SHAPE-SORTING OF SAND GRAINS BY WIND ACTION.

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ABSTRACT.

This paper presents experimental evidence showing that much of the superior roundness of eolian sands as compared to sands of other types is due to a process of shape-sorting. The experiments indicate that the wind transports sand grains chiefly by saltation and that this method of transportation favors the rounder grains.

It has long been recognized that, on the average, eolian sands are better rounded than sands of other types. The superior roundness of wind blown sand grains is usually attributed to the rapid abrasion such sands are thought to suffer. It has been suggested several times that in the case of water borne sands, sharp blows between one grain and another, except for large particles, are prevented by a film of water around the grains that acts as a cushion to soften the blows. No such cushion exists between the grains of eolian sands, and hence mutual attrition and consequent rounding might be expected to proceed more rapidly. It is also true that a grain immersed in a relatively dense medium such as water would be buoyed up and therefore would not move as rapidly under the influence of gravity as would a similar grain immersed in a less dense medium such as air.[1]

Evidence accumulated by the writers seemed to indicate that much of the superior roundness of eolian sands is produced by a process of selective sorting rather than by intensive rounding. Although rounding by wind abrasion undoubtedly occurs, it appears to have been overemphasized. A large sand dune at Nag's Head, on the North Carolina coast, is an example of field evidence indicating the shape-sorting of sand grains by wind action. The grains composing this dune are distinctly rounder than the grains of the beach sand from which the dune has undoubtedly been derived. The dune is only a few hundred feet back from the beach and therefore the distance that the sand has been moved is far too short to permit rounding by abrasion.

[1] Twenhofel, W. H., and others: Treatise on Sedimentation. 2nd edition, p. 76, 1932.

It has been shown that sands carried along a beach under the combined influence of waves and shore currents undergo a selective sorting whereby the more angular grains are shifted more rapidly than are the rounder ones.[2] Thus both analogy and field evidence suggest that the wind is capable of shape-sorting. The experiments described in this paper are an attempt to test the hypothesis that the wind tends to carry the round grains faster and farther than it carries the angular grains.

The sand used in the experiments consisted of a mixture of very angular and very round grains made by mixing in approximately equal proportions crushed quartz pebbles and Saint Peter sandstone.[3] Both sands were sieved to pass the 20-mesh and be retained upon the 40-mesh U. S. Stand. sieves. To aid in distinguishing the grains at a glance the crushed quartz was stained a light brown. After staining, the two sands had identical specific gravities.

For the experiments a trough of heavy cardboard about four inches deep and 14 inches wide was used. Sheets of cardboard were arched over the trough for some of the experiments and in others 22 inch sides were used. This was found necessary to prevent the sand from bouncing out of the trough. The length and inclination of the trough could be varied at will, and various types of baffles and sand traps could be added. Air currents were produced by ordinary electric fans directed down the trough. The samples were introduced near the head of the trough just in front of the first fan. In the majority of experiments, the sand was spread thinly over an area of a few square inches near the head of the trough, but in a few cases it was poured into the air stream through a funnel. At no time during the experiments was the floor of the trough covered by a continuous layer of sand, wherein the experiments deviated from the usual conditions in nature. Samples of the sand traveling the full length of the trough and also the "lag gravels," which accumulated at various points, were collected and studied.

[2] MacCarthy, G. R.: The rounding of beach sands. This Journal, 25, 205-224, 1933.

[3] The Saint Peter sandstone (probably from Ottawa, Illinois) was furnished by the Indiana Limestone Company through the courtesy of Mr. R. E. Esarey.

Experiments were made with the trough level and with it inclined; with one or four fans in operation; and with and without baffles and sand traps. In no case was the inclination of the trough enough to allow the sand grains to roll under the influence of gravity alone. Without exception it was found that the sand grains that traveled the length of the trough were rounder than the average of the introduced grains, while the "lag gravels" which accumulated on the floor of the trough were composed of the more angular grains.

