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NILE DELTA BEACH PEBBLES I: GRAIN SIZE AND ORIGIN

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ABSTRACT

In the present paper a study of beach pebble size has been used to establish the source and movement of pebbles along a 75 km stretch of Nile Delta coast. A total number of 5200 pebble size measurements was done along 26 locations. Characteristic features of grain size distribution and probable origin are discussed on the basis of approaching hydrodynamic factors and old topographic features of Nile Delta continental shelf.

The average pebble size shows a general decrease and sorting improves with increasing distance of transport. It is believed that size-sorting plays an important part on pebble distribution along the coast. Three locations are considered to be secondary sources because eastwards of each there is a directional gradations in pebble size and sorting, this is with the agreement of west-east littoral current. The locations of secondary sources are closely related to the position of old submarine banks located off Nile Delta coast. Nile Delta beach pebbles are derived mainly from these banks due to onshore movement by the action of stormy waves.

INTRODUCTION

Wide consideration has been given to beach pebbles. Many authors studied pebble size and shape parameters. Early studies of beach pebbles were made by WENTWORTH, C. K. [1919], MARSHALL, P. [1928], and LANDON, R. E. [1930]. More recent works have been published by KRUMBEIN, W. C. [1941], CAILLEUX, A. [1945, 1947], KEUNEN, PH. H. [1964], BLUCK, B. J. [1967, 1969], CARR, A. P. [1971], and SPALLETTI, L. A. [1976]. Considerable attention has been given to the problem of whether size or shape is the dominant factor in the sorting of pebbles along and across a beach.

Nile Delta beach pebbles have the greatest continuity and largest areal extent between west of Burullus outlet and 12 km east of Gamasa *(Fig. 1)*. West of Burullus, the continuity becomes rare and pebbles can be observed in some restricted areas. On the other hand, as far as 12 km east of Gamasa, they have disappeared.

The pebbles are of fair size, their long, intermediate, and short diameter ranges between 300—200, 200—12, and 32—2 mm respectively. The short diameter is very small regarding to the other two diameters, for this reason, Nile Delta beach pebbles are named "flat stones".

Beach pebbles consist mostly of mudstones and silty sandstones, the later are less abundant. Many surfaces have conspicous niks and pits while the other are stained by iron oxides to various shades of brown to a depth of a few millimeters. Pebbles containing shell fragments and other fossils are common. They are characterized, especially the large pebbles, by the presence of encrusting organisms and animal borings.

SAMPLING

The area under investigation lies between longitudes 30° 55′—31° 45′ E, and extends for about 75 km along the coast. Beach, backshore plains, and coastal dune belts are the main geomorphological unites of the area *(Fig. 1)*. The pebbles tend to distribute on the surface of the beach and backshore area. They cover a wide variety of grain size. Pebbles of five size classes were abundant; 300—256 mm, 256—128 mm, 128—64 mm, 64—32 mm and 32—16 mm (—8∅ to —4 ∅). The location and sample site used in this study are illustrated in *Fig. 1*.

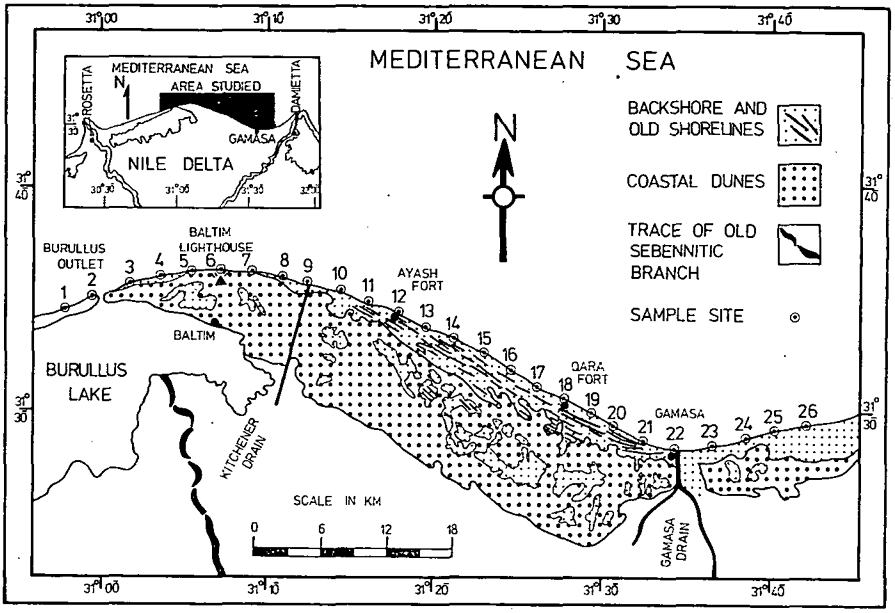

Fig. 1. Location map showing sampling sites for beach pebbles and geomorphology of coast for area studied.

During April, 1980, Nile Delta coast was surveyed and sample sites were chosen at 3 km intervals. The aim of sampling is to represent the populations of pebble size on each location along the coast. A total number of 5200 size measurements was obtained along 26 locations. At each location, a set of pebbles was collected by taking all pebbles within an area of 4 square meters to obtain a number of pebbles ranges from 60—75. Pebbles of five size classes were separated and counted. This technique was repeated for three times within the location and the average of occurrence of each size class was calculated. At some locations, it was necessary to collect some pebbles outside the considerable area in order to cover all size classes occurred within the location. Only 20 pebbles were collected from the eastern end location because pebbles were rare and absent eastward.

