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TEXTURAL CHARACTERISTICS OF THE NILE DELTA COASTAL SANDS: AN APPLICATION IN RECONSTRUCTING THE DEPOSITIONAL ENVIRONMENTS

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ABSTRACT

The textural characteristics of the Nile Delta coastal sands from the nearshore zone, breaker zone, beach, backshore zone, coastal dunes and River Nile were studied. A consistent difference exists between the coastal environments from the point of view of the bivariant scatter plots, the shape of log-probability curves and CM diagrams. This information has been used as an aid in determining the depositional environments of some unknown borehole sand deposits. The study of the vertical change for each unit of borehole sediments can be considered as a tool for reconstructing the depositional history and shoreline changes of the Nile Delta coast. It is indicated that the shoreline of the central part of the Nile Delta coast has advanced and marine sediments (nearshore zone, breaker zone, beach) with a thickness of 22 m have been laid over the backshore flat area. The false impression of many studies may be connected with the comparison of unknown sediments from one area with known sediments from another area.

INTRODUCTION

For many years sedimentary petrographers have attempted to use grain size to determine sedimentary environments. A survey of the extensive literature on this subject illustrates the steady progress that has been made toward this goal. Many excellent contributions have been published during the past twenty to thirty years, each providing new approaches and insights into the nature and significance of grain size distributions. One of the major problems of the analysis of grain size distributions is that the same sedimentary processes occur within a number of environments, and the consequent textural response is similar. Now that there are many physical criteria available to identify specific depositional environments, the textural studies do not need to stand alone, but can provide a separate line of evidence to aid in interpreting clastic deposits of unknown origin.

Several methods of treating the grain size distribution of sands were evaluated for their ability to discriminate between depositional environments of the Nile Delta coast. The following techniques were applied to sediment samples:

A. Technique of MASON—FOLK *(1958) and* FRIEDMAN *(1961, 1963):*

The basis of this technique depends on the relation between the grain size statistical parameters in the form of scatter plots. When the parameters are effective in differentiating between two environments, a boundary line is drawn that splits the fields best.

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B. Technique of VISHER *(1965, 1969):*

The shape of log-probability grain size distribution curves is used for environmental analysis. Analysis is based on recognizing rolling, saltation and suspension populations within a grain size distribution. The sorting, size range, number, degree of mixing and the points of truncation of these populations vary systematically in relation to sedimentary environments.

C. Technique of PASSEGA *(1957, 1962, 1964):*

A CM diagram is constructed by plotting the one percentile particle diameter in µm (C) versus the fifty percentile particle diameter in µm (M) on bilogarithmic paper. PASSEGA argued that the texture of a clastic sediment represented in this way is characteristic of the depositional agent. The transport mechanism that built up the deposit can be suggested on the basis of the shape and the arrangement of the pattern of the sample points in a CM diagram.

Petrographic characteristics of recent sands of the Nile Delta coast from nearshore, breaker zone, beach, backshore, coastal dune and river environments have been studied, to determine if there are textural characteristics which will permit diagnosis of the depositional environment. By using different techniques, the study shows that depositional environments can be recognized from grain size data. These techniques were applied in order to investigate the origin of deposition in subsurface sediments.

SAMPLING AND METHODS OF STUDY

Samples were collected along the Nile Delta coast between Rosetta and Damietta *(Fig. 1)*. During July, 1978, the coast was surveyed and samples were collected at 3 km intervals. The sample net consisted of 49 transects at right angles to the coast.

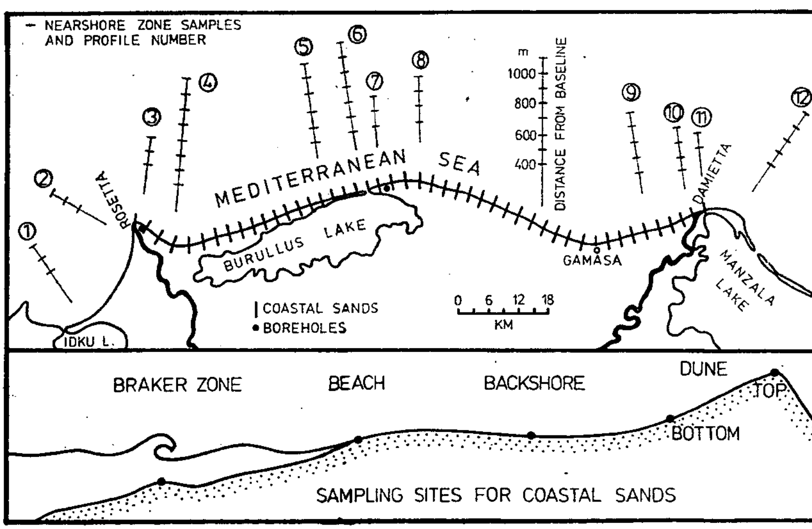

Fig. 1. Location map and sampling sites for the recent environments of the Nile Delta coast

Samples were collected from the shallow water where the waves break at the 1.00—1.25 m depth below the sea level (breaker zone samples), on the surf zone of the beach (beach samples), on the flat area at the back of the beach (backshore zone samples) and from the bottom and top of the coastal dunes (dune samples). In sampling, care was taken not to collect any special concentrate represented by unusual conditions. In general, the samples were taken from the top 5 cm of each environmental deposit.

In addition, samples from the nearshore zone, the River Nile and borehole sediments were obtained from the Institute of Coastal Research, Alexandria. Twelve nearshore profiles were selected and samples were collected every 100 m until a depth of 6 m below sea level was reached *(Fig. 1)*. Two boreholes with a depth of 30 m were selected at Rosetta and Burullus headlands for comparative studies. Borehole samples were secured every 1 m.

