Table 1. The result for the various locations have been grouped in order to facilitate data handling. Their range and average for each unit was calculated (Table 1). From the results, the sediments range from fine to coarse grain, with medium grain class being predominant. They are poorly to moderately sorted, leptokurtic and very fine skewed sands. Distinction between environments by grainsize distribution is informed by the specific properties of such environments, and is illustrated by the unique properties of one or more subpopulations within their size distribution [1].

4.1.1 Mean grain size (Mz)

This majorly characterizes the index of energy conditions during deposition. In general, the mean grain size in the study area range from (-1.533 to 3.233 ϕ) with an average value of (2.12 ϕ). From the average value for mean grain size, fine to medium grain sands predominate the study area. This indicates that the energy condition of the depositing agent was moderate, however the presence of a wide range of phi (ϕ) grain size values signifies fluctuating energy levels of the depositing medium.

4.1.2 Sorting (δ_I)

This graphic measure has an inverse relationship with standard deviation and characterizes the fluctuation of the kinetic energy of the sediments as they are transported to the deposition site. Its values for this study range from 0.294 to 2.069 ϕ, with an average value of 1.41 ϕ. The sediments are moderately sorted in nature; however, some sediments show other sorting characteristics due likely to the continuous addition of finer/coarser materials in varying proportions during deposition [5].

4.1.3 Skewness (SK_I)

Graphic skewness measures the symmetry of the distribution. It determines whether the sediments are characterized by predominantly coarse or fine sediments. The skewness of the samples in this study range from -1.631 – 12.840 ϕ with an average value of 3.80 ϕ suggesting that the samples were strongly fine skewed. Awasthi

[23] was of the opinion that the skewness sign is the most sensitive to environmental conditions amongst other grainsize parameters of terrigenous sediments. During turbulence sediments tend to be negatively skewed and characteristically becomes positively skewed in calmer environmental conditions. As observed in this study, strongly fine skewed to fine skewed sediments implies introduction of excess fine materials, mostly from the suspension fraction, associated with less turbulence during deposition.

4.1.4 Kurtosis (K_G)

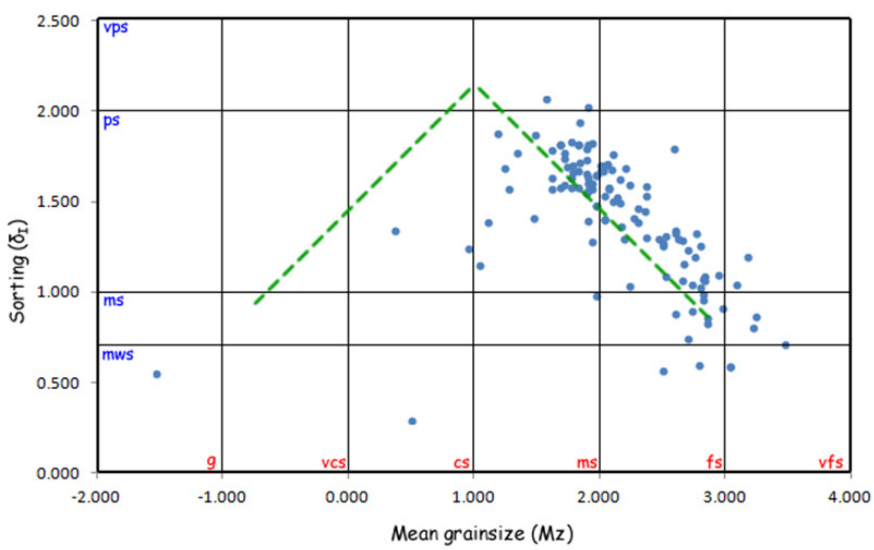
The graphic kurtosis quantitatively measures how the sediments depart from normality. It clearly describes the sorting at the tails of the curve and relate them to the central portion. In this study, the kurtosis values range from -1.082 to 8.148 ϕ, with an average of 3.21 ϕ, suggesting very leptokurtic to platykurtic character. It has been pointed out that where the kurtosis values are very high (as in this case), sediments may have achieved sorting from elsewhere in a higher energy environment before being redeposited in a different environment of completely different environmental [5,24].

