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By Hans Kuhlman.

In 1958 six representative samples of sand were collected from 2 profiles in the soil surface of the salt-marsh at Tønder; further one sample of sandy moraine material was drawn to be used like a "scale material". The sampling was done at the request of Niels Kingo Jacobsen, cf. Geografisk Tidsskrift volumes 58 p. 143 and 55 p. 106—146. The purpose of the collecting was by means of analysis of the sand texture to contribute to the solution of problems concerning identification of deposition environment of the sand, cf. *Jacobsen, N. K.* (1956) p. 119 and 130. Three of the sand samples were collected in a ditch immediately north of Pokkenbøl Gård (west of Møgeltønder), and three samples derive from the ditch at a field road which passes in the direction north west from Ved Åen, and which is situated north of the farm Sødam Gd. The moraine material was taken from a shallow boring in a field 800 m. due north of Nr. Sødam. The three localities mentioned are indicated in fig 1 in this periodical, vol. 58 p. 144 *(Jacobsen, N. K.)*; in the following they are called Pokkenbøl, Sødam, and Møgeltønder S. respectively.

Profile description.

At the locality Sødam a profile of a depth of about 1.5 m. was dug in the roadside ditch; at this place the surface was situated at a level of 102 cm. above DNN (Danish Ordnance Datum). The topmost 23 cm. below the vegetation were composed of basin-clay; underneath was found a layer of bleached sand of a thickness of 10 cm. with an underlying layer of an undisturbed podsol-horizon. From the uniform bleached sand was collected the sample: SøA,ca at the level 74 cm. (DNN). The precipitation zone below the bleached sand consisted of homogeneous, brown-coloured sand without pebbles and with no distinct traces of stratification and of lamellation. The precipitation was modest, only consisting in a colouring of the sand; however, this colouring appeared with varying strength, the cut showing light circles and finger-shaped designs, which can admirably be represented by fig. 8, *Dücker & Maarleveld*, 1958, p. 229; their figure shows a cut in a blown-sand cover. In the hard-pan-like zone, at a depth of 68 cm. was collected a sample which has been named SøB. The raw sand without any precipitation began at a depth of 118 cm.; to all appearance, it was structure-less and without pebbles, with a yellowish colour. At a depth of 143 cm. (—41 cm. DNN) the sample: SøC was collected.

In 1955 Danmarks Geologiske Undersøgelse has executed, in the vicinity of the trial locality Sødam, a boring which proved the existence of an order of the strata in the surface homologous to the stratification described above. This boring was continued to a greater depth and proved that at a depth of 230 cm. (—107 cm. DNN) the C-horizon was replaced by a new podsol-horizon, which at a depth of 240 cm. passed into sand with a few pebbles. The two orders of stratification from Sødam show that below the clay is found a sand-layer of a thickness of a few metres; this sand-layer is uniform and almost without structures, with the exception of two distinct podsol-zones. One is tempted to draw an immediate conclusion of analogy to the descriptions of blown-sand covers which have been published by *Dücker & Maarleveld*, 1958.

At Pokkenbøl too was dug a profile in the surface of a depth of 1.5 m. The visual general impression was identical with the one which we had got at Sødam. Below a layer of 60 cm. of clay were 10 cm. of bleached sand, somewhat discoloured by clay which had been washed down. From the bleached sand, the A-layer, was collected the sample PoA at a depth of 65 cm. (level +12 cm. DNN). The precipitation zone, the B-layer, had a thickness of 65 cm. and consisted of brown sand, structure-less and without pebbles. The sample PoB was collected from this sand at —21 cm. DNN. The raw sand, the C-layer, resembled the corresponding material from Sødam; the sample PoC originates from a depth of 145 cm. of this material.

For comparison with the above-mentioned samples a sample was taken from the geest material from Møgeltønder S. at a depth of 92 cm. (—32 cm. DNN) below a clay-layer of 80 cm. The sample was rather dirty owing to infiltration from a peat-layer at a depth of 80—82 cm. At a few metres to the north of the locality the geest reaches the surface and makes its appearance at this place as well as in our small boring as a stony moraine. It will be seen that within the short distance between the localities Sødam and Møgeltønder S. the material and the level are considerably altered.

Procedure of analyses.

The laboratory work on the sand samples was concentrated on the determination of their distributions of grain sizes, whereas the other textural qualities: shape, surface texture, etc. only were subjected to an inexact examination. Therefore, in the following pages the attention is concentrated on the sizes of the particles.