Since the sands under investigation are friable, no disaggregation was found necessary. All the samples collected were washed, dried and split. Mechanical analysis was carried out by the conventional sieving method, with screens placed at one-phi intervals. It is planned to use the half-phi intervals in between 3—4 phi sets because they give more accurate cumulative curves. About 100 g of materials was taken for analysis, using a mechanical shaker with a sieving time of 20 minutes. The sieve meshes give the class intervals 2000, 1000, 500, 250, 125, 90, 63 and 37 μm. These correspond to the phi classes of −1, 0, 1, 2, 3, 3.5, 4 and 5, respectively.

The data were plotted as cumulative curves on probability paper to ensure maximum accuracy in determining the grain size parameters by the graphical method (FOLK, 1968). Statistical measures proposed by FOLK and WARD (1957) for median diameter, sorting, skewness and kurtosis were then obtained from values intercepted at specific percentiles in these curves.

GRAIN SIZE VARIATION OF THE COASTAL SANDS

The grain size variation of the Nile Delta coastal environments was analysed along 49 profiles normal to the shoreline over a distance of 144 km *(Fig. 1)*. Each profile covers the nearshore zone, breaker zone, beach, backshore and dune sands. River Nile sands were also represented.

Figure 2 shows the average cumulative percentages and histograms for each environment; Table 1 illustrates the data. A visual inspection of the modal classes and tails on the histograms can be used as a preliminary interpretation of the energy conditions within each environment. The coastal sands are unimodal, but differ in the modal class and tails. Nearshore zone sands have a modal class of 3—4Φ units. In moving through the breaker zone to the beach sands, there is a shift in the modal class to the coarser size of 2—3Φ. The breaker zone retains a higher percentage of coarser fractions than does the beach sands. This indicates an increase in the energy level from the nearshore to the breaker zone, and then a slight decrease to the beach. Backshore sands keep the same feature, but their coarse tail is slightly more pronounced than the beach one. The bottom of the dune sands has the mode in the 1—2Φ unit class, while the top sands once again display a mode in the 2—3Φ unit class. Therefore, it can be said that the bottom of the dune receives more energy than the backshore, and the energy level slightly decreases from the bottom to the top of dunes. On the other hand, the River Nile sands show distinctive tails in the coarse fractions with a modal class of 2—3Φ units.

TABLE 1

Average wt. % of fractions and statistical parameters for the Nile Delta coastal environmental sands

Environment	Wt. % of fractions in Φ units								Statistical parameters			
	−2 to −1	−1 to 0	0 to 1	1 to 2	2 to 3	3 to 4	4 to 4	Pan	D_{50}	σ_I	Sk_I	K_G
Nearshore	—	0.16	0.84	2.02	17.04	68.32	8.56	3.06	3.35	0.53	+.22	1.64
Breaker zone	0.63	1.68	7.74	18.88	56.76	14.10	0.33	0.16	2.28	0.57	−.10	1.12
Beach	—	0.11	2.12	19.36	65.92	12.32	0.17	0.08	2.40	0.44	−0.1	1.04
Backshore	—	—	3.47	22.28	60.73	12.22	0.82	0.48	2.36	0.51	+0.4	1.09
Dune bottom	—	—	5.10	45.81	44.25	4.50	0.18	0.16	1.98	0.55	+0.6	1.01
Dune top	—	—	0.84	32.70	58.50	7.21	0.27	0.46	2.22	0.48	+.11	1.01
River Nile	1.58	4.10	14.36	27.08	44.50	7.44	0.67	0.26	1.86	0.74	−.03	1.11

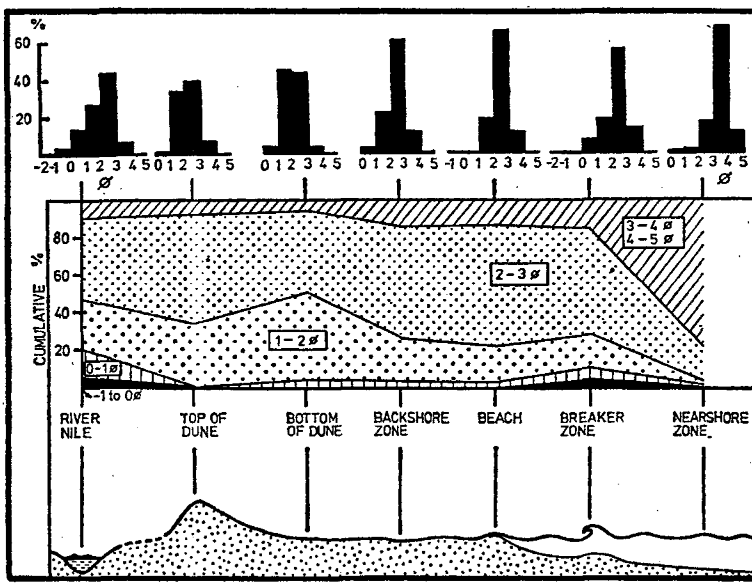

Fig. 2. Variation of cumulative percentages and histograms normal to the shoreline

BIVARIANT PLOT TECHNIQUE

The area along the Nile Delta coast was chosen as a testing ground to determine if there exists a statistically significant difference in grain size properties between the sands of the various environments. The textural evidence for environmental identification has been pursued during the last two decades; the most significant are the studies by MASON and FOLK (1958), FRIEDMAN (1961, 1967), MARTINS (1965), MOIOLA and WEISER (1968), HAILS (1967), HAILS and HOYT (1969) and EL FISHAWI *et al.* (1976). These authors found that the statistical parameters are environmentally sensitive, and combinations of these parameters permit distinction between different depositional environments. EL FISHAWI (1977) and GINDY *et al.* (1982) demonstrated that bivariant plots of skewness *versus* grain diameter gave the best differentiation between the sands of the nearshore, beach and coastal dune. On the other hand, scatter plots of grain size parameters fail to distinguish reliably between environments, as shown by SHEPARD and YOUNG (1961) and SOLOHUB and KLOVAN (1970).