In determining the degree of roundness Cox's method was used.[4] This method has the disadvantage of actually measuring neither roundness nor rounding, but the circularity of random cross sections of the grains. The circularity of a random cross section should give a fair measure of the sphericity of the grain, and perhaps "sphericity" should be used instead of "roundness." Since the latter term has been used in previous papers it is retained here. Cox's method was used because it is the only method known to the writers that eliminates the personal equation of the observer. In this scheme a roundness of 850 means that the grain under consideration showed a cross section which was 85 per cent as round as a circle and that presumably the grain was 85 per cent as spherical as a perfect sphere.

Roundness determinations showed that the crushed quartz sand had a roundness coefficient of 780 and the Saint Peter one of 936. These figures represent averages, and hereafter will be referred to as the "average roundness" of the sand. The grains of crushed quartz ranged in roundness from 591 to 925 and the grains of Saint Peter sand ranged from 830 to 997. Angular grains of Saint Peter and really round grains of crushed quartz were rare.

During the course of the experiments two different lots of mixed sand were used. One, referred to in later sections of this paper as "mixture No. 1," contained 48 per cent of angular grains and 52 per cent of round grains, and had an average roundness of 861; while the other (mixture No. 2) contained 53 per cent of angular and 47 per cent of round grains and had an average roundness of 852.

In the first series of experiments a trough eight and one-half feet long and inclined about 8° was used. One fan at the

[4] Jour. Paleontology, 1, 179-183, 1927. Also This Journal, 30, 82, 1935.

upper end of the trough furnished the air current. Detailed accounts of the individual experiments follow.

Experiment No. 1. In this experiment the sand was introduced into the air stream through a funnel at a point 18 inches below the fan and seven feet from the lower end of the trough. At the end of about ten minutes the grains that had traveled the full length of the trough were collected and examined. This sample was found to consist of 67 per cent round and 33 per cent angular grains; the percentage of round grains had increased from 52 per cent to 67 per cent. No roundness determinations were made, but it possessed a *computed roundness*[5] of 884.

Experiment No. 2 was similar to No. 1. The only change in conditions was the introduction of a series of baffles. These were small metal plates about 1/32 inch thick laid flat on the bottom of the trough. It was thought that the more angular grains might be trapped behind these obstructions, and that the final product would contain more round grains. This was not the case as the end product contained only 64 per cent round grains. This difference seems to be too small to be very significant but perhaps the baffles prevented the rounder grains from rolling.

Experiment No. 3. In this experiment the sand was spread thinly over the bottom of the trough close to the fan. No baffles were used. To facilitate the movement of sand, the table on which the apparatus stood was tapped sharply at intervals with a light hammer. At the end of ten minutes, the sand at the end of the trough was collected and found to contain 79 per cent of round grains. The computed roundness of the sand was 893.

Experiment No. 4 was identical with Experiment No. 3 except that the apparatus was not shaken or jarred in any way. The results were similar but the sorting was not as good. The grains collected at the lower end of the trough contained only 69 per cent of round grains, and had a computed roundness of 888.

[5] Computed from the average roundness of the angular and round components of the original mixture (No. 1) and the measured percentage composition of the final product. For a comparison of computed roundness and measured roundness see Tables 2-4.

The results of these experiments are given in tabular form below:

TABLE I.

	Percentage of angular grains	Percentage of round grains	Computed[6] roundness
Crushed quartz	100	000	780
Saint Peter sand	000	100	936
Original mixture	48	52	861
Experiment No .1	33	67	884
Experiment No. 2	36	64	885
Experiment No. 3	21	79	893
Experiment No. 4	31	69	888

[6] For meaning of "Computed roundness" see footnote 5.

For the second series of experiments a trough 27 feet long and inclined about 6° was used. Four fans created the air current, the first at the upper end of the trough and the others at six foot intervals. The second fan oscillated. For these experiments, Mixture No. 2 was used (53 per cent angular, 47 per cent round). Detailed descriptions of the experiments follow.