4.2 Bivariate Analysis

Bivariate analysis varies dual parameters and aid in the interpretation of energy conditions, transportation medium and mode of deposition. The bivariate plot between mean and sorting (Fig. 3, after [25]) show samples being almost restricted to the right wing of the inverted – V trend suggesting that the variation in size classes was not too large [3]. It further shows that the sediments are characterized by predominantly poorly sorted, medium to fine grain sands. Plots of skewness against mean (Fig. 4, after [25]), skewness against sorting (Fig. 5) and Kurtosis against Skewness (Fig. 6) also point to the same depositional character and suggests fluvial process predominating the study area.

The CM plot of [26] was utilized to characterize the transportation mechanism of the sediments within the study area. He suggested that two patterns for which bottom sediments are transported include tractive currents and turbidity currents.

The sediments from this study showed marked resemblance to deposits of tractive current, whereby the sediment load is transported by rolling and suspension (Fig. 7). They occupy the OP – PQ segments of the [26] model suggesting bottom rolling and suspension, and the clustering around the curve OPQ suggests the participation of graded suspension in the process. This transport mechanism ensures that the transportation agent has direct impact with the bottom. The value of C's range from 250 – 4000 microns while the M value range from 60 – 1200 suggesting that the sediments are predominantly coarse grain sediments.

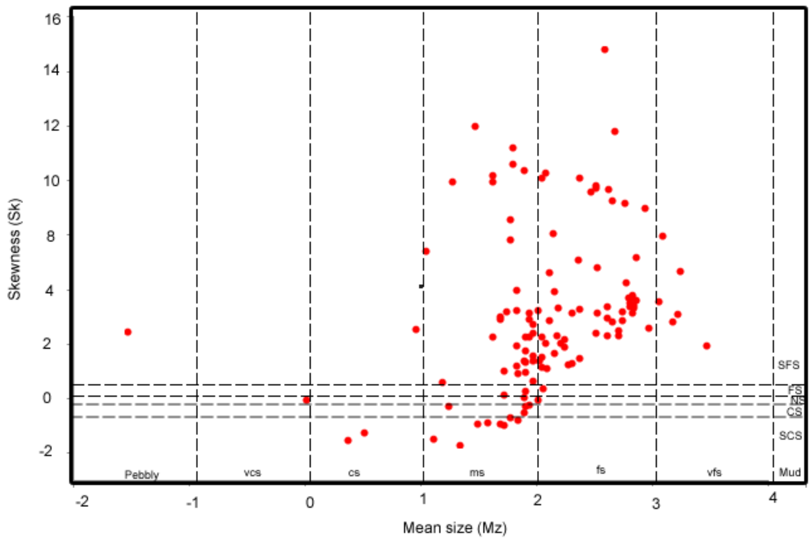


vps=very poorly sorted; ps=poorly sorted; ms=moderately sorted; mws=moderately well sorted; g=granule; vcs=very coarse sand; ms=medium sand; fs=fine sand; vfs=very fine sand

Fig. 3. Bivariate plot of mean against sorting (Folk and Ward [3])

