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# Sand size fractions of South-Peruvian barchans and a brief review of the genetic grain shape function

By G. C. AMSTUTZ and RAYMUNDO CHICO [1]


## Abstract

This paper presents the first histograms of sand samples taken from four distinct points of each of four individual barchans from Southern Peru. The remarkable feature is the sorting or sizing action of the wind as seen from the histograms of sand from different points of the barchans. Then a brief review of the genetic application of morphometric grain studies is attempted by setting up a morphogenetic equation and a brief discussion of the numerous unknown parameters.


## 1. Barchan sands from South Peru

During an exploration campaign in the South Peru porphyry copper belt in 1953 the senior author had to cross the desert areas of the coastal plains various times. The barchans in the desert south of San Juan, about eighty miles southwest of Arequipa, appeared to be of remarkable shape and to exhibit interesting details worth of sampling and description. Furthermore, the purity of the sand suggested that the barchans might represent natural concentration products of commercial grade.

The mineralogic composition is: mostly quartz, some felspar and some biotite, augite and hornblende. The percentage of these minerals changes from one barchan to the next and also from one part of the barchan to another part. Crests of secondary waves are often darker, containing a larger number of dark minerals, or (!) exhibiting a horizontal lineation of the dark platy or lathy minerals, whereas the valleys are lighter, due to less mafics or (!) a vertical orientation of the mafics. The sands most probably originated from granites and dacitic volcanics outcropping at the southern border of the desert.

The attached figure presents grain size analyses of samples taken from the tails, the crests and the wings or heads of four barchans in the vicinity of the Carretera Pan Americana, at that time a gravel or sand road. As tails we have designated the area which lags behind with regard to the wind direction. The crest is the high central portion with a smooth luv-side and a steep lee-side. The two wings are the two points farthest advanced in the wind direction. Samples were taken from all four points and exhibit an astonishing similarity with regard to their histograms.

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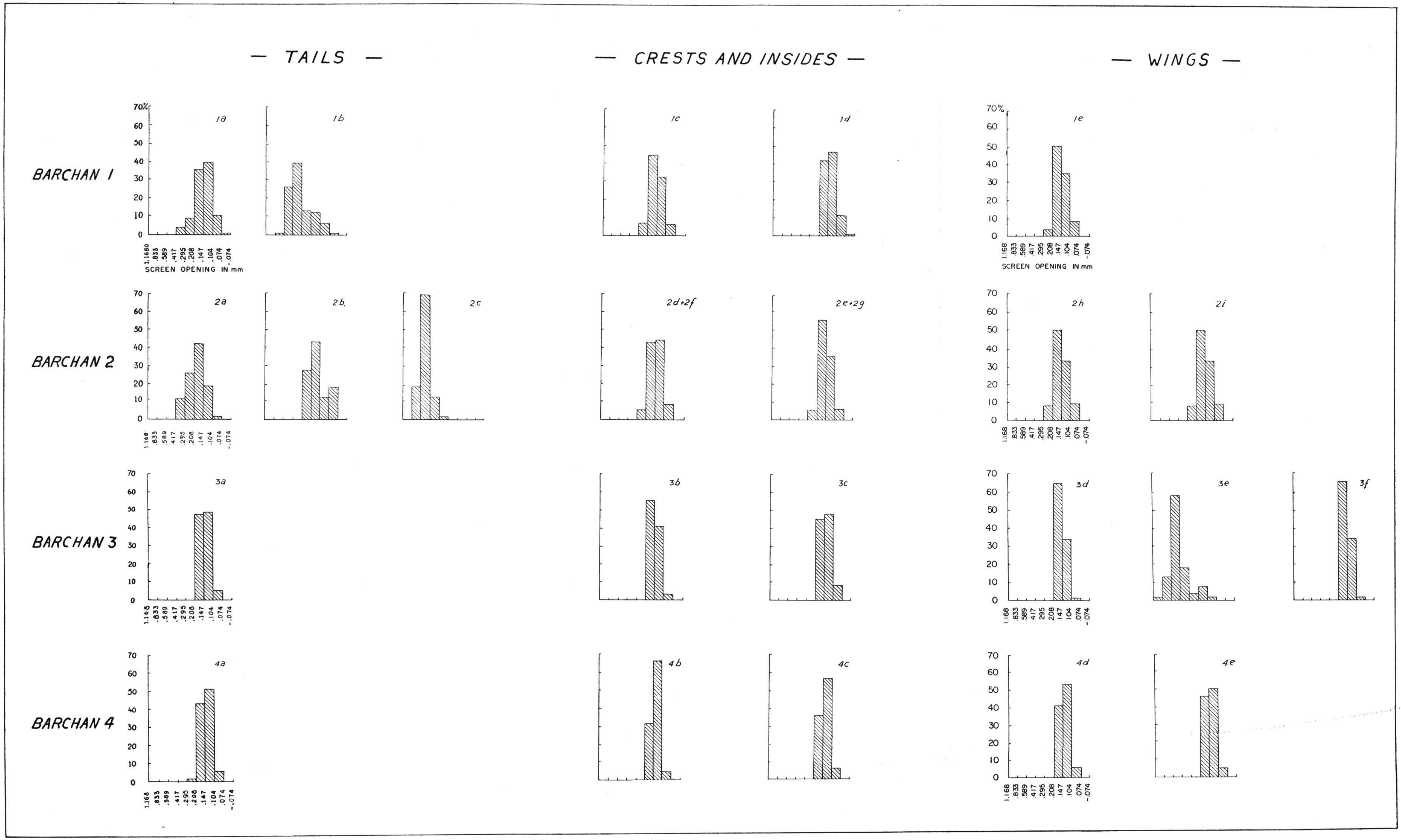
The locations and, if deviating from average, the colors of the samples are as follows:

| | | |
|---|---|---|
| Barchan 1: | Sample 1a | — luv-side, start of tail, white small wave valley. |
| | Sample 1b | — luv-side, start of tail, brownish small wave crest. |
| | Sample 1c | — crest, dark. |
| | Sample 1d | — lee-side, center bottom of slope, bright. |
| | Sample 1e | — one of the wings, dark. |
| Barchan 2: | Sample 2a | — luv-side, end of tail, small brownish wave crest. |
| | Sample 2b | — luv-side, beginning of slope; small wave valley; whitish. |
| | Sample 2c | — luv-side, beginning of slope; brownish top of wave (same as 2b). |
| | Sample 2d | — luv-side, center of crest; bright, with snow-white compounds (if disturbed turns gray-black!). |
| | Sample 2e | — luv-side, center of crest; average gray-black sample. |
| | Sample 2f | — luv-side, center of crest; dark, average sample; if disturbed, turns gray. |
| | Sample 2g | — lee-side, bright undisturbed surface sample; if disturbed turns gray. |
| | Sample 2h | — west wing; black on surface. |
| | Sample 2i | — east wing; gray-black. |
| Barchan 3: | Sample 3a | — luv-side bottom; average sample. |
| | Sample 3b | — top of crest; average sample. |
| | Sample 3c | — lee-slope, bottom; white. |
| | Sample 3d | — west wing; average sample. |
| | Sample 3e | — west wing; top of wave on bottom of luv-side of wing. |
| | Sample 3f | — east wing; surface of waves are black; this sample is a mixture of all surface and interior material. |
| Barchan 4: | Sample 4a | — luv-side, bottom of slope. |
| | Sample 4b | — top of crest. |
| | Sample 4c | — lee-side, bottom of slope. |
| | Sample 4d | — west wing, about at the end point. |
| | Sample 4e | — east wing, about at the end point. |

The comparison of the histograms of all these samples from the four distinct locations is self-explanatory. The sorting action of the wind is well displayed, and the four sets of histograms can serve as a perfect illustration of BAGNOLD's theoretical considerations on the physics of blown dune sand, chapters 14 and 15 (1942). The wind direction in this particular area seems to be so regular that the barchans do not show any secondary structures originating from bi- or multi-directional winds, nor are there any reverse wind effects noticeable. The histograms of samples from the two wings of the barchans are almost exactly the same. The irregularity of certain histograms, for example 2b, is due to contaminations from the desert floor.

With regard to the nature of the histograms it is interesting to note that, although all of them fall into the general type of size curves for desert sand, there is a remarkable degree of variation within the individual barchans. The barchans range from fifteen to thirty meters from one wing to the other. They are thus not comparable in size to the one described by SIMONS (1956) from North Peru.

Sand dunes have been studied in many countries. Detailed studies on barchantype dunes, however, are only those by BAGNOLD (1942) who mentions a few previous authors, and by SIMONS (1956). None of them gives size analyses of samples from different portions of a barchan. The first one to mention barchan dunes from southern Peru was probably BOWMAN (1916) who gives excellent drawings of barchans in figure 178, and a description on p. 261—267. He also gives rates of daily movements of sand dunes near La Joya, in the same desert as our barchans. «The average movement of the dunes from April to September, 1900, was 1.4 inches per day, while during the summer months of the same year it was 2.7 inches. In close agreement are the figures for the wind force, the record for which also shows that 95 % of the winds with strength over 10 miles per hour blew from a southerly direction.» (p. 132, 133).