Most authors plotted only two environments at a time in their graphs, and thus decided easily where to place the line that splits the fields best. MASON and FOLK (1958) plot three environments in one graph, but FRIEDMAN (1961, 1967) does not, nor do MOIOLA and WEISER (1968). The range of values of the statistical parameters of the coastal sands is wide, but many environmental sands overlap and all fields could not be shown separately. Therefore, the nearshore, beach, dune and River Nile sands can be represented in one graph, while the breaker zone and backshore can be shown in another one.

The statistical parameters generally used may not be the best means of describing most grain size distributions. However, it may be possible to determine which pair of parameters yields an optimum discrimination between environments. The properties of the Nile Delta coastal sands have been compared in 3 effective scatter plots as shown in *Figs. 3—5.*

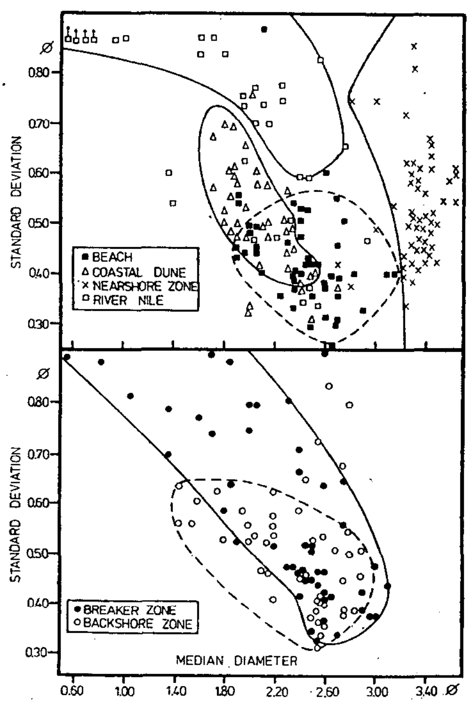

Fig. 3. Bivariate plot of median size *versus* standard deviation

Median diameter vs. standard deviation

In *Fig. 3* the median diameter is plotted against the standard deviation for sands from various environments. It results a nearly complete separation of distinct fields, although some overlap is exhibited. The River Nile sands have the worst standard deviation values and the coarsest median diameter. The nearshore sands are the finest ones and show a median size finer than 3.20Φ; the majority of the standard deviation values lie in the ranges of well and moderately well sorted. The beach sands are better sorted and relatively finer than the dune sands, although a narrow mixed area is exhibited between them. The breaker zone sands scatter in a significant trend, where the distribution field is long and narrow. Coarse, poorly-sorted sands and fine, well-sorted sands occur together within the breaker zone, indicating the wide change of the breaker heights. In general, the backshore zone sands are finer, well sorted and restricted better in their field than the breaker zone sands.

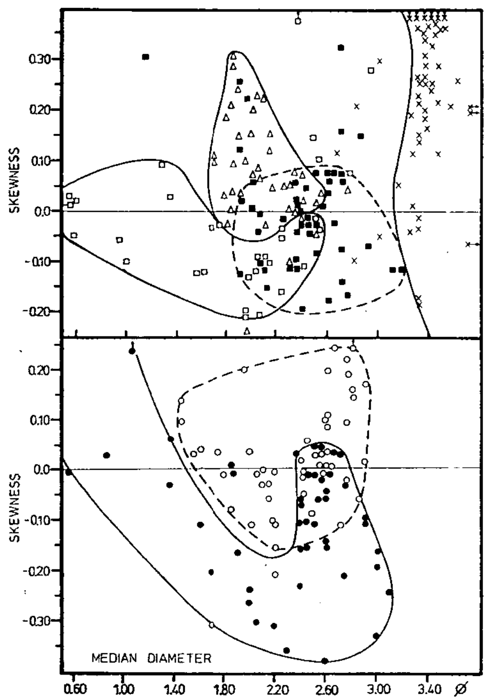

Fig. 4. Bivariate plot of median size *versus* skewness. Symboles as in *Fig. 3.*

A strong negative correlation appears to exist between the median size and the standard deviation, with the exception of the nearshore sands. The standard deviation is practically dependent on the median size: the coarser sands are less sorted than the finer ones. MASON and FOLK (1958) found no correlation between the median size and the standard deviation, which may be connected with the small range of their parameters.

Median diameter vs. skewness

Separation into environmentally designated fields is possible by plotting median size *versus* skewness *(Fig. 4).* In this diagram, the best differentiation of the samples is accomplished with the aid of the skewness. Both nearshore and dune sands are for the most part highly positively skewed, but the latter are coarser. The River Nile sands are coarser than the beach ones; they show both negative and positive skewness, with a considerable difference; they contain percentages of negative skewness samples of 53% and 68%, respectively. The breaker zone and backshore sands fall into distinct groupings, separating the plot of *Fig. 4* into two environmental fields. The breaker zone sands are for the most part negatively skewed (72%) with high values. The backshore sands are generally positively skewed (61%) and the remainder give symmetrical or nearly symmetrical curves. No predictable correlation could be determined between the median size and the skewness.

Median diameter vs. first percentile

In *Fig. 5,* the first percentile is plotted *versus* the median size in phi units for all coastal sands, and shows a good separation into environmental fields. The River Nile sands have the coarsest maximum size in the first percentile range. The 1% range of the dune sands is relatively coarser than that of the beach sands. Nearshore sands have the finest size in this range. The backshore sands are finer in both the 1% and 50% ranges than the breaker zone sands, which show wide scattering toward the coarse end. In general, the separation owes more to the 1% range than to the median size; the 1% range correlates well with the environment.