After a stay in a solution of 30 % hydrogen peroxide, the samples collected were given a parboiling, the plant residues were skimmed off, whereafter a suitable quantity of sediments was thoroughly rinsed in a sieve with a size of meshes of 60 mu. The material which was washed through the sieve was collected, and its weight was determined without further analysis. The retained sand was, in a dry state, passed through sieves with the following sizes of meshes: 2000 μ (— 1.00 φ), 1000 μ (0.00 φ), 750 μ (0.415 φ), 500 μ (1.00 φ), 400 μ (1.32 φ), 300 μ (1.74 φ), 250 μ (2.00 φ), 200 μ (2.32 φ), 150 μ (2.74 φ), 120 μ (3.06 φ), 100 μ (3.32 φ) and 60 μ (4.06 φ).

The weight quantities which had been fractioned out by means of these sieves were distributed in cumulative frequencies, "bigger than". Each sieve-fraction was microscoped, during which procedure the shape, the roundness and the polish of the grains were examined. We have previously given an account of the classification, the scale and the statistics which we usually employ. We refer to the prescriptions given by *Krumbein & Pettijohn* and by *Bagnold*. In order to facilitate the comprehension of the following text, some comments are given here on the applied statistics. The results of the wet sieving and of the dry sieving are represented in three different sorts of diagrams. The abscissa of the first diagram-type (fig. 1) was logarithmically divided, its ordinate was linear; the abscissa indicated the grain-size, the ordinate the cumulative frequency. The other type (fig. 2) was normal probability paper with a linear abscissa, which was divided into *Krumbein*'s units. The last diagram-type (fig. 3) was the one described by *Bagnold;* here the ordinate was log. N., where N. is the weight percentage, retained between two sieves, divided by the logarithm to the proportion between the size of meshes of the two sieves. The abscissa indicated the grain-sizes in the logarithm scale.

From the two types of cumulative distribution curves the following parameters were read: the three quartiles Q_1, Md, Q_3 and the deciles P_{10} and P_{90}. Md, the median value, represents the average of the distribution. The statistical deviation $\frac{Q_{3\varphi}-Q_{1\varphi}}{2}$ and $\frac{Q_{3\varphi}-Q_{1\varphi}}{2(P_{90\varphi}-P_{10\varphi})}$ were chosen as the expression of the sedimentological sorting, the parameters being expressed in φ units; refer *Kuhlman* 1957 b.

In order to make it possible to determine the parameters, the distribution curve sketched in *Bagnold*'s diagram must form a figure of a definite nature, comparable with a pair of compasses. To the right and to the left of the modal grain-class, characterized by the concept Pd, the other grain-frequencies must decrease at two constant rates of speed, which differ from each other, in the fine and in the coarse addition of material. The decrease of the coarse grains is represented by the coefficient:c, that of the fine grains by the coefficient:s.

The aeolian separation-processes.

By the term of separation is understood the dispersion of the elements of the sediment which takes place during the transport; if this has gone on for a long time or over big distances it can be said that the "separation-route and the separation-time" have been long, the sediment thereby having obtained "a mature sorting", whict reflects the homogenizing effect of the separation. It is open to question whether the separation is specific to a given kind of transport. Therefore, it is unknown whether one can always determine the physical environment which was reigning during the deposition of the sediment, if only the texture and the composition of the mass is known. In some cases the determination of the environment is easy, for instance for moraine material; in other cases it is apparently impossible, cf. *Udden* 1914, *Pettijohn* 1957 and *Sindowski* 1958.

As far back as the time of *Udden* a great importance has been attached to the distribution of the grain sizes of sand as a contribution to the determination of its sedimentary environment, because the grain sizes gave a picture of the forces which had been active there. However, it looks as if different environments may produce identical grain distributions, cf. *Sindowski*'s outline from 1958. Such a convergence is especially known for dune-sand and beach-sand, cf. *Pettijohn* 1957 p. 590—592, *Kuhlman* 1957 b, *Mason & Folk* 1958.

The problem of diagnosis is rendered further difficult thereby that the terminology concerning the sedimentary environment is unprecise and illogical from a geo-dynamic point of view. The environments are nearly always designated according to the general geo-morphological usage. This may give rise to a certain confusion; for instance: "beach sand" stands both for aquatic and aeolian sorting; consequently, the resemblance to "dune sand" is natural enough.