In the laboratory, cumulative percentages of number of occurence were plotted on probability paper and grain size parameters were calculated using formulae of Folk, R. L. and Ward, W. C. [1957].

According to the studies of Institute of Coastal Research [1973], QUÉLENNEC, R. E. [1976], and MANOHAR, M. [1976], two types of waves are predominant. Storm waves of winter season rarely exceed 3.5 m in height, and summer swells are generally 40—70 cm high. The wave period 7—10 sec. predominates over all other periods for all class intervals of wave heights. The predominat direction of wawes is NNW and NW, but this is somewhat changed during stormy period when waves from N, NNE and NE are dominating. The direction of energy flux are the same as those of waves. *Fig. 2A* shows the average wave-rose of Nile Delta.

The interaction of the wave stresses with the beach induces a net boundary current flowing in the direction of wave travel. Along Nile Delta coast, the net result littoral current feeds from west to east. Measurements indicate that over 50% of the readings, the eastward current is up to 80 cm/sec. [MANOHAR, M., 1976].

In the present study, littoral current has been measured 6 times during 1976—1977, it was intended to make a measurement every 2 km. The results are shown in *Fig. 2B*. Due to the wide variation of the wave breaker angle and beach orientation, the net results are strong variations of the direction, occurrence and velocity of littoral current along Nile Delta coast. Moreover, the irregular form of some shorelines cause relative convergence and divergence of current. Thus, depending upon direction, percentage of occurrence, and corresponding average velocity, littoral current can be divided into three groups. Eastward littoral current predominates with percentage of occurrence >50% and average velocity of 36 cm/sec. Westward current occurs with lesser degree (20—50%) and velocity of 33 cm/sec. At some stretches, the current is often reversed causing convergence and divergence current with lesser occurrence (<20%) and velocity (27 cm/sec.). It is worthy to say that eastward current plays an important role in the movement of beach materials along Nile Delta coast.

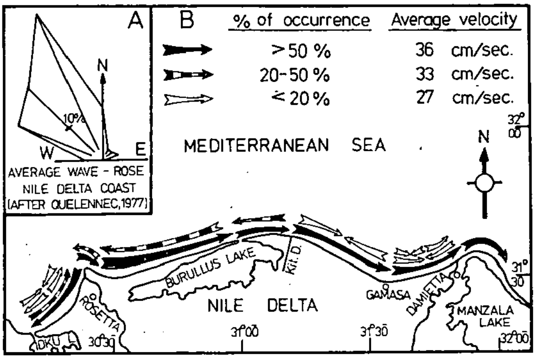

Fig. 2. Littoral currents along Nile Delta coast and average wave-rose.

LONG-AXIS ORIENTATION OF PEBBLES

The up-and-down motion of beach materials with the action of wave produces a net drifting of pebbles to beach surface. It thought that the orientation of long-axis is perpendicular to the direction of incoming waves.

Several readings of long-axis orientation were made only for elongated pebbles of each location (26—37 readings), and a total number of 781 readings were tabulated.

Brunton compass was used for measurements and each pebble was laid flat on its maximum projection face. Percentage of reading for 30° intervals, arithmetic mean, standard deviation, and coefficient of variance were calculated (Table 1). Rose diagrams were plotted on a map of the area *(Fig. 3)*.

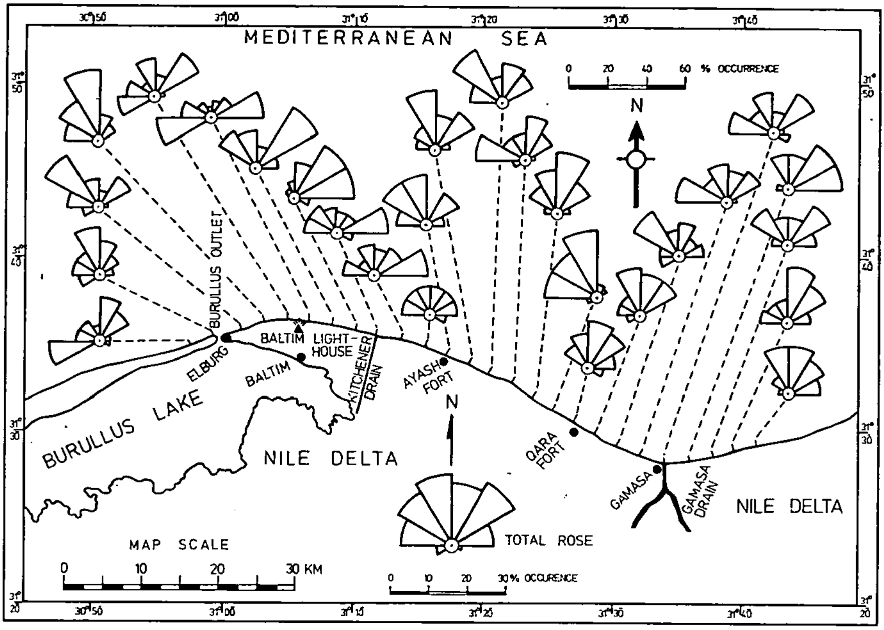

Fig. 3. Rose diagrams of long-axis orientation of beach pebbles.

