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ROUNDNESS AND SPHERICITY OF THE DELTA COASTAL SANDS

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ABSTRACT

The roundness and sphericity of the Nile Delta coastal sands were studied. Definite correlations between the size and the roundness and sphericity were established. The roundness and sphericity were observed to be complex functions of each other, rather than to be in a linear relationship. A difference in roundness and sphericity was found normal to the shoreline, so that a distance of a few hundred metres makes a complete change in their values. The principal difference comes from the sorting processes of the hydrodynamic forces affecting the coast. It is possible that these studies can be used to differentiate sediments of the Nile Delta coast. The lateral variation of roundness and sphericity was found to be improved and can be applied to the tudy of the sediment movement.

INTRODUCTION

Early studies of roundness and sphericity of the sand grains were made by many authors [WADELL, 1935; MACCARTHY and HUDDLE, 1938; RUSSELL and TAYLOR, 1937; PETTIJOHN and LUNDAHL, 1943]. More recent works have been published by MATTOX [1955], BEAL and SHEPARD [1956], WASKOM [1958], SHEPARD and YOUNG [1961] and MISDORP [1967]. Few comprehensive studies have been carried out on the relation between size and roundness and sphericity. Whether or not sand grains show a progressive increase in roundness and sphericity with distance of transport is an unsettled problem. Many investigators have questioned the authenticity of any actual difference in roundness and sphericity normal to the shoreline.

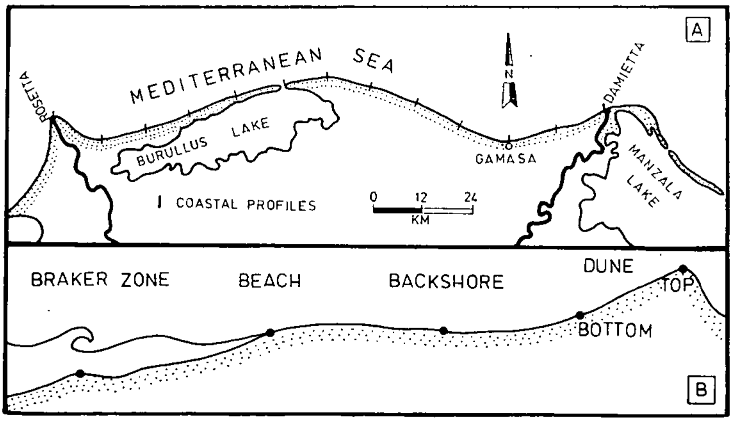

Fig. 1. Location map *(A)* and sampling sites *(B)* for the recent environments of the Nile Delta coast.

The studied area located between Rosetta and Damietta and extends for about 144 km along the coast *(Fig. 1)*. Theoretically, samples collected along profiles normal to the shoreline indicate the importance of waves and winds as selectors of round and spherical grains. Therefore, samples were collected along profiles perpendicular to the shoreline: in total 13 profiles being chosen *(Fig. 1A)*. Each profile contains a breaker zone, beach, backshore and dune sample where possible *(Fig. 1B)*. In this way, it may be possible to obtain appreciable differences between adjacent environments and to detect if there is a definite change over a distance of some hundred metres.

The aim of the present study is to correlate the roundness and sphericity with the grain size, depositional environments and distance of transport along the Nile Delta coast.

METHODS OF STUDY

BOGGS [1967] describes the use of grain photographs and the Zeiss electronic particle size analyzer (Zeiss TGZ 3) in the analysis of grain roundness and sphericity. This technique is used in the present study, where the photographic print is mounted on the analyzer and the radius measurements are rapidly and automatically tabulated for each grain image. The study was made on grain sizes of 2000—1000 μm, 1000—500 μm, 500—250 μm, 250—125 μm, 125—63 μm. Sieve fractions were put through a microsplitter to obtain a few hundred representative grains. Loose grains to be photographed are placed on a slide and tapped gently so that they come to rest with long and intermediate axes in projection view. 50—100 grains are photographed and a suitably enlarged photomicrograph is prepared on thin photographic paper.

Of the several formulae proposed for measuring roundness in detrital particles, Wadell's may be regarded as the most indicative measure [FLEMMING, 1965; SWAN, 1974]. This measure was applied in the present study:

WADELL [1933] roundness $= \sum D_c / N D_i$

where: D_c is the diameter of the curvature of a corner; N is the number of corners; and D_i is the diameter of the largest inscribed circle.