Let us try to consider "blown sand" — "dune sand" from a geo-dynamic point of view; below we are speaking, for the sake of convenience, of almost ball-shaped quartz grains. In the aeolian environment it is possible to distinguish between the following kinds of transport: suspension, saltation, creeping and landslides (for instance in the case of lee dune-slopes). Each of the three first mentioned kinds of transport is, at a given velocity interval, inseparably bound up with definite grain dimensions, *Inman* 1949, *Bagnold* 1954 and *Sundborg* 1955 and 1956. For winds below gale force, grains smaller than 0.10 mm. are transported suspended in the air and are not deposited until the terminal velocity of fall exceeds the buoyancy, Stoke's law. Grains bigger than 0.10 mm. most often saltate or "creep" (pushed by the saltating grains). The saltation and the creeping is bound to the surface. Saltation grains are able to move creeping material having six times its own diameter; however, in return the creeping is much slower.

The diameter of a saltating grain is directly proportional to the square of the smallest wind-force required for keeping alive the movement, cf. *Kuhlman* 1958, p. 54. This means that a small decrease of the wind-force will cause the exclusion of many grain-sizes from the saltation material. Under aeolian transport the grains about 0.10—0.20 mm. are almost always in a jumping movement, whereas grains of a size of about 1 mm. but rarely reach beyond the "crawling stade". A pronounced separation of the material is liable to take place owing to the different kinds of transport.

Bagnold has experimentally examined the grain separation in the course of the aeolian transport. In his diagram the grain distribution of the saltation material is represented by the above-mentioned "compasses"; it is possible to describe the creeping material too by this characteristic figure.

The aeolian material subjected to long-time influences shows a coarseness coefficient which is very close to —9. This drop of coarser elements during the action of the wind has been demonstrated in nature in recent processes, cf. *Harris* 1957 and 1958, *Kuhlman* 1957 and *Mason & Folk* 1958.

It is near at hand to ask whether aquatic transport may not give the same grain distributions as those proved in blown sand by *Bagnold*, whose results can be summarized as follows: In aeolian sand extra-modal, coarse material only seldom appears. In streaming water grains between 0.15 mm. and 0.50 mm. require almost the same stream-force in order just to be transported, cf. *Å. Sundborg* 1956 p. 169—201. This means that in the grain-interval mentioned a separation only with difficulty takes place in a water-stream, whereas in a current of air it is easily realized. However, oscillating water-streams seem to be able to produce as fine separations as those created by the wind, cf. *Sindowski* 1958.

The natural sorting by the wind often interferes with other processes, the theoretical scheme thereby being distorted. During the wanderings of dunes, landslides, on a large as well as on a small scale, often happen, partly at lee-slopes, partly at erosion-walls. As a result of the landslides, coarse grains are concentrated at the foot of slopes; high-lying sand-material is further homogenized, cf. *Bagnold* 1954 p. 140 and *Kuhlman* 1957 p. 38—39. In humid regions the humidity of the sand causes an alteration of the movement thresholds; the fine sand will be hardly as mobile, cf. *Sundborg* 1956 p. 179 and *Kuhlman* 1957 p. 45—50.

The material of the aeolian environment can be dynamically classified as follows; suspension- (dust and loess), saltation-, creeping-, residual- (aeolian pavement-) and landslides-material. Each of the five groups may have either an arid or a humid character. It will be seen that the terms "blown sand" and "dune material" are ambiguous notions.

Description of the sand samples.

In table 1. are shown selected, characteristic grain-size parameters, read from the normally drawn distribution curves, fig. 1. In table 2 are indicated the same parameters; however, they have been determined by means of fig. 2, which shows the grain distributions of the seven samples marked out on probability paper. Homologous values in the two tables deviate at highest 0,03 units from each other.