Rose diagram figures give an idea about the changes in long-axis orientation along the coast. Such variation is a function to the directional effect dynamic forces and beach orientation. Rose diagrams show that 9 locations have a unimodal pattern and 12 ones have essentially a bimodal pattern, while 5 locations have a polymodal pattern.

The determination of actual direction of dynamic forces affecting each location is one definite aim of these measurements. But, how well do long-axis orientation correlate with the direction of dynamic factors? Indeed, it is so difficult to say because waves with different heights and directions, and littoral current with different velocities and directions are acting together to drift and orient pebbles on beach surface. But, however, by tracing the changes in long-axis orientation on each site along the coast, and as is evident from rose diagrams, it can be concluded that there is a gradual significant trend. From west of Burullus outlet to Baltim the orientation changes gradually from W to NW and then to N. Baltim coast characterized by E—W orientation and towards west of Ayash it tends to be from NE to E. Between Ayash and Gamasa, high percentage of occurrence are oriented again from NW to N, and eastwards it becomes from NE at the eastern end. In fact, the final rose diagram of long-axis orientation well represent all types and directions of dynamic factors affecting any location at a certain period.

TABLE 1

Long-axis orientation for beach pebbles along Nile Delta coast

Sample site	Percentage of reading								Ar. m.	St. dev.	Cof. var.
	0°—30°	30°—60°	60°—90°	90°—120°	240°—270°	270°—300°	330°—330°	330°—360°			
1	23.07	11.53	3.84	3.84	26.92	11.53	11.53	7.69	180	±129	0.72
2	17.85	10.71	7.14	—	10.71	14.28	14.28	25.00	212	137	0.64
3	8.10	18.91	2.70	—	8.10	16.21	32.43	13.51	227	126	0.56
4	13.33	10.00	—	—	—	16.66	23.33	36.66	254	129	0.51
5	11.11	25.92	3.70	—	18.51	14.81	7.40	18.51	193	133	0.69
6	7.69	11.53	26.92	—	26.92	15.38	7.69	3.84	178	114	0.64
7	11.11	37.03	11.11	—	—	—	22.22	18.51	161	143	0.89
8	19.23	30.76	30.76	7.69	—	—	3.84	7.69	87	95	1.09
9	10.00	10.00	26.66	6.66	—	16.66	16.66	13.33	179	130	0.73
10	12.90	16.12	29.03	—	—	16.12	9.67	16.12	163	134	0.82
11	15.15	15.15	15.15	9.09	—	15.15	15.15	15.15	173	135	0.78
12	3.22	19.35	9.67	—	—	16.12	25.80	20.80	233	129	0.55
13	16.66	23.33	6.66	—	—	10.00	13.33	30.00	192	148	0.77
14	20.00	16.66	3.33	—	—	16.66	30.00	13.33	201	142	0.71
15	22.58	16.12	3.22	—	6.45	25.80	12.90	12,90	188	138	0.73
16	31.25	18.75	6.25	—	—	6.25	15.62	21.87	160	150	0.94
17	5.88	2.94	—	—	2.94	26.47	26.47	35.29	290	88	0.30
18	25.00	21.42	14.28	7.14	—	—	14.28	17.85	138	138	1.00
19	21.42	21.42	3.57	—	7.14	10.71	16.71	25.00	184	146	0.79
20	16.66	10.00	13.33	—	10.00	10.00	26.66	13.33	201	135	0.67
21	16.12	19.35	3.22	—	3.22	25.80	12.90	19.35	203	138	0.68
22	10.00	23.33	3.33	6.66	—	23.33	13.33	20.00	199	155	0.78
23	18.18	27.27	27.27	3.03	—	6.06	—	18.18	119	124	1.04
24	13.88	25.00	13.88	—	2.77	8.33	22.22	13.88	173	139	0.80
25	27.27	22.22	11.11	—	2.77	13.88	11.11	11.11	143	137	0.96
26	25.00	20.00	15.00	—	—	5.00	10.00	25.00	156	148	0.95
Mean	16.13	18.56	11.01	1.66	4.60	13.44	16.13	18.43	185	137	0.74

Ar. m. = Arithmetic mean, St. dev. = Standard deviation, Cof. var. = Coefficient of variance

RESULTS

The distribution of Nile Delta beach pebbles along the coast shows a directional gradation in size with the presence of three major fluctuations. Results of the study are summarized in Table 2 and illustrated in *Figs. 4* through *9*.

Distribution of size classes

The distribution of particle size of beach pebbles is unimodal. *Fig. 4* illustrates the average histogram and cumulative curve for all pebbles. Pebbles greater than 256 mm constitute the smallest percentage with an average of 2.22%. Particles of size 128—64 and 64—32 mm constitute the main bulk of beach pebbles (36.70 and 37.17% respectively). Nile Delta beach pebbles characterize by an average median of —6.12∅ (64 mm). Pebbles are moderately well sorted (0.64∅), negatively skewed (—0.10), and mesokurtic kurtosis (0.99).