Grain size analyses of Barchan-sands from the coastal plains of South-Peru

The tremendous Pur-Pur dune in northern Peru moves only 5—9 m per year, according to SIMONS (1956, p. 520). This difference in velocity is due to the fact that «the rate of movement varies inversely with the size of the dune» (SIMONS, p. 521). Another interesting account on sand movement along the coast was given by BROGGI (1952).

Size (-fraction) analyses are, of course, not the only way of characterizing sands or pebbles. Another interesting approach is the shape analysis. Various standardized methods are available. At the time only a review of the principles of genetic interpretation of such quantitative and qualitative descriptive methods can be offered. The actual shape analysis will be published at a later date. We might say at this time that we used the universal stage in order to obtain Zingg-values from sand grains (ZINGG, 1935). We found this method much faster and handier than the ones described by WRIGHT (1957), by ASCHENBRENNER (1955) and by HULBE (1955). And, in order to speed up the procedure for the concave-convex values of SZADECZKY-KARDOSS and the sphericity and roundness results of WADELL, we projected the grains on a table and moved the projection plane in such a way as to be able to compare the grains with the standard size circle. Another method used was mass-photography with 35 mm film and the projection on a wall. By varying the projection distance somewhat, the grains could again be fitted easily into the standard circle.

## 2. On the genetic use of shape classifications

DUNBAR and RODGERS state on page 184 of their book «Principles of Stratigraphy» (1957): «The shape of sand grains and pebbles is one of their most obvious characteristics and one of the most significant in sedimentation; it is also one of the most difficult to describe and measure in quantitative terms. Indeed, the problem still defies satisfactory solution.»

The microscopic study of the dune sands from Southern Peru leads us to think about the possible origin of the sand grains. The literature reports about relationships between degree of sorting and the process of transportation, etc. A few papers also report about the shape in relationship to distance of transport, means of transport and attrition, etc., and it seems to us after setting up a list of possible factors influencing the shape, that, while the problem of describing and measuring sand grains and pebbles in quantitative terms was solved to a remarkable degree by WADELL (1932, 33, 35), by ZINGG (1935), and by SZADECZKY-KARDOSS (1933), we are lacking almost completely a useful solution of what we might call the morphogenetic equation, the actual genetic significance of the results of measurements of roundness, sphericity and ZINGG-values. We have thus a similar situation as in igneous petrology. One might also say in regard to a good descriptive classification of rock textures that the problem still defies satisfactory solution. Yet, what we need, rather than better descriptive or quantitative terms is, now, an approach to the genetic significance of the terms and forms we know — and we do know quite a large number of them. The qualitative and quantitative descriptive terminology of grains and pebbles is younger than the terminology of textures and structures of igneous rocks. That is, on one hand, an advantage, because it has not been contaminated so much by genetic connotations or premature ideas on genesis which hinder the advancement of genetic petrology. On the other hand, as just stated, what we are lacking now, what «still defies satisfactory solution», is the genetic use of the quantitative and qualitative data.

It is hoped that the following brief outline on the «morphogenetic equation» will stimulate the thinking of workers in this field.

In any type of research, particularly in natural sciences, there are these steps involved:

1. Analysis: *Observation,* measurement, description; accumulation of data.
2. Synthesis a): *Interpretation* of individual data; logical connection of data.
3. Synthesis b): Final *conclusions;* the insertion into the overall scientific theory of the particular field, and, if an applied branch, the practical consequences of the results.

Obviously these steps often overlap. Yet, too often they are not well enough separated or step 2 is even left out, or observations and mere descriptions are confused with interpretations and conclusions. Well known examples are, for instance, the «field evidences for atomic diffusions» propagated by certain «granitizers», or the evidences for replacement in disseminated ore deposits. A detailed discussion of the first example was given in a paper on «granitization» and mineral deposits (AMSTUTZ, 1957) and a discussion of the second case is in print.

«Morphogenetic» considerations of sands are extremely important in petroleum geology, particularly in reservoir engineering (see SCHEIDEGGER, 1957). However, a close examination of certain vital problems of ore genesis shows that for the lack of a good knowledge of sedimentary petrology — or may be also simply for the lack of freedom from a dogmatic view — the genetic history of the largest uranium, the largest lead-zinc, and some large copper deposits was misinterpreted. It is only recently that the misinterpretation of these so called disseminated replacement deposits was fully analyzed (AMSTUTZ, 1958).

The sand grains which together with the matrix, were assumed to be replaced do not show any traces of corrosion whatsoever. A careful study of their shape in thin and polished sections shows that the shape of sand grains is the same close and even inside the ore minerals, as outside in the normal sandstone. This and other criteria make the genesis of the three important types of ore deposits syngenetic and simple. Once again FEUERBACH was right where he said that the simplest things are the last ones to be understood by men.