Experiment No. 5. The sand was spread thinly over the floor of the trough just in front of the first fan and all four fans were turned on for ten minutes. At the end of this time the grains that had reached the end of the trough were examined. It was found that the proportion of round grains had risen from 47 per cent to 65 per cent, giving a computed roundness of 881. It was suspected that the actual roundness exceeded this figure, since the "lag gravels" left on the floor of the trough seemed to consist of extremely angular grains. A roundness determination showed that the actual roundness had risen to 902 rather than the computed 881. The discrepancy is due to the fact that the angular grains which reached the end of the trough were much rounder than the average angular grain. In computation the roundness of all angular grains was considered to be equal, i.e. 780.

Experiment No. 6. This experiment was designed to test the effect of the inclination of the trough. The trough was leveled and experiment No. 5 was repeated. The grains emerged from the apparatus as 63 per cent round and 37 per cent angular; giving a computed roundness of 878. A roundness determination showed the actual figure to be 886; slightly less than in the preceding experiment. Apparently the effect of leveling the trough was to decrease the effectiveness of wind action or to prevent the transportation of some of the round sand grains by rolling. The difference may not be significant.

The results of Experiments 5 and 6 are shown below in Table II.

TABLE II.

	Percentage of angular grains	Percentage of round grains	Computed roundness	Measured roundness
Original mixture	53	47	852	852
Experiment No. 5	35	65	881	902
Experiment No. 6	37	63	878	886

In a previous paper by one of us[7] it was suggested that the apparent tendency of the wind to shift the rounder grains rather than the more angular ones implied that eolian sands are rolled along the surface rather than blown through the air. Further field observation, a search of the literature, and observations of the sand moving through the experimental apparatus, all indicated that such was not the case. Sands moved by air currents tend to travel in a series of jumps rather than rolling along the surface or being carried in suspension. Any tendency for the wind to roll the more rounded grains is easily understood, but why such grains would be selected during suspension or saltation (jumping) is less obvious. It would seem that in suspension, the more angular grains would present larger surfaces to the air, would suffer more resistance, fall more slowly than the rounder grains, and would therefore be carried farther before falling back to the ground. Grains carried by saltation would also be affected by air resistance, but another factor must also be considered. The height to which a grain bounces will influence the distance it can be carried before falling back. The average altitude reached through elastic rebound should vary from one grain shape to another since the angular grains must occasionally strike on a corner or edge and rebound with extremely low trajectories. If this is true the round grains must on an average bounce higher than the

[7] MacCarthy, G. R.: Eolian sands; a comparison. This Journal, 30, 91, 1935.

angular ones. Experiments were made to determine whether the round grains actually did reach higher altitudes in the air stream and whether there is any difference in the elastic rebound of round and angular grains.

The third series of experiments utilized the trough and fans set up for Experiment No. 5. In *Experiment No. 7* a sand trap whose bottom was four inches above the bottom of the main trough was placed midway between the third and fourth fans. The sand caught in the trap contained 55 per cent round grains, compared with 47 per cent round grains in the sand introduced into the apparatus. These grains possessed a computed roundness of 866. Actually, as shown by measurement, the average roundness of this sand was 879.

Experiment No. 8 was identical with No. 7 except that the sand trap was lowered to two inches above the bottom of the main trough. The trapped sand had 52 per cent of round grains, a computed roundness of 861, and measured roundness of 855. These figures are below those for the sand trapped at an altitude of four inches, and seem to show that the rounder grains do tend to move at higher altitudes. The results are shown below in Table III.

TABLE III.

	Percentage of angular grains	Percentage of round grains	Computed roundness	Measured roundness
Original mixture	53	47	852	852
Experiment No. 7	45	55	866	879
Experiment No. 8	48	52	861	855

The "lag gravels" which had accumulated during Experiments 7 and 8 were collected and examined. The lag at the second fan contained only four per cent round grains and was composed almost entirely of the most angular grains of crushed quartz. It had a roundness of only 731, 049 units less than the average for the crushed quartz. The lag at the third fan contained only nine per cent of rounded grains, and had a roundness of 775, again less than the average of the crushed quartz. Finally the lag at the fourth fan contained 42 per cent of rounded grains, and hence was only slightly more angular than the mixture fed into the apparatus. The great difference between the lag at the third and fourth fans is probably due to the fact that the sand trap between the fans interfered with the air currents.