In conclusion, of the different statistical parameters used, bivariant plots of median size *versus* standard deviation, skewness and first percentile gave the best sepa-

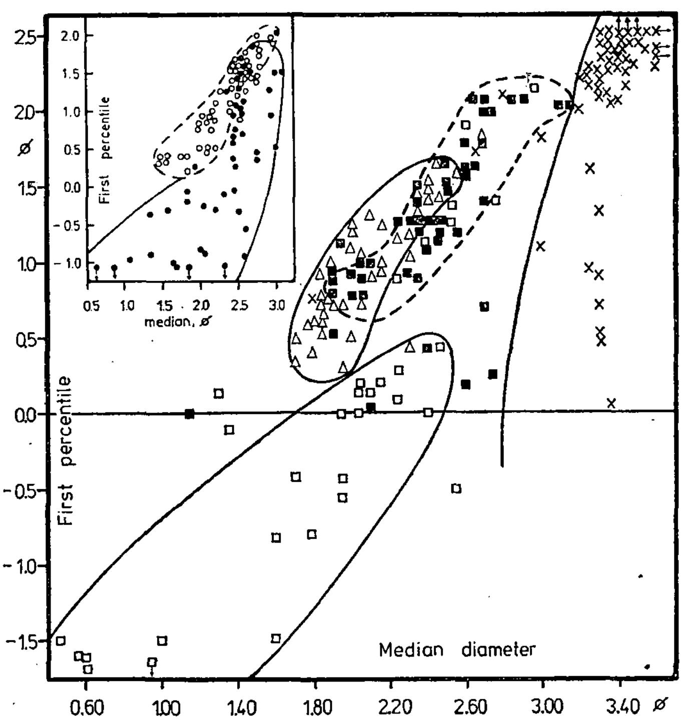

Fig. 5. Bivariate plot of median size *versus* the first percentile. Symboles as in *Fig. 3.*

ration between the sands of the coastal environments. On the other hand, the combinations of kurtosis *versus* median and skewness are ineffective, and complete overlap is exhibited between the sands of different depositional environments.

LOG-PROBABILITY CURVE TECHNIQUE

One of the most significant papers relating sedimentation dynamics to texture was published by INMAN (1949). He recognized that there are three fundamental modes of transport; surface creep, saltation and suspension. Many authors, including SINDOWSKI (1958), FULLER (1961), SPENCER (1963) and VISHER (1965, 1969), used the grain size distribution curves drawn on probability paper for environmental analysis. For these curves, the truncation points between traction, saltation and suspension transport may reflect the physical conditions at the time of deposition, and hence give the true limiting value of grain size for each mode of transport. The most important aspect in the analysis of textural patterns is the recognition of separate log-normal populations which relate to the position of truncation points and the degree of mixing between these population. Moreover, it is valuable to depend upon the degree of sorting as indicated by the slope of each population to characterize the environmental deposits.

Figure 6 shows the grain size distribution curves for the Nile Delta coastal environments. The analysis revealed that there are several different fundamental curve shapes and many differences appear.

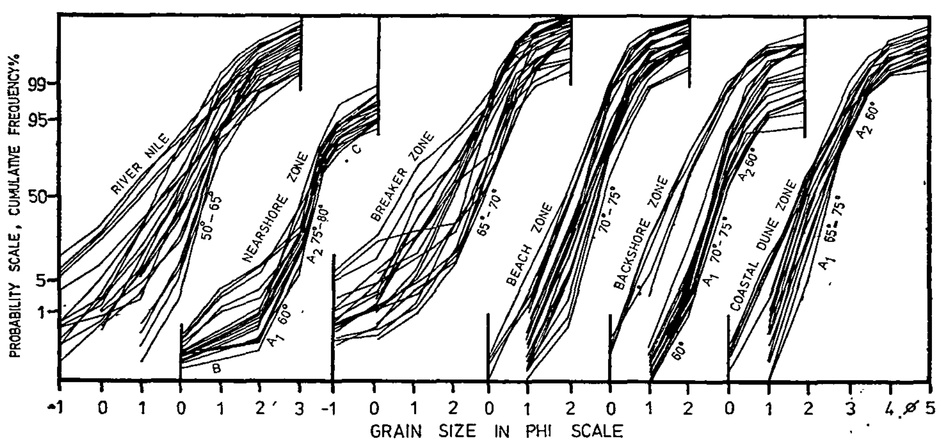

Fig. 6. Grain size distribution curves, probability scale, for the Nile Delta coastal environments. B: rolling, A_1: coarse saltation, A_2: fine saltation, C: suspension.

River Nile sands

Of special significance is the fact that the samples are characterized by high percentages of sediment in the coarse and very coarse rolling population. Size distribution curves show the three population modes of transport with a high degree of mixing. The positions of the coarse truncation points are highly variable and the range is between 0—2Φ (1—30%) of the distribution. The saltation population has a size range between 2—3Φ (5—95%). It is clearly observed that mixing occurs between rolling and saltation populations. A suspension population has been defined; it represents less than 1% of the distribution. In general, the River Nile sands have poorly sorted populations, usually with a slope between 50° and 65°.

Nearshore sands

The rolling population in the nearshore samples is more pronounced, without mixing, than that in the Nile samples. The truncation point lies at 2Φ with values less than 5%. Of most significance is the development of two saltation populations with different slopes. The coarse saltation population extends between 2—3Φ (7—30%), with a slope of 60°. The fine saltation is better sorted than the coarser one (75°—80°) and has a size range between 3.0—3.5Φ (5—80%). The suspension population is well defined and ranges between 70—99% of the distribution.

Breaker zone sands

The grain size distribution curves for breaker zone sands appear to be fundamentally different from those described for the Nile sands, but some similarities do exist. These sands reflect the characteristic features of the breaker waves. They have a well-developed rolling population, relatively smaller in amount and less sorted than that in the Nile sands. This population joins the saltation population without mixing between 1—2Φ. The saltation population has a size range between 5—95% and is truncated well at the fine end to contain the suspension population near 3.5Φ. The slope of the saltation population ranges between 65° and 70°, and therefore it is better sorted than that in Nile sands.