Yet, the genesis we are going to discuss on the basis of a tentative morphometric equation deals only partly with processes of mineralization. The larger number of factors influencing the shape concerns original forms, and erosional forces acting upon the grains.

Again, the reason for placing the emphasis on the complexity of the morphogenetic function is based on the literature. Too often is the shape of grains used loosely to prove a simple origin, disregarding the host of additional factors which may have had a major or minor part in the shaping of a grain. An interesting example was published by INGERSON and RAMISCH (1942). These authors showed that the elongation of quartz grains in St. Peters sandstone is due to an original elongation and not one caused by differential abrasion. It is, as was shown by these authors, premature and incorrect to draw comparative genetic conclusions on the origin of a grain or pebble shape without considering all the factors involved.

The following equation shows thus that we are dealing with numerous factors influencing th shape of detrital materials, aggregates or individual grains. In other words, one and the same roundness, or sphericity or ZINGG-value may be produced by different factors, and with different materials. We are working with many unknowns and should be aware of the fact that, in order to solve a problem with X unknowns, we need X + 1 different equations.

The morphogenetic function:

$$S_{x,t} = f(i_c, i_p, h, s_a, s_r, w_a, w_i, v, s_m, o_a, q_r, ch, m_s, m_e, \ldots)$$

| | |
|---|---|
| Sx, t : | The shape of a grain or pebble at a certain time t, at a certain place x, whereby x may be the distance from the place of origin. |
| $i_c$ : | internal properties of a monomineralic grain, such as crystal structure or symmetry, inclusions, alterations, flaws, etc. |
| $i_p$ : | internal properties of a pebble, such as the fabric, grain size, etc. |
| h : | hardness. |
| $s_a$ : | original shape and size of a grain or a pebble. |
| $s_r$ : | relative size (and shape) of a grain or pebble compared with the size (and shape) of the rest of the components associated with it. This is important because the relative abrasion loss of a small grain from the impact with a large grain is greater than vice versa. |
| $w_a$ : | path, way, travelled by water transport. |
| $w_i$ : | path, way, travelled by wind transport. |
| v : | velocity of transport; influences the impact of grains on grains and thus also the amount of abrasion. |
| $s_m$ : | symmetry of water or wind motion; harmonic wave motion, creates e. g., trapezoidal pebbles. |
| $o_a$ : | average lithologic, petrographic origin; this parameter may be used instead of $i_c$ or $i_p$ in cases where an approximate, average origin is sufficiently accurate. |
| $q_r$ : | relative quantities of the individual mineral or rock species present; this influences, mainly through the hardnesses, the paths a grain or pebble moves with reference to a certain abrasion loss. |
| ch : | the chemical environment, including humidity; solution or accretion may have a definite influence on the changes of shape. |
| $m_s$, $m_e$ : | effects which syngenetic ($m_s$) or epigenetic ($m_e$) mineralization may have had on the shape of grains or pebbles. |

Some of these parameters were discussed by SORBY as early as 1880 and by MACKIE in 1893—98. PHILLIPS (1881) and SHALER (1894) are also among the first ones to report on classification and genesis problems of sands and sandstones. WADELL (1932, 33, 35), SZADECZKY-KAROSS (1933, 1938) and ZINGG (1935) showed many detailed relationships and created the quantitative tools which serve now for discussions on a common basis. KRUMBEIN and PETTIJOHN (1938, 1957) and P. NIGGLI (1948, 1952, 1954) gave the most complete review of the problems involved. Many of the parameters listed in this paper are treated in detail in NIGGLI's review. Yet, it appeared appropriate to restate the problem in a somewhat different way and to open the discussion anew and to show the relationship with some hot problems of economic geology.

A student who is unfamiliar with the many other dimensions of grain studies might assume that size and shape considerations are the only approaches to the solution of genesis of detrital material. In order to show at least two more approches we find in ENGELHARDT's study of wind and water transported sands an example. He observed (1939/40) that it is possible to distinguish between wind blown and water transported sands by comparing the radii of light and of heavy minerals. The ratio r-light : r-heavy is greater for water sorted than for wind sorted sand. This interesting observation could not be studied on our sand dunes for the lack of samples from underwater dunes such as were formed on the Atlantic shelf a few hundred miles south-southeast of Florida.

Another interesting genetic approach are orientation studies. An excellent example was recently given by RUSNAK (1957). Last not least it should be mentioned that excellent approaches to a morphogenetic interpretation were also found in KRUMBEIN's paper on the effect of abrasion (1941).

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