Table 1. Results of statistical analysis of grain size data

S/No	Median		Mean		Sorting		Kurtosis		Skewness	
	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average
J2 (n=8)	1.35-2.80	1.96	1.33-2.83	1.94	1.04-1.84	1.6	1.8-7.02	4.67	-1.63-3.38	0.76
J3 (n=2)	2.4-2.45	2.43	1.82-1.97	1.89	1.82-1.65	1.74	4.77-6.03	5.4	0.72-4.03	2.38
J4 (n=9)	0.50-3.50	2.44	0.50-3.47	2.21	0.29-2.07	1.24	0.14-8.10	3.41	-1.2-3.86	1.92
J5 (n=5)	2.0-3.1	2.6	1.68-2.60	2.07	1.34-1.82	1.61	2.7-7.68	5.21	-0.85-2.80	1.27
J6 (n=9)	1.4-3.3	2.71	1.18-2.83	2.21	1.07-2.02	1.55	1.98-8.15	4.48	-0.23-3.48	1.99
J7 (n=2)	1.9-2.6	2.25	1.72-2.02	1.87	1.67-1.74	1.71	5.97-6.33	6.15	1.06-1.45	1.25
J8 (n=11)	2.0-3.25	2.65	1.9-3.05	2.39	0.59-1.60	1.21	0.66-4.86	2.92	1.02-7.02	2.89
J9 (n=12)	2.30-2.90	2.66	1.83-2.85	2.41	0.75-1.72	1.28	-0.58-6.62	2.81	-0.75-9.88	3.6
J10 (n=6)	-0.2 - 3.3	2.31	0.37 - 2.82	2.18	0.9 - 1.4	1.18	1.48 - 3.79	2.72	-1.46 - 3.75	2.34
J11 (n=7)	-1.5 - 2.8	2.49	-1.53 - 2.85	2.02	0.55 - 1.58	1.63	-1.08 - 5.28	4.87	1.20 - 4.86	1.53
J12 (n=8)	1.20-3.40	2.66	1.10-3.23	2.16	0.87-1.69	1.58	1.07-5.97	4.7	-1.44 - 4.74	1.86
J13 (n=8)	1.35 - 3.10	2.51	0.95 - 2.70	2.17	1.24 - 1.83	1.48	1.51 - 6.25	4.52	-0.47 - 4.66	1.92
J14 (n=3)	1.90-2.35	2.7	1.77 - 2.18	2.5	1.30 - 1.58	0.99	3.7 - 5.07	1.6	2.01 - 5.07	3.96
J15 (n=3)	1.85 - 2.60	2.2	1.62 - 2.13	1.89	1.53 - 1.67	1.64	4.24 - 5.47	5.3	2.34 - 6.14	1.39
J16 (n=7)	2.0 - 3.35	2.71	1.48 - 3.22	2.45	0.81 - 1.87	1.17	0.98 - 6.20	2.72	- 0.87 - 8.45	3.09
J17 (n=3)	2.70 - 3.05	2.63	2.50 - 2.75	2.42	1.07 - 1.26	1.14	1.97 - 2.58	2.25	7.21 - 7.86	3.33
J18 (n=8)	1.0 - 3.35	2.69	1.03 - 3.08	2.48	1.05 - 1.71	1.21	1.35 - 5.84	2.24	5.48 - 10.03	4.09
J19 (n=5)	1.9 - 3.70	2.7	1.62 - 2.92	2.53	1.33 - 1.79	0.98	0.88 - 6.84	1.66	0.76 - 9.27	3.79
J20 (n=3)	2.80 - 3.05	2.52	2.47 - 2.58	2.14	1.28 - 1.79	1.45	2.64 - 6.64	2.1	7.63 - 12.84	3.09
J21 (n=1)	2.4		2.03		1.54		5.01		8.14	



[vcs - very coarse grain sands; cs - coarse grain sand; ms - medium grain sand; fs - fine grain sand; vfs - very fine grain sand; SCS - strongly coarse skewed; CS - coarse skewed; NS - Near symmetrical; FS - fine skewed; SFS - strongly fine skewed

Fig. 4. Plot of Skewness against mean grain size (modified after Friedman [24])