Because of the difficulty of making three-dimensional measurements of sand grains, the sphericity method of RILEY [1941] was applied in this study. He proposed an expression of sphericity based on two intercept dimensions. His projection sphericity is defined as the square root of the ratio of the inscribed and circumscribed circles, as indicated by the formula:

Projection sphericity $= \sqrt{D_i/D}$

where D_i refers to the diameter of the inscribed circle; and D to the diameter of the circumscribed circle.

Roundness and size

All roundness values for each environment were plotted against size, as shown in *Fig. 2*. A line connecting the mean roundness of each size is presented; the comparison generally shows a marked decrease in roundness with decreasing size. This is in agreement with RUSSELL and TAYLOR [1937], PETTIJOHN and LUNDAHL [1943], INMAN [1953], INMAN *et al.*, [1966], RAMEZ and MOSALAMY [1969], KHOLIEF *et al.* [1969], BALAZS and KLEIN [1972] and MISDORP [1976]. The mean roundness line for each environment shows similar behaviour. It is observed that there is a sharp decrease in roundness with decrease in size between 500—125 μm; little difference was found with grain sizes smaller than 125 μm. It may be true that the coarser sands show a better tendency to selective wear than the finer sands.

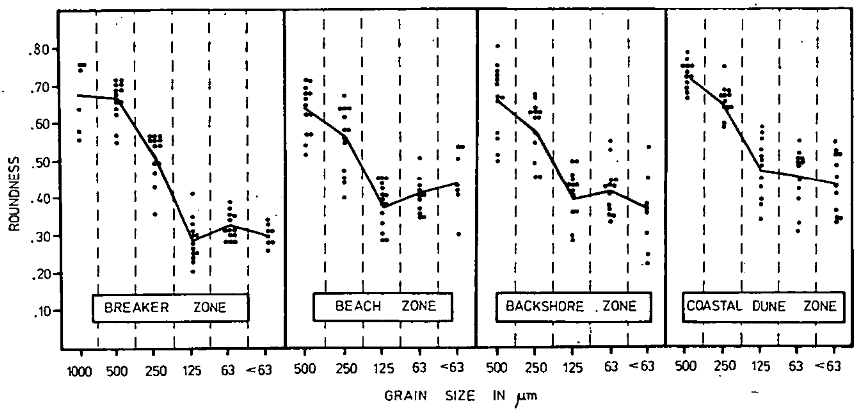

Fig. 2. Relationship between roundness and grain size of the coastal sands.

Sphericity and size

The most striking result comes from testing the sphericity of various grain sizes, as indicated in *Fig. 3.* The coastal sands are characterized by a steep decrease in sphericity, associated with a decrease in grain size. This marked correlation between sphericity and size has been investigated by MacCarthy [1935], Wadell [1935], Russell and Taylor [1937], Pettijohn and Lundahl [1943] and Mattox [1955]. The mean sphericity line for each environment shows similar behaviour.

The lines connecting the mean roundness and sphericity values for each size of various coastal sands were overlapped *(Fig. 4)* to correlate between them. A significant difference in roundness values was found between the different coastal sands

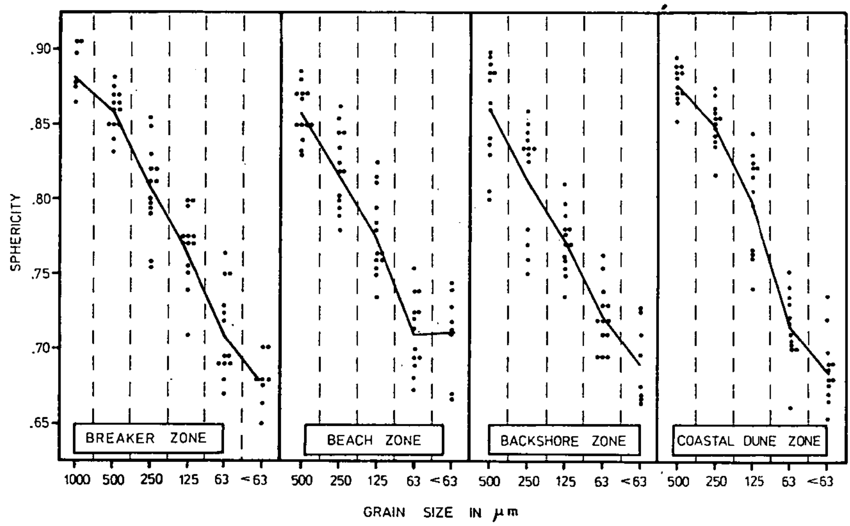

Fig. 3. Relationship between sphericity and grain size of the coastal sands.