Beach sands

The grain size distribution curves for the beach sands appear to be related to the action of waves on the beach sands, with a distinctive pattern. The absence of a rolling population characterizes the majority of beach sands. It may be true that the rolling and saltation populations are completely mixed together, with the same degree of slope. The development of a well sorted saltation population with a slope between 70° and 75° is the distinguishing characteristic of the beach sands. This population represents 99% of the size distribution. The suspension population is defined well and is truncated at 3.5Φ with an amount of 1%.

Backshore sands

The backshore zone curves are different from those developed in other environments. In the majority of the samples, the main difference lies in the presence of a somewhat mixed rolling population and two well developed saltation populations. The rolling population occurs between 1—2Φ (1—10%), with a slope of 60°. The coarse saltation population is better sorted than the finer one. The slope of the coarse saltation population ranges between 70° and 75°, with a maximum value of 90% (2—3Φ), while the finer one ranges between 60—90% (3—4Φ), with a slope of 60°. A well-developed suspension population occurs between 4—5Φ, with a variable amount of very fine sand and silt, which ranges between 95—99.90% of the distribution.

Coastal dune sands

The rolling population is absent from the coastal dune sands. The lack of this population in the beach and dune, and its weakness in the backshore sands appears to characterize the inland coastal deposits. Two saltation populations can be observed. The coarser one extends between 0—3Φ and is better sorted (65°—75°) than the finer one (60°), which extends between 3—4Φ. The amount of the suspension appears to be less than 1%.

CM DIAGRAM TECHNIQUE

PASSEGA (1957, 1962, 1964) proposed a combination on a bilogarithmic diagram of two parameters of a cumulative grain size distribution; the coarsest one percentile value C, and the median diameter M in μm. He argued that the texture of a clastic sediment represented in this way is characteristic of the depositional agent. The transport mechanism that built up the deposit can be suggested on the basis of the shape and the arrangement of the pattern of the sample points in a CM diagram. The position of sample points in a CM pattern depends on the mode and agent of transport. The change from a pattern parallel to the CM line (graded suspension) to a pattern parallel to the C-axis (rolling, suspension) corresponds to a difference in mode of deposition. The maximum value of C in the pattern is an indication of maximum turbulence caused by dynamic forces in each environment.

This subject is an attempt to establish the relationships between the textures of sediments and coastal environments. The sediments of each environment are represented in a CM pattern as shown in *Fig. 7*. Each pattern is formed by 32—53 samples.

Nearshore zone pattern

The CM pattern of the nearshore sands is generally narrow and long. It can be subdivided into 2 groups *(Fig. 7A)*. The first group is a pattern of concentrated points on the finer lower side with C values of 125—270 μm and M values of 55—125 μm. The upper coarser group is long, narrow and parallel to the C-axis; the C values are limited to 300—2000 μm, while the M values range between 95—160 μm. During periods of strong wave activity, there are many indications that the waves can cause some movement toward the nearshore zone. TRASK (1955) observed that at a depth of about 14 m, the passing waves disturbed the bottom sediments. The tractive currents generated by surface waves can roll coarser sand grains with C values of 300—2000 μm, to form fairly poorly sorted deposits. Finer grains with maximum C values of 270 μm are kept in suspension; they are generally better sorted and form the fine groups of the pattern. In quiet conditions within 6 m depth, these sediments settle together and give their characteristic pattern to the nearshore sediments.

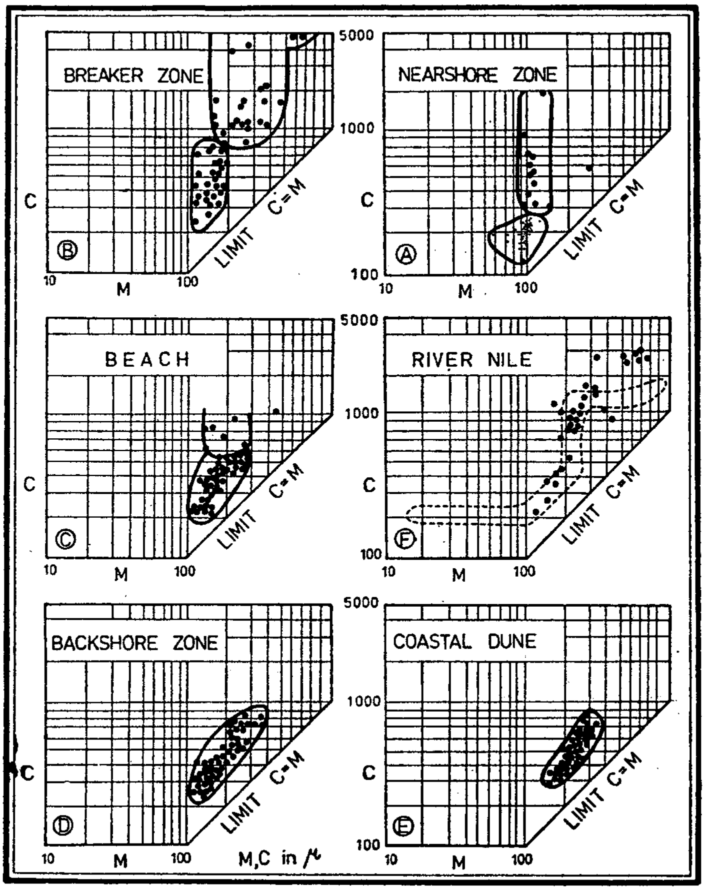

Fig. 7. CM diagrams for the Nile Delta coastal environments

Breaker zone pattern

The CM pattern of the breaker zone sands is the widest and longest pattern among the coastal environments. Two parts can be observed, depending on the spreading C with relation to the M values *(Fig. 7B)*. The upper part is formed essentially by particles with C values of 850—5000 μm and M values of 170—700 μm. The lower part is finer, with C values of 250—800 μm and M values of 100—200 μm. Therefore, the breaker zone sands are characterized by a restricted variation of the M values whilst the C values are more scattered, resulting in a CM pattern elongated and parallel to the C-axis. If the M values are not too strongly varying, the coarse grains in sediments may be responsible for the rolling pattern of these sediments by spreading the C values as in the breaker zone. The approaching breakers carry all available sediments; the coarser part can be transported by rolling under the action of vigorous waves, while the finer one can also be transported by rolling when the conditions became weaker. The breaker zone sands are often poorly sorted because, when the coarse sands settle, a large amount of fine sand generally settles with them and the pattern tends to be distant from the limit C=M.