The grains that passed through the trough during the twenty minutes the fans were operating for Experiments 7 and 8 were also collected and tested. They contained 75 per cent of rounded grains and had a measured average roundness of 897. These facts are given below in tabular form (Table IV).

TABLE IV.

	Percentage of angular grains	Percentage of round grains	Computed roundness	Measured roundness
Original mixture	53	47	852	852
Lag at 2nd fan	96	4	786	731
Lag at 3rd fan	91	9	794	755
Lag at 4th fan	58	42	846	837
Sand passing through trough	25	75	897	897

Table IV shows conclusively that air currents have a strong tendency to transport the more rounded grains and leave the more angular ones behind, which tendency is exactly the reverse of that found in the case of wave and shore current action.[8]

A fourth and last series of experiments was devised to determine whether or not the elastic rebound of round grains differed from that of the angular ones. Small portions of mixed sand were dropped through a funnel upon a slightly tilted anvil. The anvil had a flat, solid surface with a transverse slot about one-half inch wide cut through it. A cardboard barrier about three-quarters of an inch high was mounted on the downslope side of the slot. Some of the sand grains striking the anvil bounced far enough to clear the barrier, and the rest slid or rolled down the incline and through the slot. A diagram of this apparatus is given in Fig. 1.

In Experiment No. 9 the anvil was a flat strip of steel covered with blotting paper to give a rough textured surface. The sand was dropped slowly from a height of about five inches so

[8] This Journal, 25, 205-224, 1933.

that it struck the anvil about one inch above the slot. The sand that cleared the barrier contained 55 per cent round grains as compared with 52 per cent round grains in the sand which failed to clear the barrier. This difference is very slight, but it seems to show that the rounder grains did have a tendency to bounce the farthest.

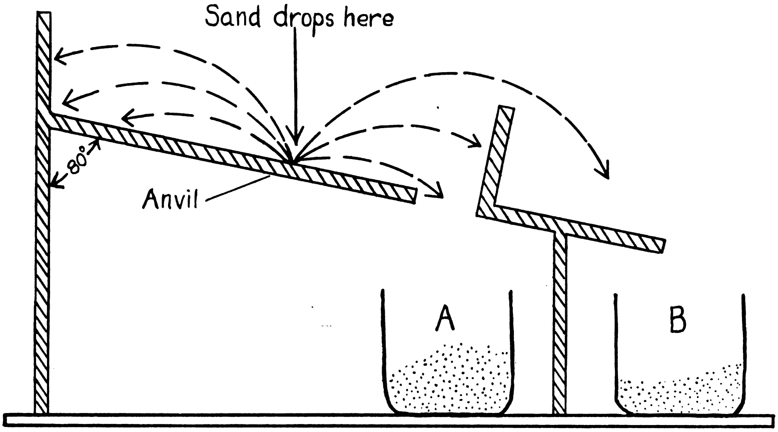

Fig. 1. Sketch of the apparatus used in experiments 9, 10, and 11. The sand was dropped through a funnel on to the anvil. The grains that bounced over the barrier collected in beaker B, while the grains that failed to clear the barrier collected in beaker A.

Experiment No. 10 was the same as No. 9 except that a bare steel plate was used as the anvil. In this experiment the sand clearing the barrier contained 54 per cent round grains; a separation not quite as good as in the former experiment.

Experiment No. 11 was identical with No. 10 except that the sand which cleared the barrier was poured back into the apparatus again and again so that the end product consisted of those grains that had cleared the barrier nine successive times. This end product contained 75 per cent round grains, and possessed an average roundness of 913. The original mixture had an average roundness of about 861. This seems to indicate that the slight difference in the behavior of round and angular grains on a single rebound can be magnified by repetition and is therefore significant.

CONCLUSIONS:

From these experiments the following conclusions have been drawn:

1. The wind transports sand grains chiefly by saltation (jumping).
2. Round grains on the average bounce higher than angular grains, and are therefore carried farther before falling back to the ground.
3. Round grains show a strong tendency to move under the influence of wind action while the angular grains tend to remain behind as "lag gravels."
4. Much of the superior roundness of eolian sands as compared to other types of sands is due to a process of shape-sorting.

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