(*Fig. 4A*). As regards sphericity, it is generally possible to distinguish the dune sands, because little sphericity difference exists between breaker zone, beach and backshore sands.

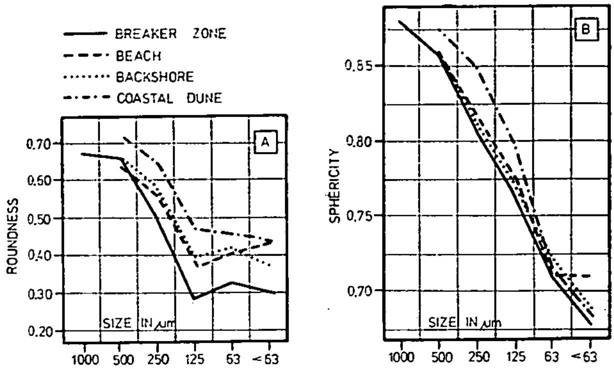

Fig. 4. An overlap of the mean roundness (*A*) and mean sphericity (*B*) for the coastal sands.

Relationship between roundness and sphericity

Early studies mentioned that the roundness and sphericity are functions of each other, and the roundness seems to bear a linear relation to the sphericity [WADELL, 1935; RUSSELL and TAYLOR, 1937; PETTIJOHN and LUNDAHL, 1943]. These studies depended upon few samples, which gives the impression that the data were insufficient. Moreover, it is observed that the slope of their curves is probably a little too steep. ROSENFELD and GRIFFITHS [1953] feel that this sympathetic relationship arises from pshychological bias on the part of the operator.

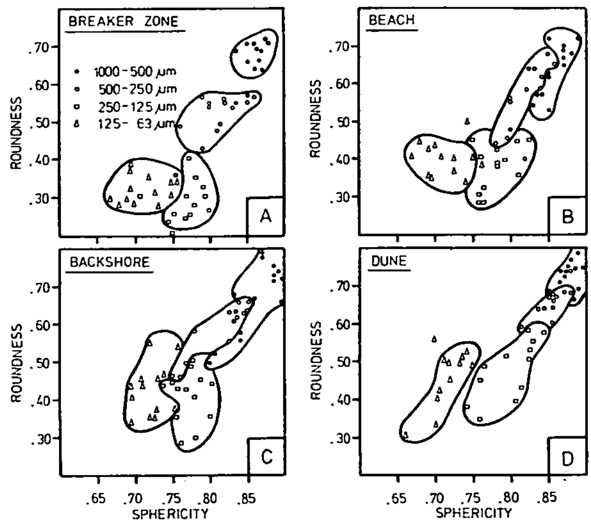

Fig. 5. Relationship between roundness and sphericity.

In fact, the roundness and sphericity are functions of the grain size, and the better rounded grains are the more spherical. The two parameters, however, were found to be complex functions of each other. *Figure 5* shows the relationship between them for each coastal sand. Roundness and sphericity data are based on measurements on four size grades; at least 12 pairs of roundness and sphericity vallues are drawn for each size grade. *Fig. 5* deals with the following observations:

1. The field of each size grade was found to be separated from the other size grade fields. The separation may be complete, as in the breaker zone, and may involve some overlaps, as in the backshore.

2. The increase of the roundness and sphericity with increasing grain size found to be a general trend. The coarse sizes (1000—250 μm), however, display a better roundness-sphericity relation than do the finer sizes (250—63 μm).

3. The best correlation between the size grade fields was demonstrated for the coastal dune sands. The size grades are gradually arranged according to size, roundness and sphericity. This arrangement may be related to the wind action.

4. Mathematically, it is very difficult to consider that the roundness bears a linear relation to the sphericity, in spite of the positive correlation between them. It is better for such relationships to be expressed as fields of data than as regression equations.

Roundness and sphericity in relation to depositional environments

For many years sedimentary petrographers have attempted to determine the relationship between the depositional environment and the form of sand grains. To detect this relationship in this study, the mean roundness and sphericity values for each size grade were plotted against the coastal environments *(Fig. 6)*; the values are summarized in Table 1.