Beach zone pattern

The distribution of the points in the CM pattern gives a broad shape *(Fig. 7C)*. The points are concentrated in the finer lower part and scattered in the coarser upper one. The lower part is limited by C values of 200—600 μm and M values of 100—300 μm. The sediment points are distributed parallel to the limit C=M, indicating an area of good sorting. It is observed that C is subjected to marked variations, while M varies proportionally. The upper part of the pattern consists of scattered coarser sands, where C ranges between 600—1000 μm and M between 130—450 μm. These sediments are poorly sorted, because their points are situated at a considerable distance from the limit C=M. The action of the tractive current caused by the waves is reflected in the CM pattern of the beach sands. The approaching waves keep the finer materials in suspension, while the coarser ones can be transported by means of rolling.

Backshore and coastal dune pattern

The backshore and dune sands have the same distribution points, but the field of the dune is more condensed *(Fig. 7D* and *E)*. These sediments are characterized by their elongation parallel to the limit C=M, where C and M are directly covariant. The backshore pattern is limited by C values of 220—850 μm and M values of 120—350 μm, while the dune pattern is limited by C values of 280—850 μm and M values of 150—380 μm. These sediment are well sorted, because the wind is responsible for their transport. Dry winds with an onshore directional component actively deflate the beach and carry its sediment to the backshore and dune zones. The aeolian sediments may be transported as a graded suspension in air; the coarse grains are transported close to the ground, while the finer ones are blown far up into the air.

River Nile pattern

The River Nile sands are sufficiently coarse and fine to form a more complete CM pattern than for the other environmental deposits. The CM pattern of the sands *(Fig. 7F)* shows that the fine sands are transported as graded suspensions, the medium sands by rolling and as suspensions, and the coarsest ones by rolling.

The deposit formed from a graded suspension when turbulence decreases is characterized by a value of C proportional to the value of M. It is observed from *Fig. 7* that the relationship between C and M becomes very close on passing from the breaker zone through the beach and backshore and up to the coastal dune sands. At the same time the sorting improves. The strict proportionality between C and M indicates one origin for the coastal sands, which may arise from offshore drift. When the waves disturb the bottom sediments, the coarsest part of the suspension, which tends to stay in the bottom water, moves shoreward, while finer particles will move seaward (King, 1972). This selective transportation keeps the coarses materials in the breaker zone, whereas most of the fine and very fine materials go back and deposit in the nearshore zone. As might be expected from the interpretation of the CM patterns, some of the coastal sands are deposited by a single transport mechanism, while the other are subjected to more complicated ones. It is generally possible to differentiate between coastal environments with the criteria given by the CM pattern.

Following the finding that a consistent difference exists between the Nile Delta coastal environments from the point of view of the shape of the log-probability curves, bivariant plots and CM diagrams, this information has been used as an aid in determining the depositional environments of some unknown sand deposits. Two borehole samples to a depth of 30 m were chosen at Rosetta and Burullus. Table 2 illustrates the grain size parameters.

To get a better idea of the depositional history of the subsurface sediments, samples from known depositional environments must be studied and compared with the subsurface sediments at the same area. The false impression of many studies may be connected with the comparison of unknown sediments from one area with known sediments from another area. Therefore, the shape of the grain size distribution curves, bivariant plots and CM diagrams of the Nile Delta coastal environments have been used to predict the depositional environments of the subsurface sands of the Nile Delta coast at Rosetta and Burullus. The study of the vertical change for each unit of the borehole sediments can be considered a tool for the depositional history and shoreline changes of the Nile Delta coast.

Log-probability curves of borehole sands

A comparison of log-probability curve shapes between known depositional environments and subsurface sequences will be available for interpreting the origin of the borehole sands. Log-probability curves for borehole sands were plotted, and those showing similar features were grouped together in one unit according to their depth. The next step was to compare each unit with *Fig. 6* to predict the environment of deposition.

For Rosetta borehole, three units can be recognized *(Fig. 8A)*. The following depths reveal the origin of each unit:

a) 29—19 m depth: backshore zone. It is followed by a 10 m thickness of silty clay deposits which may be derived from Rosetta branch.
b) 8—5 m depth: nearshore zone.
c) 4—1 m depth: beach zone.

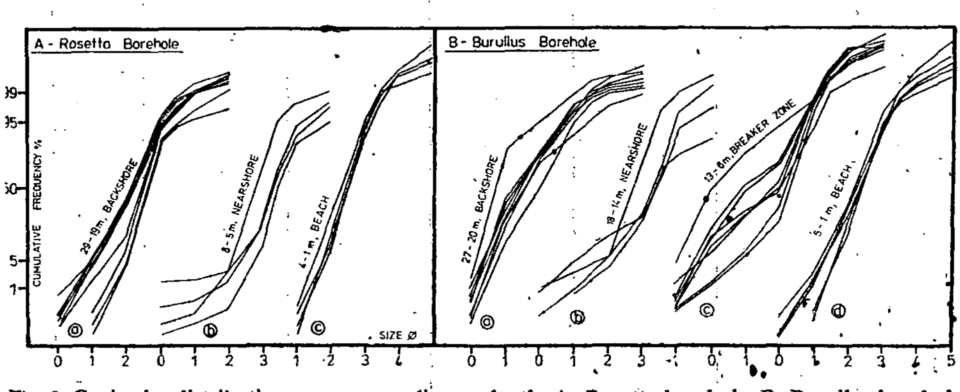

Fig. 8. Grain size distribution curves according to depth. A: Rosetta borehole, B: Burullus borehole