Twenty six sample sites were investigated for lateral variation of particle size analysis along the coast. Lateral variations of pebble size are graphically shown in *Fig. 5*.

TABLE 2

Particle size variation and statistical parameters for beach pebbles along Nile Delta coast

Sample site	% of size classes					Statistical Parameter			
	256 mm	256—128 mm	128—64 mm	64—32 mm	32—16 mm	D_{50}	σI	SK_1	K_G
1	7.69	42.31	34.62	15.38	—	—7.00	0.78	0.12	0.87
2	21.43	50.00	21.43	7.14	—	—7.40	0.80	0.11	1.05
3	—	30.30	39.39	27.27	3.03	—6.50	0.92	—.05	0.94
4	—	30.30	36.67	30.30	3.33	—6.45	0.94	—.10	0.94
5	—	18.52	44.44	29.63	7.41	—6.25	0.81	—.16	0.94
6	—	7.69	50.00	30.77	11.54	—6.10	0,71	0.16	0.94
7	—	14.81	51.85	33.33	—	—6.30	0.53	—.19	1.02
8	—	11.54	69.23	19.23	—	—6.45	0.44	0.01	1.08
9	—	33.33	46.67	20.00	—	—6.65	0.70	—.08	0.87
10	9.68	19.35	51.61	19.35	—	—6.60	0.80	—.25	1.05
11	6.06	18.18	66.67	9.09	—	—6.65	0.63	—.23	1.29
12	6.25	31.25	43.75	18.75	—	—6.75	0.73	—.09	0.91
13	6.67	33.33	46.67	13.33	—	—6.80	0.71	—.13	0.94
14	—	10.00	46.67	43.33	—	—6.10	0.51	—.33	0.97
15	—	6.45	54.85	38.71	—	—6.15	0.43	—.23	0.99
16	—	3.13	43.75	46.88	6.25	—5.59	0.59	0.05	0.94
17	—	—	43.45	45.45	9.09	—5.90	0.68	—.02	1.00
18	—	—	42.86	39.29	17.86	—5.80	0.81	—.09	0.87
19	—	—	17.86	60.71	21.43	—5.45	0.53	—.07	0.87
20	—	—	30.00	53.33	16.67	—5.65	0.62	—.08	0.91
21	—	—	6.45	70.97	22.58	—5.30	0.42	—.05	1.04
22	—	—	6.67	63.33	30.00	—5.20	0.42	—.09	0.88
23	—	0.09	21.21	60.61	0.09	—5.75	0.73	—.22	1.20
24	—	5.56	22.22	61.11	11.11	—5.65	0.66	—.17	1.17
25	—	—	8.33	69.44	22.22	—5.35	0.43	—.05	0.95
26	—	—	5.00	40.00	55.00	—4.95	0.43	—.40	1.02
Mean	2.22	14.42	36.70	37.17	4.49	—6.12	0.64	—.10	0.99

The largest beach pebbles (>256 mm) are found in two restricted areas; just astride the Burullus outlet and between 27—36 km to the east. The percentage of largest pebbles ranges between 21.43 and 6.06% from west to east. It is believed that littoral current is often insufficient to move the larger pebbles along the coast, therefore, they concentrated in the two mentioned areas.

Pebbles range between 256—128 mm are well distributed than the other pebbles. Their percentage attain the maximum value (50%) near Burullus outlet. There is a steady decrease in the percentage of these particles to Kitchener drain where it reaches to 11.54%. Eastward, the percentage increases more or less gradually and attains the value of 33.33% in the location 36 km. It appears to decrease again rapidly where the percentage is reduced to 3.13% (location 45 km). Eastward of this location, such particles have disappeared, however, a small amount are only present near Gamasa.

Beach pebbles whith size 128—64 mm are dominantly found along the coast and characterized by a higher percentage of occurrence. There is a trend to a regular increase in the percentage from 21.43% near Burullus outlet to the maximum value of 69.23% near Kitchener drain. Toward the east, the percentage of particles decreases slowly with some fluctuations, then it decreases rapidly to Gamasa (6.67%). East of Gamasa, the percentage increases again and then decreases to the minimum value (5%) because they are replaced by an abundance in finer pebbles.

Pebbles with size 64—32 mm are well distributed and behave in different way rather than the other populations. Between Burullus outlet and 3 km east of Ayash

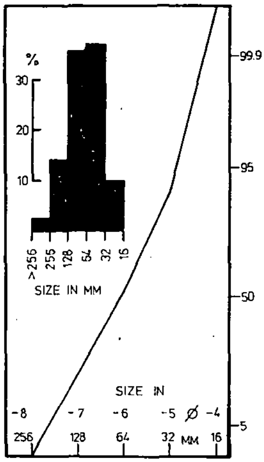

Fig. 4. Average histogram and cumulative curve for all beach pebbles.