TABLE 1

Mean roundness (R) and sphericity (S) values for the Nile Delta coastal sands

Size	1000—500 μm		500—250 μm		250—125 μm		125—63 μm		Mean	
Environ	R	S	R	S	R	S	R	S	R	S
Breaker zone	.664	.860	.516	.808	.289	.767	.327	.712	.449	.787
Beach zone	.638	.858	.560	.822	.378	.777	.408	.712	.496	.792
Backshore	.664	.859	.589	.816	.413	.772	.423	.721	.522	.790
Dune bottom	.748	.876	.671	.856	.479	.802	.471	.718	.592	.813
Dune top	.706	.877	.647	.842	.490	.794	.443	.710	.572	.806

a) Roundness and depositional environments

At first sight, it will be seen that a difference in roundness was found between the Nile Delta coastal sands, so that a distance of a few hundred metres makes a complete change in the roundness values *(Fig. 6A)*. All size classes show a definite improvement in roundness normal to the shoreline. In moving from the breaker zone through the beach and backshore, and up to the dune, the mean roundness increases from 0.449 to 0.592. The sands of the dune top are relatively less rounded than those of the bottom, but are still more rounded than the other types of sands.

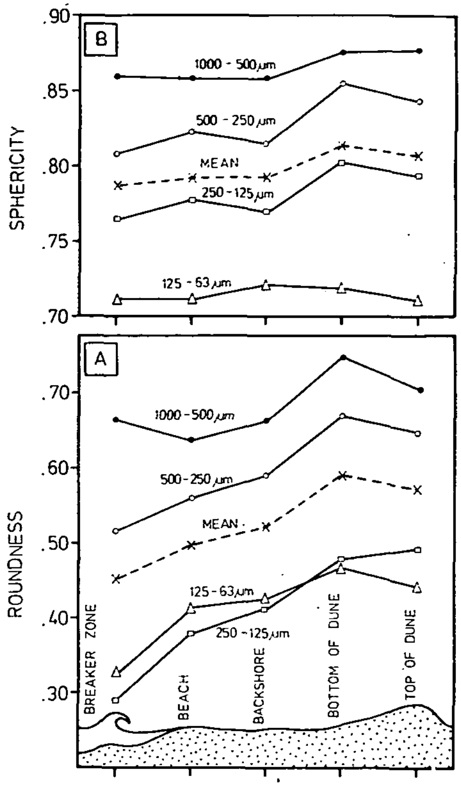

Fig. 6. Variations of mean roundness *(A)* and mean sphericity *(B)* normal to the shoreline.

Roundness has been referred to by a number of authors as being greater in dune sands than in the adjacent beach from which the dune was derived [MacCarthy, 1935; Russell, 1939; Beal and Shepard, 1956; Pettijohn, 1957; Shepard and Young, 1961]. In contrast, Waskom [1958] found that the beach ridge sand grain roundness is greater than that of sands in other environments. Other sedimentologists have questioned the authenticity of any actual difference in roundness between beach and dune sands [Mattox, 1955; Mason and Folk, 1958]. Many textbooks and articles contain statements to the effect that sand grains found in aeolian deposits generally possess a higher degree of roundness than do grains found in other environments. There is no reason to believe that the grains are rounded appreciably by the wind in transit to the dunes, but very little rounding may occur in transporting sand from the beach to the adjacent dunes.

The principle difference in roundness between the adjacent coastal environments comes from the sorting action of the hydrodynamic forces affecting the coast. The possible explanation for the greater roundness in the beach than in the breaker zone is that the waves carrying the sand up onto the beach may select the rounder grains. The increase in roundness landwards may be related to the sorting action of the wind in picking up more rounded grains from the beach. It is evident that well rounded grains can roll and be blown more easily than grains with angular corners. Therefore, the wind can select the more rounded grains from the beach to be rolled, the relatively less rounded grains may be added to the backshore zone, while the more rounded ones can easily continue to be transported and finally to be added to the dune. In some areas, where beaches and dunes are most difficult to distinguish, it is thought that the dune sands are blown back onto the beaches, causing intermixture. In some cases, the dunes are derived from sources other than the adjecent beach [BEAL and SHEPARD, 1956].

b) Sphericity and depositional environments

Figure 6B shows that the sphericity values of the coastal dune sands are consistently larger than those of the other environments. The sphericity values of the breaker zone and backshore zone sands are generally lower than for all other sands. The dune top sands are slightly less spherical than the bottom ones. It is noted that the sphericity of the 125—63 µm size grade behaves separately.