TABLE 2

Grain size parameters of borehole sands

A. Rosetta borehole, BH 6:

Depth m	D_{50}	σ_I	SK_I	K_G	C µm	M µm
1	2.50	0.36	0.13	1.14	342	177
2	2.30	0.46	—.02	1.06	435	203
3	2.55	0.42	0.02	1.08	380	171
4	2.50	0.42	0.02	1.08	406	177
5	2.85	0.43	—.05	0.99	320	140
6	3.50	0.49	0.21	1.26	196	88
7	3.50	0.59	—.12	1.64	1000	88
8	3.35	0.44	0.13	1.39	287	98
9	2.40	0.35	—.02	0.94	380	190
19	2.25	0.61	—.11	1.15	660	210
20	2.15	0.62	—.09	1.08	683	225
21	2.20	0.61	—.09	1.08	637	218
22	2.15	0.60	—.16	1.02	683	225
24	2.45	0.43	—.10	1.31	555	183
25	2.50	0.39	0.04	1.27	380	177
26	2.60	0.42	0.16	1.46	330	165
27	2.60	0.44	0.19	1.43	320	165
28	2.15	0.56	—.10	1.04	933	225
29	2.60	0.43	0.16	1.19	354	165

B. Burullus borehole, BH 3:

Depth m	D_{50}	σ_I	SK_I	K_G	C µm	M µm
1	2.20	0.51	0.00	1.07	518	218
2	2.30	0.54	—.05	1.05	536	203
3	2.35	0.43	0.05	1.08	392	196
4	2.40	0.41	—.04	1.15	420	190
5	2.20	0.50	—.17	1.07	637	218
6	1.85	0.90	—.37	0.91	2144	277
7	2.15	0.58	—.31	1.26	1150	225
8	2.30	0.60	—.32	1.80	1000	203
9	2.00	0.94	—.48	0.95	1570	250
10	1.10	0.97	0.12	0.78	1626	467
11	0.95	1.04	0.12	0.72	1803	518
12	0.05	0.91	0.32	1.12	2640	966
13	2.05	1.13	—.43	0.77	1625	242
14	2.70	0.43	—.05	0.99	933	154
15	3.25	0.61	—.33	1.36	484	105
16	3.30	1.27	0.54	2.30	435	102
18	3.35	0.85	—.37	1.90	707	98
20	1.55	0.90	0.28	1.07	871	342
21	1.55	0.66	0.19	1.06	785	342
22	1.45	0.65	0.18	0.93	841	366
23	1.40	0.71	0.11	1.01	966	380
24	0.80	0.49	0.10	1.73	1036	574
25	1.30	0.71	0.19	0.90	933	406
26	1.25	0.73	0.27	0.98	901	420
27	1.90	0.68	0.01	0.93	707	268

For Burullus borehole, four units were observed *(Fig. 8B)*. The following depths reveal the origin of each unit:

a) 27—20 m depth: backshore zone.
b) 18—14 m depth: nearshore zone.
c) 13—6 m depth: breaker zone.
d) 5—1 m depth: beach zone.

Bivariant plots of borehole sands

The preliminary origins of the subsurface units, as suggested by the shape of the grain size distribution curves, should be examined by plotting their data in bivariant plots of known fields. A plot of median diameter against skewness *(Fig. 4)* provides the best menas for distinguishing beach, backshore, nearshore and breaker zone sands. By replotting the boundary of these environments, the depositional environments of the borehole units can be predicted as shown in *Fig. 9.*

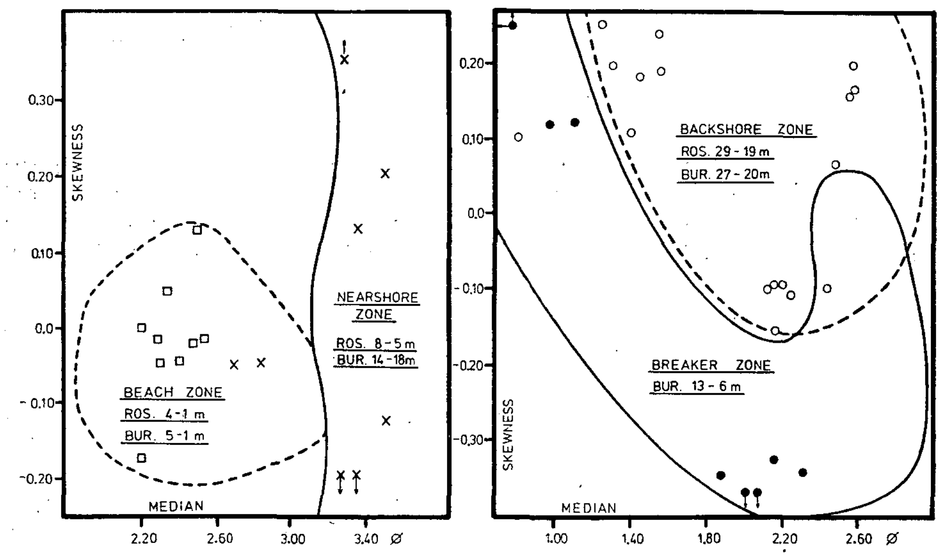

Fig. 9. The origin of Rosetta and Burullus borehole sands as indicated by the relation between median size and skewness. The boundaries are from *Fig. 4.*

In Rosetta and Burullus boreholes, the sediments of the upper 5 m thickness lie in a given position of the beach sands. Rosetta sediments between 8—5 m depth, and Burullus sediments between 18—14 m depth, were found to be nearshore. Burullus sands between 13—6 m depth lie within the breaker zone field. Rosetta sands between 29—19 m depth, and Burullus sands between 27—20 m depth, were found to be backshore. As shown before, the same results were obtained by using the shape of the curves and the bivariant plots for the prediction of the subsurface units.