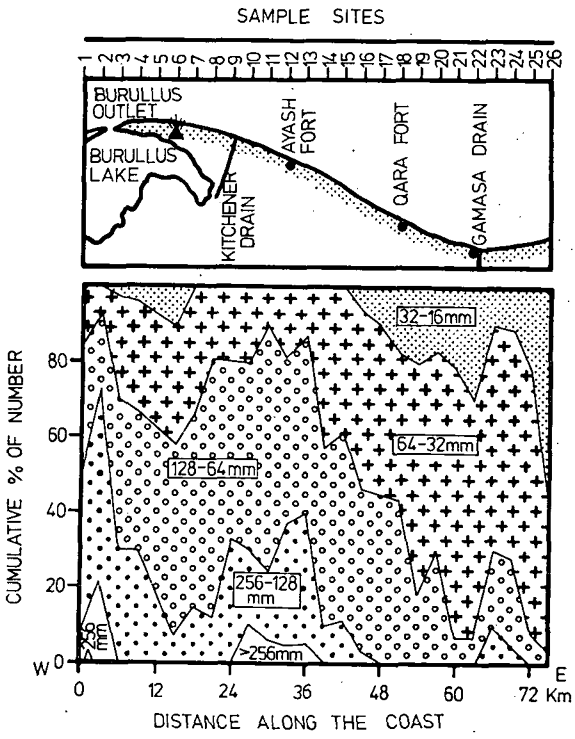

Fig. 5. Lateral variation of particle size of pebbles along Nile Delta coast.

Fort, the percentage ranges between 7.14 and 33.33%. Eastwards, it observed that the percentage increases rapidly with some fluctuations and attains the maximum abundance (70.97%) east of Gamasa.

The smallest beach pebbles (32—16 mm) does not occur dominantly along the coast, but they are only found in two areas *(Fig. 5)*. Between the locations 6—15 km, the percentage ranges from 3.03 to 11.54%. The pebbles appear again from the location 45 km, the percentage becomes higher and attains its maximum value (55%) in the eastern end.

It is observed from the lateral variation of beach pebbles size *(Fig. 5)* along the coast that:

1. The largest pebbles are distributed in limited areas while the smaller ones are well distributed and dominantly occurred with increasing trend. It is believed that the ordinary hydrodynamic factors (littoral current and waves) are often insufficient to move the larger pebbles along the coast. On the other hand, the smaller pebbles were washed out laterally by littoral current and shifted to the beach with ease by waves.
2. In such progressive decrease in pebble size, fluctuations might also result. With fluctuations, the largest pebbles will be moved only occasionally, whereas the smallest ones may be carried even when the transporting agent is at a minimum competency [PETTIJOHN, F. J., 1949].
3. The lateral variation of pebble size along the coast reflects a decreasing trend with the presence of three main peaks in the locations 3, 36, and 66 km.

Distribution curves and grain size parameters

Pebble size distribution curves, plotted on probability paper, are illustrated in *Fig. 6*. It is clearly observed from the last figure that the cumulative curves are shifted gradually from the coarse to the fine area of the figure; *i.e.* there is a fining cycle median size from Burullus toward the east. It is also noticed that the three groups of curves commonly show a truncation with certain trend. Moreover, the angle of central part of curves shows a significant trend reflecting an improvement in sorting eastwards. Table 3 summarizes the last results.

Table 2 shows the statistical parameters (median, sorting, skewness, and kurtosis) for pebbles. They are illustrated graphically in *Fig. 7* where visual analysis of data can be made by plotting these parameters against distance along the coast.

Median tends to decrease gradually from west to east. At first, it decreases slowly from Burullus outlet (—7.4 ∅) to the location 36 km (—6.8 ∅). Eastwards, the decreasing trend in median became quick until it reaches to the minimum value (—4.95 ∅) in the eastern end of the investigated area. This is may be an indication for the active motion of pebbles during transport which is certainly responsible for the quick decreasing trend.

There is a general improvement in the standard deviation (sorting) from west to east with some fluctuations. It ranges between 0.94∅ (moderately sorted) east of Burullus outlet and 0.42∅ (well sorted) in the eastern end. *Fig.* 7 shows that both median and sorting follow each other in many locations.

Inclusive graphic skewness ranges between +0.16 and —0.40. The pebbles become more negatively skewed from west to the location 39 km. Eastwards, they tend to be more symmetrical and then again high negatively skewed near the end (—0.40).

The variation of graphic kurtosis behaves differently along the coast. It ranges between 0.87 (platykurtic) to 1.29 (leptokurtic). Kurtosis values tend to increase

Table 3

Characteristic features of cumulative curves

Features \ Location	Burullus to Kitchener	Kitchener to Gamasa	East of Gamasa
Median	—6.70 ∅	—6.00 ∅	—5.40 ∅
Truncation	90—80 %	80—60 %	45—30 %
Angle of slope	70°	75°	79°