The increase in the sphericity of the dune sands can best be explained by the hypothesis that a more spherical grain will roll more easily than a less spherical one. BAGNOLD [1937], however, has shown that most aeolian transportation occurs by saltation. Therefore, another idea must be suggested to explain this condition. On the basis of a series of experiments, MACCARTHY and HUDDLE [1938] concluded that aeolian transportation favours sand grains with high sphericity values, because such grains tend to bounce higher than grains with lower sphericity values. A critical examination of this conclusion leads to disagreement along the lines suggested by MATTOX [1955]. He stated that a grain with a lower sphericity value will have a greater tendency to move, because of the larger surface area exposed to the wind, and thus the dune sands are less spherical than the beach sands.

During the present study on the Nile Delta coast, it is observed that most of the sand transportation takes place during normal conditions, when the wind velocity is enough only to initiate sand movement. During the course of transportation, a considerable amount of sand was observed in motion by rolling. If two grains of different sphericity values, but of equal mass, are subjected to the action of wind which is strong enough to initiate the movement, the grain with the higher sphericity value will have the greater tendency to start rolling. Therefore, because they roll more easily, grains with higher sphericity values, are transported greater distances by traction than grains with lower sphericity values.

To sum up, where the dunes are formed close to the adjacent beach, the few hundred metres distance of transportation is enough to allow the development of sphericity. The wing picks up from the beaches more grains with higher sphericity values than those with lower values. As a result, the grains of the dune sands become relatively more spherical than those of the beach sands. In fact, during storm periods sands movement takes place regardless of shape. On the other hand, the possible reason for the relatively higher sphericity in the beach than in the breaker zone may be related to the effect of waves in selecting spherical grains to be added to the beach sediments.

Lateral variations of roundness and sphericity

In all experimental and field work, the roundness and sphericity of beach sands increased with distance [KRUMBEIN, 1941; PETTIJOHN, 1957]. The studies of beach and river sands by MACCARTHY [1935], RUSSELL and TAYLOR [1937] and PETTIJOHN and LUNDAHL [1943] show a small, though unequivocal decline in sphericity during movement. They attribute their findings to progressive fracturing or sorting action.

Variations of roundness and sphericity for each size grade of the breaker zone, beach, backshore and dune sands along the coast are shown in *Figs. 7* and *8*. Sands grains apparently become better rounded and more spherical as a result of abrasion during the course of transport. Abrasive action in the absence of coarse materials is exceedingly slow [PETTIJOHN, 1957], which may explain the decline in roundness and sphericity of the fine sands of the Damietta beaches. Although roundness and sphericity are geometrically distinct, they react in a dynamically similar manner to abrasion along the coast. It is observed that a small increase in sphericity is accompanied by a large increase in roundness.

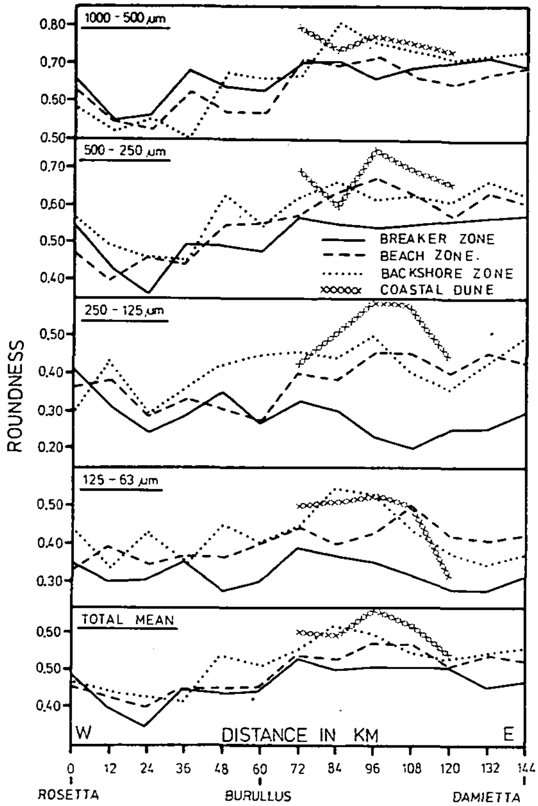

Fig. 7. Relation of roundness of coastal sands to distance of transport along the Nile Delta coast.

The relation of grain roundness to distance of transport *(Fig. 7)* involves the following concepts:

1. The mean roundness of the coastal sand grains generally exhibits a definite though fluctuating increase with distance of transport eastward. In the early stages of transport (0—24 km), the roundness of the coastal sands shows a relative decrease, and then progressively increases to the maximum value near the location 96 km. It tends to decrease relatively eastwards.

