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SURFACE FEATURES OF SAND GRAINS FROM THE COUDE DU DRA REGION (MOROCCO)

Abstract: The analysis of grain surface character, especially of quartz grains, allows to obtain precious information on environmental conditions which shaped the grains and thus can inform about the sediment source. Results of such an analysis performed on grains from the dunes of the Coude du Dra erg showed that the grains underwent heavy chemical weathering processes such as dissolution and re-precipitation of silica on the grain surfaces. This is inferred from intensive crusting of the grains. Only limited amount of the grains exhibits effects of aeolian abrasion. Majority of the grains is angular or sub-angular and only few grains are well or very well rounded. This shows that the sediment was not transported for a long distance and the sediment source for this growing erg is local. Only very few grains which are very well rounded can represent another sediment source.

Key words: dune sediments, grain surface character, surface crusting.

1. Introduction

Surfaces of detrical quartz grains exhibit traces of mechanical abrasion and chemical weathering (Krinsley, McCoy 1978, Pell, Chivas 1995). The use of scanning electron microscope (SEM) in analysis of the grain surfaces provides precious information about environment of grain transportation, duration of processes modelling the grains, degree of change of the source sediments and any postsedimentary processes (Krinsley, Doornkamp 1973). Each environment produces specific set of microstructures on surfaces of quartz grains which can be treated as indicative features (Morgolis, Krinsley 1974, Krinsley, Doornkamp 1973). One of such environments is a hot desert. First researchers found that desert sand grains are well or very well rounded (Mac Carthy 1935 in Pye, Tsoar 1990). Results of first experimental studies supported previous findings. Nevertheless, later studies (Folk 1978, Goudie et al. 1987) put into doubt certain ideas. It was demonstrated that majority of dune sand grains is sub-angular, and even angular (Folk 1978, Pye, Tsoar 1990, Bullard et al. 2004). Moreover, the dune sands have a specific colour (red or deep yellow) which distinguishes them from other aeolian sediments. Majority of the grains is crusted (Lucchi, Casa 1968, Pye, Tsoar 1990, Woronko 2000, 2003, 2006).

A microrelief character of the sand grains which build dunes in the Coude du Dra region (Morocco), analysed in the scanning electron microscope (SEM) is a focus of this paper. The aims of the research are: to determine the source of the aeolian material, to check changeability of the grain microrelief within the researched dune field, to assess a degree to which the source material is changed and also to reconstruct environment and processes shaping the grain surface. Some of the presented results were already published by the author of this paper as a report from an expedition to Morocco in 2001 (Woronko 2003, 2006). This paper precise, and sometimes sheds a new light on previously published data.

2. Methods

Detailed analysis of quartz sand grain surfaces was performed on sediments building four dunes of the barchan type (dunes number 1, 5, 10, 13) localised within the Coude du Dra dune field. The analysis also included sediments building one dune localised on a surface of the Iriqui dry lake (dune number 4) (Dłużewski, Krzemień 2008 – Figure 2). Each time the samples were collected from crests of the dunes. Without previous sieving, eaching or washing, the samples were analysed in SEM. 30 grains were randomly selected from each sample in order to measure grain dimensions (axis X and Y), degree of rounding with a use of the 9-degree scale (Krumbein 1941), and to study in detail the character of the grain surface microrelief. Relatively thick crusting of the analysed grains made it impossible to distinguish between quartz and other minerals, therefore all grains seen in the SEM screen were analysed with a use of 500 magnification. Only grains which exhibit clear lamellar structure were excluded (Woronko 2003, 2006).

3. Surface texture of aeolian sand grains

Researchers commonly recognise five types of textural features characteristic of grains of aeolian origin. The types represent combinations of mechanical abrasion and chemical weathering (Krinsley, McCoy 1978, Pye, Tsoar 1990):

1. rounding of edges;
2. „upturned plates" seen on grains larger than 300–400 ěm (Krinsley, Doornkamp 1973, Krinsley, McCoy 1978);
3. equidimensional or elongated depressions;
4. smooth surface resulting from solution and re-precipitation of silica (Folk 1978). S.D. Pell and A.R. Chivas (1995) who studied surface features of sand grains from the Australian Continental Dunefield, found at least two forms of chemical precipitation features and pointed at specific environmental conditions during creation of grain crusting;
5. arcate, circular or polygonal fractures.

4. Results

Dunes in the Coude du Dra dune field migrate on a wide plain which spreads between the Jebel Bani and the Hamada du Dra upland surface. The Oued (Wadi) Dra incises the plain (Dłużewski, Krzemień 2008 – Figure 2) (Dłużewski 2003). The plain is built with lacustrine sediments, alluvial fans, sandy alluvia of the Oued Dra. Western part of the researched area is composed of clayey-silty sediments accumulated in the Iriqui Lake which is contemporary a dry basin (Dłużewski 2003). Full physico-geographical characteristisc of the region is provided by Dłużewski and Krzemień in the present volume.