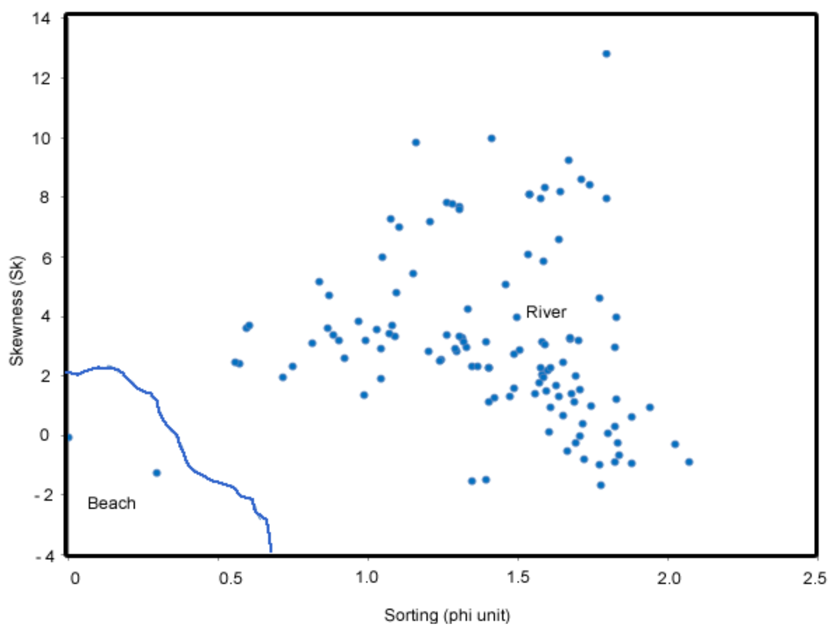


Fig. 5. Plot of Skewness against sorting (after Friedman [24])

The linear discrimination analysis (multivariate analysis) of [4] was used to categorize the depositional environments wherein the sediments were deposited. For distinction between beach (backshore) and shallow agitated marine environment (subtidal environment), the following equation was used:

$$Y_2 = 15.6534\,M_Z + 65.7091\,\sigma_I^2 + 18.1071\,Sk_I + 18.5043\,K_G \quad [4] \qquad (1)$$

If $Y_2 < 65.3650$ = beach; $Y_2 > 65.3650$ = shallow agitated marine.

Also for the distinction between shallow marine and fluvial (deltaic) environment, the equation was used:

$$Y_3 = 0.2852\,M_Z - 8.7604\,\sigma_I^2 - 4.8932\,SK_I + 0.0482K_G \quad [4] \qquad (2)$$

When $Y_3 < -7.419$ = fluvial (Deltaic) deposition; $Y_3 > -7.419$ = shallow marine deposit.

These where further subjected to bivariate scatter plots (Figs. 7 and 8, after [27]) to further improve the success rate of deposition mechanism characterization. From the plots it was shown that the sediments were characteristically from shallow marine (Intertidal) and deltaic (Delta front) environment.