2. In all the cases, it seems that the change in roundness may quite abrupt at first, but subsequently it becomes rather smooth. This suggests that the process of

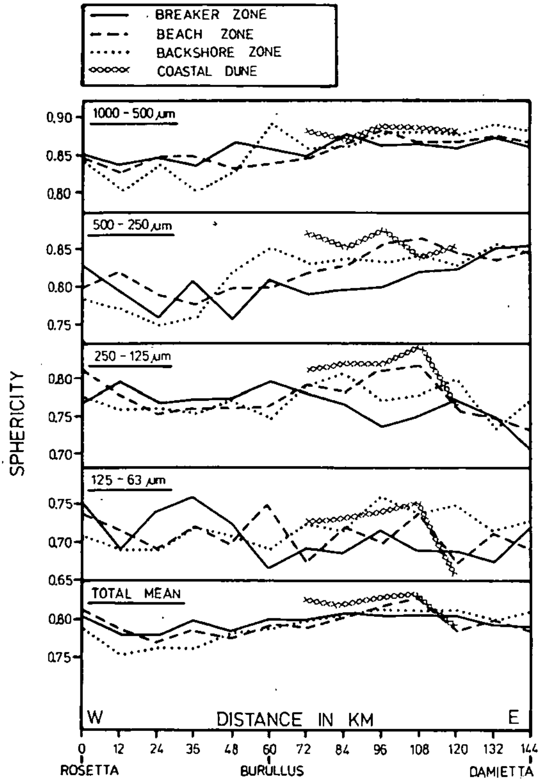

Fig. 8. **Relation of sphericity of coastal sands to distance of transport along the Nile Delta coast.**

rounding is more rapid when the grain is angular and that it slows down as it becomes more rounded.

3. The roundness of the coarser sands increases more rapidly than that of the finer sands. The coarse sands are most readily rounded because they may wear most rapidly.

4. The difference in roundness between the sands of the different environments in greater in the finer grades than in the coarser ones.

5. No significant difference in the lateral variation of roundness of breaker zone sands for 250—125 μm and 125—63 μm size grades could be correlated with transport.

Lateral variations of sphericity are shown in *Fig. 8*. The following were observed:

1. The mean sphericity values of the coastal sands reveal that the grains become more spherical with transport. Little, but definite sphericity change is found.

2. The lateral variation of the coarser grades (1000—250 μm) is more pronounced than that of the finer ones (250—63 μm). It seems evident that the coarser grains moved undergo a modification.

3. The sphericity changes for the 1000—500 μm size grade are slow, which may be related to the limited effect of abrasion. These changes become quicker for the 500—250 μm size grade.

4. For the 250—125 μm size grade, the wear plays little role from Rosetta to the location 84 km. These sediments attain higher sphericity values between 84 and 120 km and then tend to decrease sharply.

5. No significant change in sphericity for the 125—63 μm size grade could be correlated with distance.

6. A rapid increase in sphericity takes place in the early stages of transport for the backshore sands; the other coastal sands do not display such a feature.

CONCLUSIONS

1. A definite correlation between the size of the coastal sands and both the roundness and sphericity is established. The sands are characterized by a steep decrease in roundness and sphericity, associated with a decrease in size. The coarse sands may be abraded more easily than the finer sands. It was found that the better rounded grains are the most spherical.

2. The roundness and sphericity were observed to be complex functions of each other, rather than to be in a linear relationship, in spite of the positive correlation betveen them.

3. A difference in roundness and sphericity was observed normal to the shoreline, so that a distance of a few hundred metres makes a complete change in their values. All size classes of the sand become more rounded and spherical in moving from the breaker zone through the beach and backshore and up to the dune. The principal difference comes from the sorting processes of the hydrodynamic forces affecting the coast. A possible explanation for the greater roundness and sphericity values in the beach than in the breaker zone is that the waves carying the sand up onto the beach may select the rounder and more spherical grains. The increase in these values landward may be related to the sorting action of the wind in picking up more rounded and spherical grains from the beach. It is evident that well-rounded and spherical grains which can roll and can be blown more easily than grains with angular corners and flat surfaces, are to be added to the dune sands. Therefore, the roundness and sphericity of sands can be used as indicators of depositional environments.

4. The roundness and sphericity of the sands show a definite, though fluctuating increase with the distance of transport along the coast. This change may be quite abrupt at first, but subsequently becomes smoother. It may be suggested that rounding is more rapid when the grain is angular, and it slows down as it becomes more rounded. The change in the coarser sands is more pronounced than in the fine sands, and therefore the coarser sands seem to undergo a modification.

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