From fig. 2 it appears that none of the samples was evidently bi-modal or poly-modal. With the exception of the sample from Møgeltønder S. they have a pronounced tendency towards a Gauss

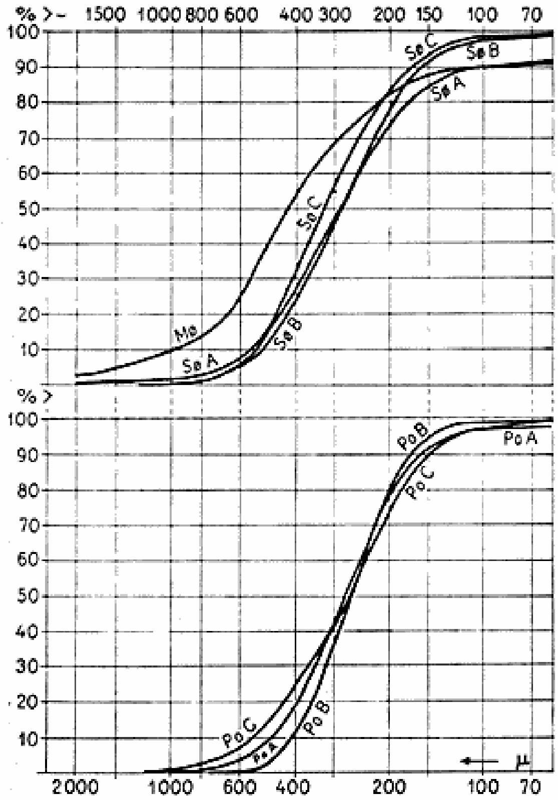

Fig. 1. The destributions of grain sizes in the seven samples of sediment from the salt-marsh area at Tønder. The abscissa is the log. grain diameter in mu, the ordinate shows cumulative weight percentage. The marking of the curves is explained in the text.

distribution in relation to the φ scale in the interval 0φ—3φ; the diverging distribution among the fine grains is due to secondary material infiltrated with water. With the applied sieves the sand showed a monomodal grain distribution, which seems to be in equilibrium with the ancient sedimentological forces.

The variation range offers a certain interest by virtue of the extreme values by which it is marked. In the present case the maximum grain diameter has importance as an aid at the determination of the nature of the sand, whereas the minimum grain size, which it is almost impossible to determine, does not offer any interest. The sand from Pokkenbøl and from Sødam did not contain grains larger than 2 mm., whereas it was accidental that the moraine material did not contain cobbles. The absolute lack of granules and pebbles may be interpreted to the effect that the wind has been active. The content in the sand of particles <0.06 mm. is, as far as the layers below the bleached sand are concerned, less than 1 %.

Table 1.

Sample	Md		Q_1		Q_3		P_{10}		P_{90}	
	μ	φ	μ	φ	μ	φ	μ	φ	μ	φ
Mø	422	1.25	600	0.74	255	1.97	1000	0.00	110	3.19
SøA	282	1.83	405	1.30	192	2.38	550	0.86	109	3.20
SøB	284	1.82	395	1.34	208	2.27	505	0.99	157	2.67
SøC	320	1.64	433	1.21	230	2.12	530	0.92	168	2.57
PoA	276	1.86	370	1.43	206	2.28	475	1.07	159	2.65
PoB	264	1.92	338	1.57	209	2.26	412	1.28	171	2.55
PoC	270	1.89	395	1.34	199	2.33	562	0.83	150	2.74

Table 3 shows the sorting ($QD\varphi$ and $Kq\varphi$) and the symmetry ($Skq\varphi$) of the samples, calculated on the basis of the parameters noted. $Kq\varphi$, kurtosis may be called the sorting of second degree; it indicates the proportion between the quartile-sorting, $QD\varphi$, and the range between 1st and 9th decile; its normal value is 0.26.

As could be expected, the moraine material has a moderate sorting (0.6 and 0.2) obliquely distributed around an "average grain size" of about 0.4 mm.

The three sand samples from Sødam have almost the same mean value 0.3 mm., and their quartile sorting is about 0.5 with a symmetry, or almost. The central grain size of the sand from Pokkenbøl is close to 0.27 mm. in the three samples. The quartile sorting varies from 0.35 to 0.50, the B-horizon being the best sorted. Of all the six sand samples only SøA is distinctly anormal. The "average grain sizes" and the parameters which have been found must be characterized as exceptional for monomodal sand, cf. *Sindowski* 1958, p. 236.

Figure 3 and table 4 show grain distributions described by means of *Bagnold*'s method. It is remarkable that his parameters only with difficulty can be determined, because the distribution curve has absolutely not the expected form, cf. also *Kuhlman* 1957b. The divergence from the hypothetical corresponds to the approximate Gauss distribution which has been observed, and which is seen in fig. 2, cf. fig. 34, *Bagnold* 1954 p. 117. However, from fig. 3 clearly appears the poor sorting in modal grain classes.