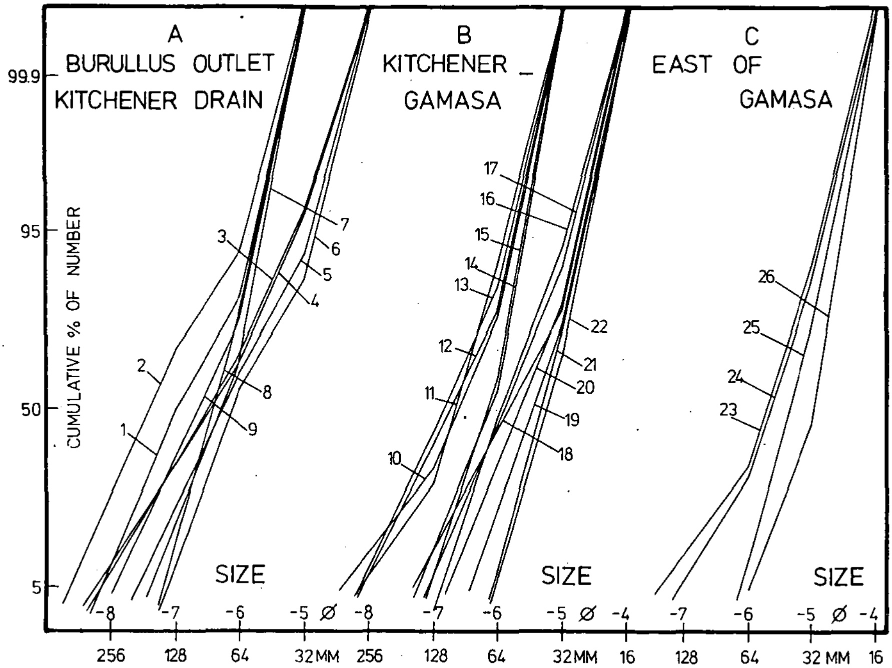

Fig. 6. Particle size distribution curves for beach pebbles. Numbers indicate sample sites.

generally from west to the location 30 km and then decrease with some higher values east of Gamasa.

The marked variations of median along the coast did not correspond to any change in other parameters, with the exception of sorting. Actually, these relationships can not be properly interpreted.

Size-sorting of pebbles

During lateral movement of sediment along the coast, hydrodynamic factors tend to sort particles according to their size and shape. Great attention has been given to the problem of whether size or shape is the dominant factor in the sorting of pebbles. Recent studies mentioned that waves sorted pebbles by shape on a beach and sorting, not abrasion, is the cause of the presence of discs pebbles high on the beach [Krumbein, W. C. and Griffith, J. S., 1938; Van Andel, Tj. H. *et al.*, 1954; Bluck, B. J., 1967; Humbert, F. L., 1968].

Along Nile Delta coast, beach pebbles show a progressive decrease in cumulative percentage of larger pebbles, increase of smaller ones, decrease of median size and improvement of sorting *(Figs. 5* and *7)*. Such decreasing trend is caused, with the direction of eastward current, by decreasing availability of larger pebbles. There is also a significant correlation for the relationship between the standard deviation and the size of pebbles *(Fig. 8)*. The positive correlation shows that the larger pebbles are ill sorted, and the sorting improves when the pebbles becoming more smaller.

During the course of transport, the ability of pebbles to be abraded is high due to their clay-silt-sand components. There are also some instances where larger peb-

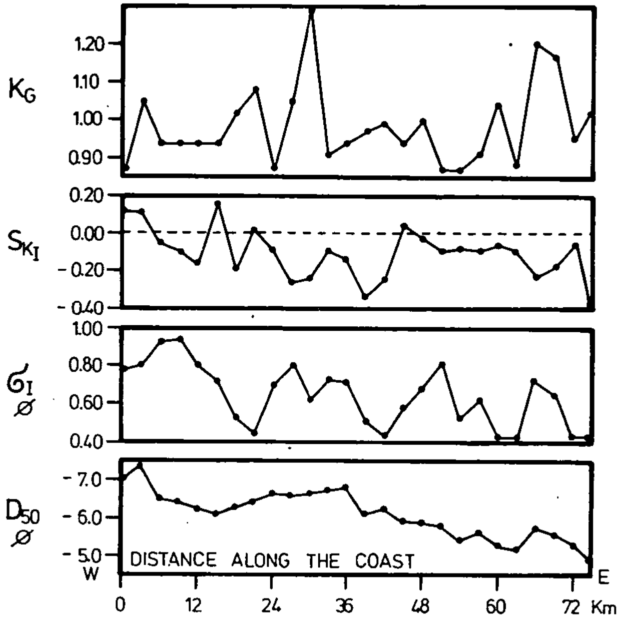

Fig. 7. Lateral variation of statistical parameters for beach pebbles.

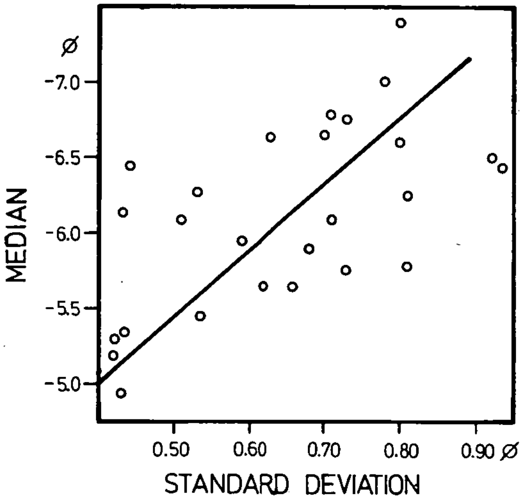

Fig. 8. Relationship between median size of pebbles and standard deviation along Nile Delta coast.

bles can be broken due to splitting and crushig (Bluck, B. J., 1967]. By sorting processes, pebbles displaying a similarity of size are naturally separated by the action of waves because wave energy may be high enough to move all the different shape of pebbles. This is with the agreement of the relationship between size and sorting of pebbles. For these reasons, size-sorting plays a major role on beaches and is the dominant factor in the sorting of pebbles along Nile Delta coast.