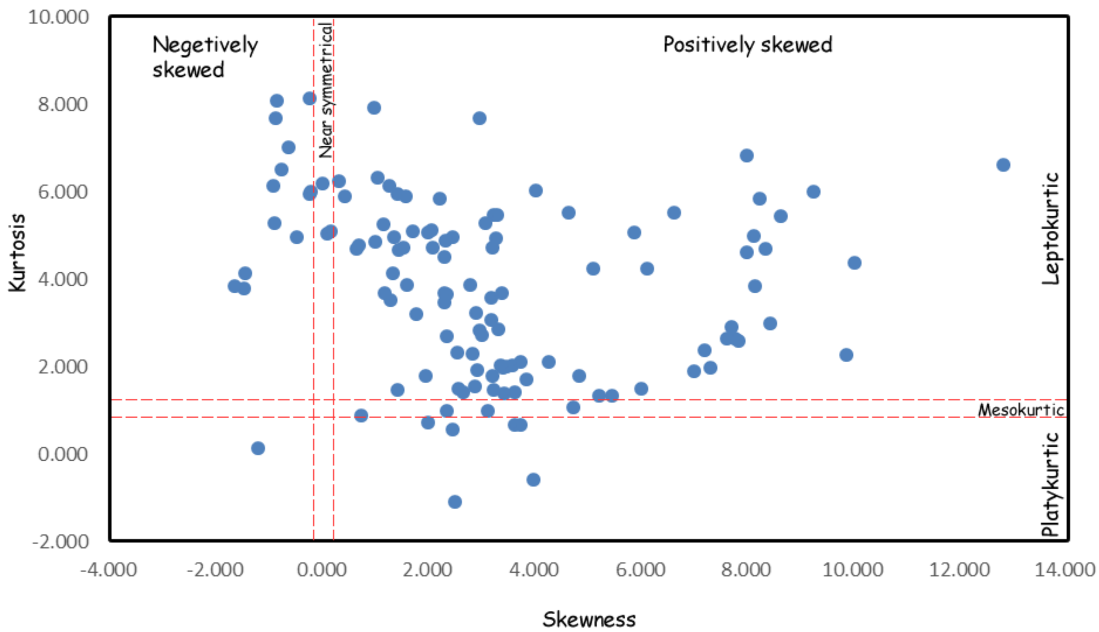


Fig. 6. Plot of Kurtosis against Skewness [modified after Friedman [24])

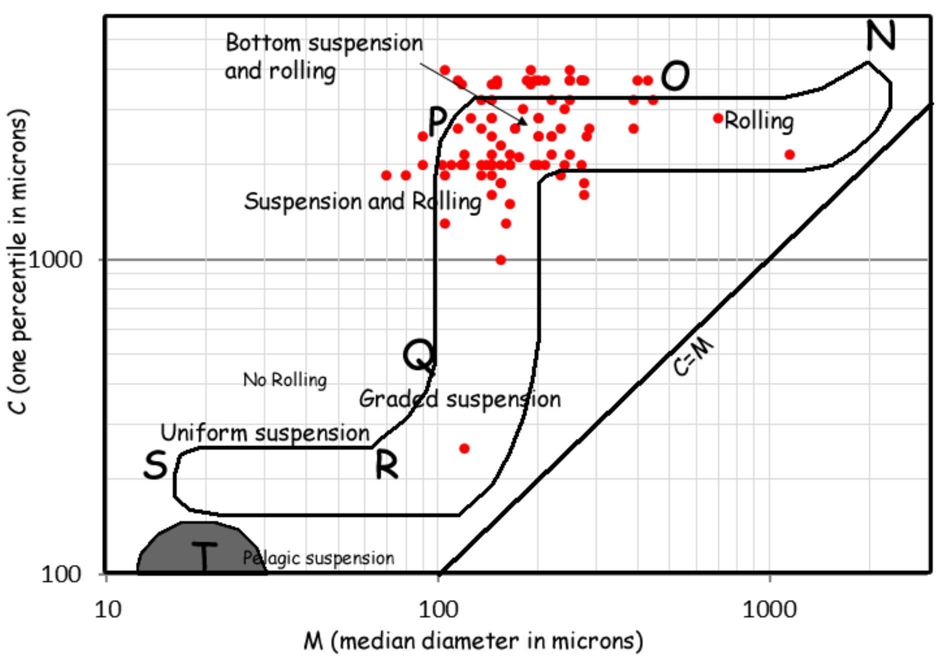


Fig. 7. CM pattern for the sediments (fields after Passega [26])