The microscopy of the sand showed the following conditions: in the samples from Pokkenbøl and Sødam the greater part of the grains bigger than 0.30 mm. were well rounded and half-mat, whereas smaller grains were shiny and edged. The uncorroded grain structure was predominant in all sieve-fractions from the

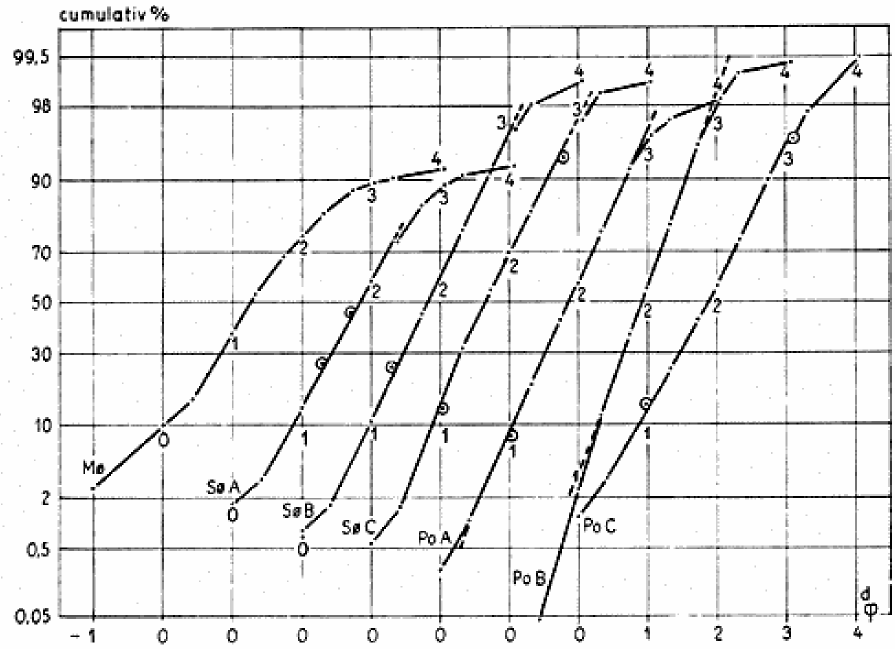

Fig. 2. Size compositions of the sediments that were pictured in fig. 1, the cumutative weight percentage is plotted on logarithmic probability paper, abscissa shows grain sizes in Krumbein phi-scale. For each curve the abscissa is moved in accordance with figures given.

Table 2.

Sample	Md φ	Q_1 φ	Q_3 φ	P_{10} φ	P_{90} φ
Mø	1.25	0.70	1.98	0.01	3.20
SøA	1.83	1.32	2.38	0.86	3.23
SøB	1.82	1.37	2.26	0.97	2.67
SøC	1.65	1.23	2.13	0.89	2.56
PoA	1.88	1.45	2.29	1.07	2.67
PoB	1.92	1.58	2.26	1.29	2.56
PoC	1.88	1.34	2.34	0.86	2.75

geest material; further, it was striking to see that the sand from the C-horizons in the finest sieves contained considerable quantities of light mica flakes.

Discussion of the measuring results.

The unidentified sand was surely not mature aeolian saltation-material and creeping-material; however, there is no observation which excludes the diagnosis: wind-sediment. If it is here a question of aeolian material the separation-time must have been short, and it must be classified as creeping material with a residual character. Unfortunately, we have still but a poor knowledge of

Table 3.

Sample	QD_φ	Skq_φ	Kq_φ
Mø	0.62	+ 0.11	0.19
SøA	0.54	+ 0.02	0.23
SøB	0.46	— 0.01	0.27
SøC	0.46	+ 0.02	0.28
PoA	0.42	0.00	0.27
PoB	0.35	— 0.01	0.27
PoC	0.50	— 0.05	0.26

dune material having glacial deposits as mother material; nor do we know enough about the aeolian separation processes in connection with landslides and humidity cohesion.