Size-sorting processes due to littoral current drift may be responsible to the pebble size decreasing trend. Such trend is caused by either a current of decreasing strength or by the decreasing availability of larger pebble size away from west to east.

Peaks pattern

The study of the distribution of beach pebbles along the coast can be truly significant when it can related its distribution to the probable source area. In fact, pebble size variations reveal a progressive decrease of median size and an improvement of sorting along the coast. There has been, however, a pattern of peaks. They are marked by a higher percentage of large pebbles, higher median size and badly sorted than in neighbouring sites of sampling. These peaks can be seen in three locations and *Figs 5, 6* and *7* reflect them clearly. The first peak occurs just east of Burullus outlet and it is the sharpest one. The second peak can be found in the location 36 km, and it is smaller than the first one. The third peak is the smallest one and can be seen east of Gamasa drain. Eastwards of each peak, there is a directional gradiations in size of pebbles and sorting along with a considerable increase in the percentage of finer pebbles *(Fig. 9)*. Such trend may serve to indicate the sources supplied the pebbles.

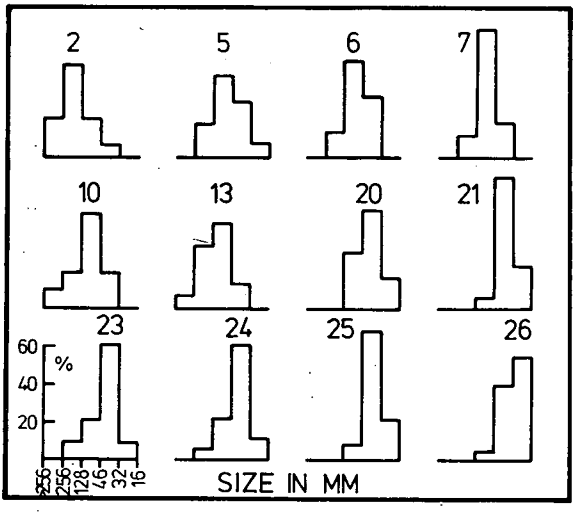

Fig. 9. Histograms for size classes distribution of beach pebbles. Observe the directional gradations in size and sorting from left to right within each peak. Numbers indicate sample sites.

Logically, the three major peaks are considered to be the secondary sources for pebbles, this is with the agreement of the eastward littoral current.

Whereas for the distribution of beach pebbles along the coast, it is observed that they are periodically added to the coast during winter storms. So, a primary source of these pebbles is not available in the coast itself and these pebbles should come from outside.

Primary source areas: a discussion

The aim of the present surveying and discussion would be identify the probable sources, the general path of pebbles from these sources and then along Nile Delta coast.

EMERY, K. O. [1955] mentioned that there are four main possible sources of beach pebbles: sea-cliff erosion, stream discharge, sea-floor erosion, and longshore transport from one or more of the first three primary sources. In fact, Nile Delta coast is sandy without any cliffs, and the main Nile branches do not discharge any sort of pebbles like that which are seen along the coast. But, the occurrence of large pebbles astride Burullus outlet, Kitchener and Gamasa drains can be assumed that the outlet discharge and the present drains may be the sources for pebbles formation. These drains discharge fine sand, silt and clay which are lithologically similar to pebble components. Coagulation between these components and salt water may be occurred. But it is difficult to relate the origin of pebbles to the load of channels due to lacking of pebbles near the other branches.

The stretch of pebbles coincides with a part of the coast where Nile branches discharged in ancient times (Sebennitic, Saitic, and Atribic). Offshore of this stretch, there are old lagoonal deposits which were formed during the low stands of sea level. So, some ideas related the origin of pebbles to these old lagoonal clays (personal communication with PROF. DR. M. G. BARAKAT, Geology Dept., Cairo Univ.).

Nile Delta beach pebbles do not come from the local erosion of sub-beach layers, nor do they seem to be formed by diagenesis in place [EL-FISHAWI, N. M. *et al.*, 1976]. On the other hand, at the top of Rosetta Submarine Banks, the CHAIN (an American Vessel) dredged lagoonal mudstone and sandstone which are lithologically similar to the beach pebbles along the coast [MISDORP, R. and SESTINI, G., 1976]. For these reasons, sea-flower erosion from the old banks is the probable source for Nile Delta beach pebbles.

A map of physiographic units of the Nile Delta continental shelf (after Coastal Erosion Studies, 1976) gives some ideas about the old topographic banks *(Fig. 10)*.