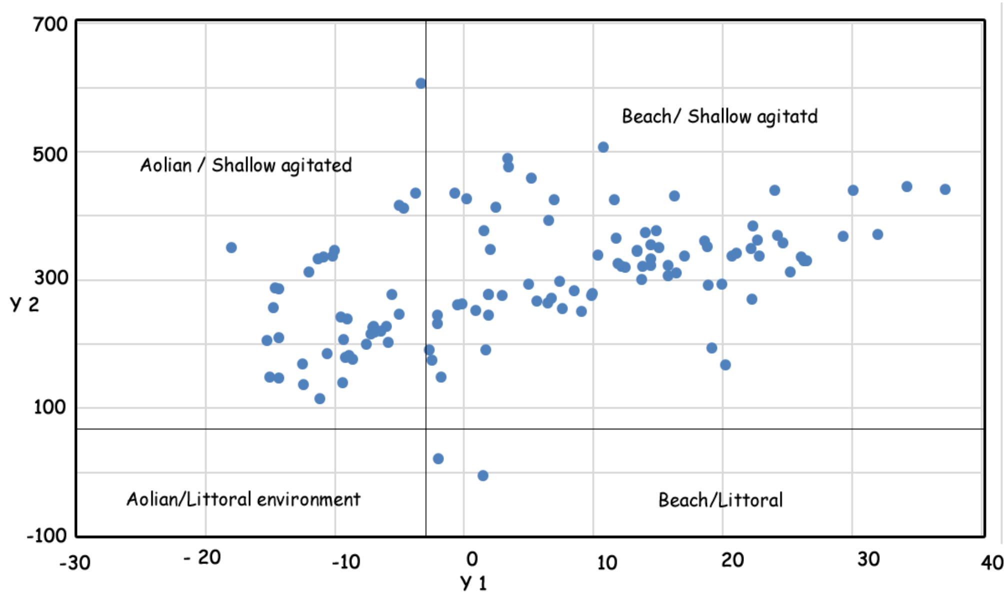


Fig. 8. Relationship between discriminant functions Y2 and Y1 showing the estimated environments (fields after Alsharhan and El-Sammak [27])

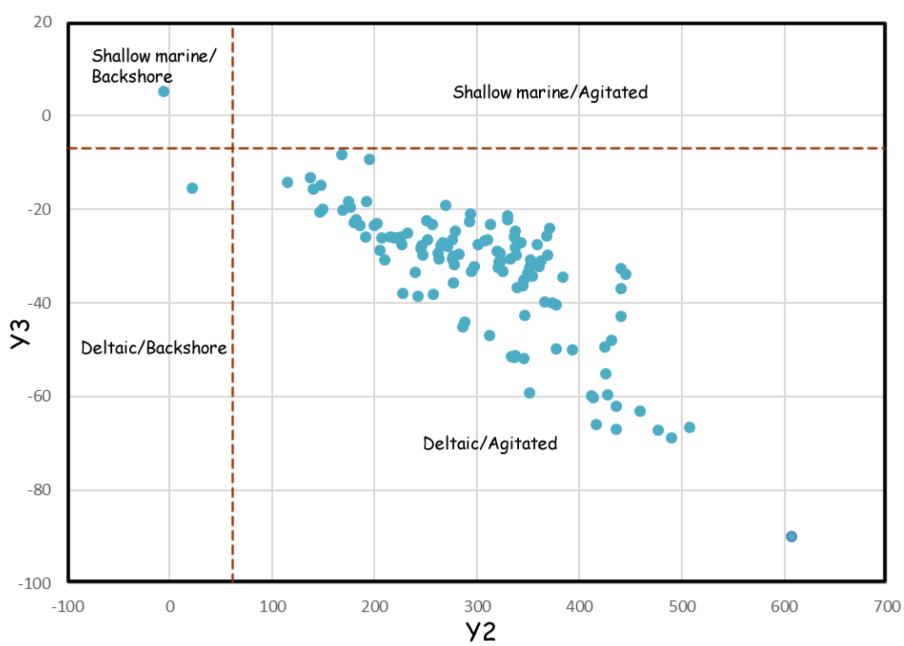


Fig. 9. Relationship between discriminant functions Y3 and Y2 showing the estimated environments (fields after Alsharhan and El-Sammak [27])

5. CONCLUSION

Based on the sediments characteristics and the respective graphic and discrimination analysis carried out on them, the analyzed sediments may have been under the influence of an environment characterized by both shallow water agitation (high energy) and poorly to moderately sorted low energy conditions. The sediments admixture is likely to be as a result of re-sedimentation of previous sedimentary rocks with sediments from first cycle of deposition. The sediments may have been subjected to intertidal influence in a deltaic setting. Thus, the sediments along the studied transect show energy setting associated with a mix of high and relaxed energy at different times during depositional process, with moderate sorting, predominantly positively skewed and leptokurtic nature. It is hereby emphasized that despite the huge success in the characteristic of sediments in discriminating depositional environments and processes, uncertainties that still persist should be reduced by the integration of other available sedimentary features like sedimentary structures as well as available fossils or trace fossils.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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