The sand cannot be marine or lacustric, because, cf. *Kingo Jacobsen* 1956, the transgression did not reach the examined localities until after the beginning of the Bronze Age; this means, if marine, that afterwards there could not be sufficient time for creating two undisturbed podsol-horizons. Nor can the sand have been deposited by the river Vidåen, as the depth-researches carried out by *Kingo Jacobsen* in these localities show that no fossil ravines are found in the geest below the alluvium. This leaves two possible diagnosis: either it is a question of glacio-fluviatile sand from the Ice Age, or it is niveo-aeolian from late-glacial time, cf. *Edelman & Maarleveld* 1958 p. 665—668. The distribution of the grain sizes speaks in favour of fluviatile sand, because it is monomodal, approximate Gauss-normal and because the modal grain classes between 0.15 mm. and 0.50 mm. are equal; there is here a moderate quartile sorting of 0.4, and kurtosis is almost normal. The even sorting about 0.3 mm. is typical of streaming water, because the critical stream-force varies but little for the above-mentioned modal grain sizes, cf. *Sundborg* 1956 p. 197. If it is a question of aeolian deposits it is strange that *Bagnold*'s diagram dit not allow a reliable determination of the parameters applied by him. The statistical probability of encountering a distribution deviating from *Bagnold*'s distribution is unknown; however, studies in literature seem to indicate that it is but small.

Conclusion:

On the basis of the knowledge which we now possess we are able to give the following exposé of the facts speaking in favour

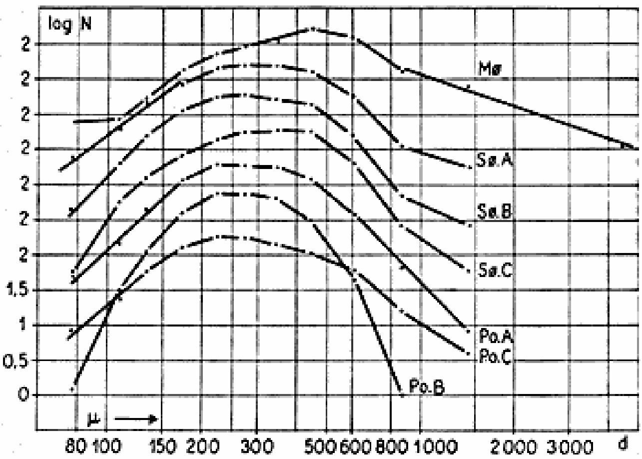

Fig. 3. The seven samples of sandy sediments demonstrated by means of Bagnold-diagram for size analysis. The abscissa is the log. grain diameter in mu, the ordinate shows logarithmic weight percentage per unit in the abscissa scale. For each curve the ordinate is shifted in accordance with the figures given.

of and those speaking against the supposition that the sand collected at Pokkenbøl and at Sødam had been deposited by the wind. In favour of this supposition speak the following facts:

1) The unevenly hilly morphology of the geest surface below the alluvium in the region in question.
2) Probably the region has not been exposed to a marine transgression in the period between Older Dryas and the Bronze Age.
3) The cut structure almost free of stratification which appeared at the digging of the surface profiles.
4) The presence of undisturbed podsol-horizons, the precipitation layers of which showed patterns of finger-shaped and circle-shaped spots, cf. *Dücker & Maarleveld* 1958.
5) The sand was free of granules and pebbles.

The following circumstances speak against the above mentioned supposition:

a) The grain-size distribution of the sand.
b) The presence of mica flakes in the fine sieve-fractions.

The reason why we have given here the result of this "torso"-like examination is to expose a problem which offers the possibilities of unprejudiced considerations on an interesting "sedimentological paternity case".

Table 4.

Sample	Pd μ	s	—c
Mø	?	?	ca 1.5
SøA	282	3.5	3
SøB	260	5	4
SøC	?	?	ca 4.5
PoA	300	4	4.5
PoB	?	?	ca 8.5
PoC	276	3.5	3

RELEVANT LITERATURE

The following list contains more literary works than those used for the elaboration of this paper, because we consider it useful to give a guidance on the essential sources for additional studies of aeolian sediments.
Abbreviations:

D.G.U.	Danmarks Geologiske Undersøgelse, København.
G.A.	Geografiska Annaler, Stockholm.
G.J.	Geologischen Jahrbuch. Geologischen Landesanstalten der Bundes-republik Deutschland, Hannover.
G.T.	Geografisk Tidsskrift, København.
J.S.P.	Journal of Sedimentary Petrology, (Tulsa, Oklahoma), Menasha, Wisconsin.
P.R.S.L.a	Proceedings of the Royal Society of London. Series A. London.

Bagnold, R. A. (1937): The size-grading of sand by wind. P.R.S.L.a 163 p. 250–264.

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– (1957): Sedimentary characteristics of dust storms. 1. Sorting of wind-eroded soil material. American Journal of Science. 255 p. 12–22. New Haven, Connecticut.

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