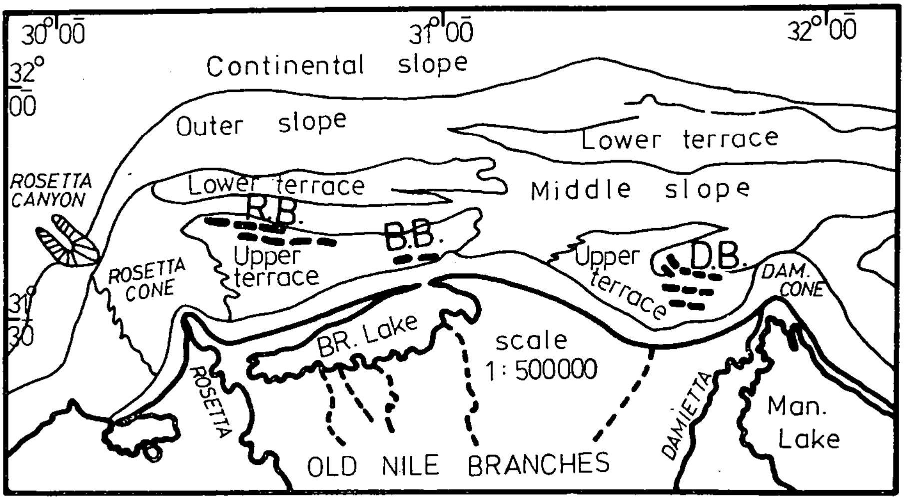

Fig. 10. Physiographic units of the Nile Delta continental shelf (after Coastal Erosion Studies, 1976), R. B. = Rosetta Banks, B. B. = Burullus Banks, D. B. = Damietta Banks.

These banks appear to be remnants of erosional surfaces, made of indurated sands with lagoonal muds, which may consider to be the primary sources for beach pebbles. Analyses of submarine morphology carried out by MISDORP, R. and SESTINI, G. [1976] illustrated that three old banks are occurred, they are Rosetta, Burullus, and Damietta *(Fig. 10)*.

Rosetta Banks located between long. 30° 23′ and 30° 42′ E (60—30 km NW off Burullus outlet) and marked by a line of small ridges and hills elongated NW—SE. Burullus Banks located 4—6 km north off Burullus outlet between long. 30° 53′ and 31° 00′. These hills parallel with coast and less elongated. Damietta Banks are a group of E—W hills, 10—20 km off Gamasa. They are three parallel ridges lie between long. 31° 35′ and 31° 43′, and 5—13 km long.

Now, the analysis made of beach pebbles suggests that the three peaks of size (secondary sources) are closely related to the locations of Rosetta, Burullus, and Damietta Banks (primary sources). Rosetta Banks appear to feed west Burullus outlet stretch with pebbles, while Burullus Banks feed the eastern stretch. Waves and swells approaching the coast from NNW and NW play an important role in onshore movement from primary sources to the coast. On the other hand, Damietta Banks seem to be responsible for feeding Gamasa coast with pebbles. However, the location of these banks (NE off Gamasa) does not agree with the approaching NNW waves. But in fact, winter waves coming from N and NE may throw a light on the processes of pebbles movement.

During storms, a lot of material is in suspension, and due to onshore movement, coarse sand is periodically added to the accretional areas of Burullus coast [Coastal Erosion Studies, 1976; EL-FISHAWI, N. M. *et al.*, 1976; EL-FISHAWI, N. M., 1977]. It is possible also that the pebbles appear to have come in the same way especially there are many evidences of large pebbles reaching the coast from known places even many km away from the shore [JOHNSON, D. W., 1919; EMERY, K. O. and TSCHUDY, R. H., 1941; SHEPARD, F. P., 1963; BASCOM, W., 1964].

To sum up, Nile Delta beach pebbles can be derived from the submarine banks. Materials from offshore reach the beach under the influence of wave action. Long waves move sediment in greater depth than short waves [KING, C. A. M., 1972]. So, during winter storms and summer swells waves are coming from NNW, NW, N and NE. Owing to their enough energy flux, they play an effective role in carrying sediments in suspension, the pebbles are then moved shorewards. The eastward littoral current is predominant and pebbles can be shifted sideway by ease to complete the processes of transport with directional gradation along the coast.

CONCLUSION

The distribution of beach pebbles along the eastern Nile Delta coast of Burullus is a function to the source area and sediment movement. Beach pebbles are periodically added to the coast during winter storms so that primary source is not available in the coast itself. The average pebble size generally decreases and sorting improves along the coast in the direction of littoral current from west to east. The decreasing trend of pebble size is mostly related to abrasion and size-sorting processes during transport. Lateral decreasing of median size results mainly from abrasion of particles. The ability of pebbles to abrasion is high owing to their clay-silt-sand components. Also, by size-sorting processes, pebbles displaying a similarity of size are naturally separated from associated by a decreasing trend of current, then waves with enough energy can shifted them easily to the coast.

Three beaches along the coast are characterized by presence of higher percentage of pebbles than the other beaches. This is do not agree with the eastward littoral drift and it have to be explained in the assumption that there are three secondary sources, derived from primary sources, because eastward of each peak there is a tendency to decrease the median size and improve the sorting.

Beach pebbles are considered remnants of old alluvial banks related to old Nile branches in classical times. During winter storms and summer swells, waves approaching the coast from NNW, NW, N and NE owing to their enough energy flux, pebbles are moved shorewards. The littoral current feeding from west to east complete the processes of transport by shifting the pebbles sideway with decreasing trend along the coast.

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