CM pattern of borehole sands

The boundaries of the environments were replotted from the CM patterns in *Fig. 7*. The data of the subsurface units were plotted for the suggested environmental fields to test the degree of fitness *(Fig. 10)*. The examined samples from the

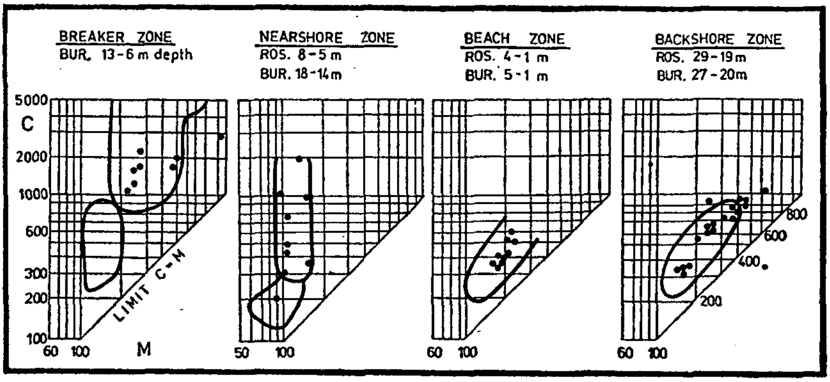

Fig. 10. CM patterns for Rosetta and Burullus borehole sands.

breaker zone, nearshore and beach lay inside each given field. The majority of the backshore samples were found to be inside the given field; some samples were located outside, but near the boundary. Thus, the application of the CM pattern for the subsurface units gave the same results as in the distribution curves and bivariant plots.

Shoreline changes: a result

Distinguishing subsurface coastal sediments may serve as a tool to reconstruct the historical geology and the approximate position of the shoreline in a stratigraphic sequence. The results obtained in this study are summarized in *Fig. 11*.

The position of the Rosetta borehole was located at a wide backshore flat, as indicated by the lower 29—19 m depth sediments. This unit was followed by a 10 m thickness of silty clay deposits, maybe from Rosetta branch. A transgression was observed, and as a result the location of the borehole was situated in the nearshore zone, as represented by the sediments of 8—5 m depth. The shoreline began to retreat gradually and then stopped near the present shoreline, leaving the upper 4 m thickness unit as a beach zone.

The position of the Burullus borehole was located at the backshore flat. The shoreline advanced and a 5 m thickness of nearshore deposits was laid over the 8 m thickness of the backshore deposits. A little regression of the shoreline was observed in that the position of the borehole was located in the breaker zone. After an 8 m thickness of breaker zone sands, the shoreline retreated again, to stop near the present shoreline, as indicated by the upper 5 m thickness of beach sediments.

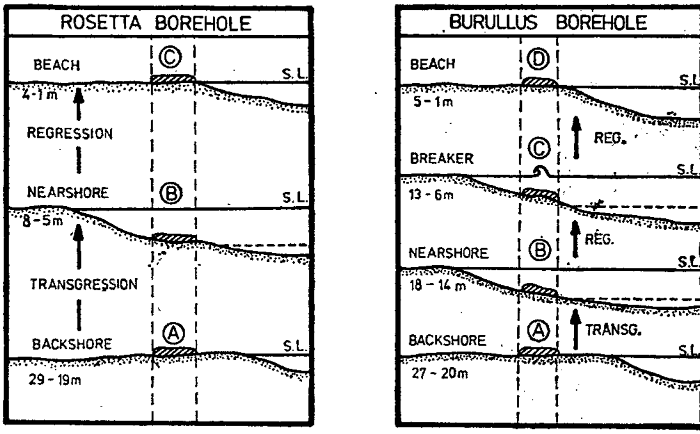

Fig. 11. Transgression and regression of shoreline at Rosetta and Burullus

CONCLUSIONS

1. It is possible to demonstrate some changes in sand textures normal to the shoreline. The breaker zone receives more coarse and very coarse sands than does the beach zone. The median diameter decreases, the sorting improves and the skewness trends from negative to positive as one progresses from the breaker zone across the beach and backshore and up to the dune sands.

2. Several methods of treating the grain size distribution of coastal sands were evaluated for their ability to discriminate between the depositional environments. Of the different scatter plots used, bivariant plots of median diameter versus standard deviation, skewness and first percentile gave the best discriminations between the sands of the River Nile, nearshore, breaker zone, beach, backshore and coastal dune.

3. The analysis of log-probability grain size distribution curves was found to be a good method for distinguishing between the depositional environments. The most important aspect in the analysis of textural patterns is the recognition of separate log-normal populations which are related to the position of truncation points and the degree of mixing between these populations. It is also valuable to make use of the degree of sorting and the extension of coarse and fine tails.

4. The mechanism of the transport that built up the deposit can be suggested on the basis of the shape and arrangement of the pattern of the sample points in a CM diagram. The position of the points in a CM pattern depends on the mode and agent of transport. This method permitted distinction between the Nile Delta coastal environments.

5. After the discovery that a consistent difference exists between the Nile Delta coastal environments from the point of view of the bivariant plots, the shape of the log-probability curves and the CM diagrams, this information is used as an aid in determining the depositional environments of borehole samples on Rosetta and Burullus. The false impression of many studies may be connected with the comparison of unknown sediments from one area with known sediments from another area.

6. The study of the vertical change for each unit of the borehole sediments can be considered a tool for the depositional history and shoreline changes of the Nile

Delta coast. Distinguishing subsurface sediments of the Burullus headland indicates that the position of the borehole was located at the backshore flat. The shoreline has advanced and a 5 m thickness of nearshore zone deposite has been laid over the backshore sands. A slight regression of the shoreline happened in that the position of the borehole was located in the breaker zone. After an 8 m thickness of breaker zone deposits, the shoreline continued to retreat again and stopped near the present shoreline, as indicated by the upper 5 m thickness of the beach sands.

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