Sediments building the dune number 4 and migrating on a surface of the Iriqui dry lake (Dłużewski, Krzemień 2008 – Figure 2), are characterised by a very high variety of grain rounding (Figure 1). Grains of a very bad rounding (0.1-0.3 according to the Krumbein scale) constitute over 33%. They have sharp edges and corners and a very complex microrelief. Apart from such grains there are grains which are well or very well rounded (0.7--0.9 in the Krumbein scale) (Woronko 2003, 2006). Nevertheless, their share in the sample is only ca. 11% (Figure 1). These grains have diameters over 0.35 mm. Grains with rounding 0.4 dominate in the sample and constitute 33.3%.

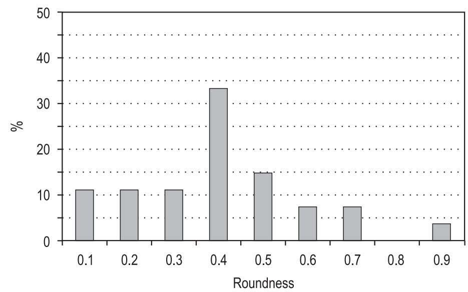

Figure 1. Roundness of grains from the dune No 4, according to the Krumbein (1941) scale

The character of the grains microrelief, from the dune number 4, is very similar on each grain. The surfaces of all the grains exhibit chemical weathering, which result in a thick crusting (Woronko 2003, 2006). On 80% of the analysed grains the crust constitutes a continuous precipitated silica sheet (Photo 1) which consists of a great number of little globules of 1-5 μm (Photo 2). Such a crust is visible in every microdepressions, on edges and on corners, therefore it makes all microrelief irregularities blunt. Polygonal or oval fractures are visible in the microdepressions (Woronko 2006). 20% of the grains exhibit effects of the chemical weathering of the already-existing crust. Such effects usually can be observed on relatively big grains, exceeding 0.35 mm in diameter, within local microdepressions or flat surfaces (Woronko 2003, 2006). Fresh microstructures which result from mechanical abrasion (conchoidal fractures) are not observed. Moreover, there are no broken grains or grains which experienced chemical weathering directly on quartz surface, not on the crust.

Sands building dunes in the central part of the Coude du Dra dune field (dunes number 1, 5, 10, 13) (Dłużewski, Krzemień 2008– Figure 2) consist of grains which are better rounded (Figure 2) in comparison with the grains from the dune in the Iriqui Lake surface. Nevertheless, they still have irregular shape with numerous microdepressions (Photo 3). Grains exhibiting extremely poor rounding (0.1 in the Krumbein scale) were not observed in the sample (Figure 1). On the other hand there were no grains

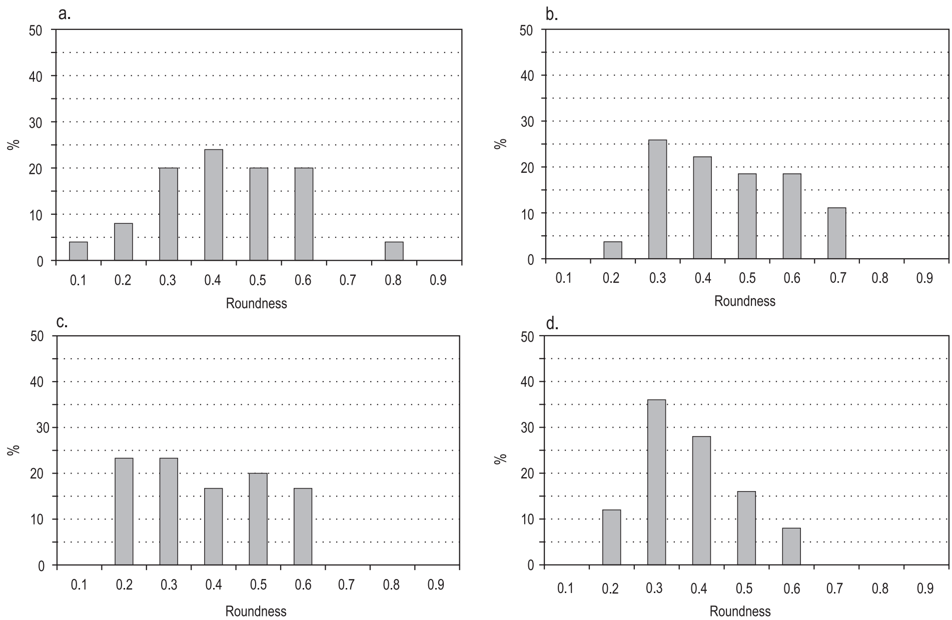

Figure 2. Roundness of grains from the dunes: 1 (2a), 5 (2b), 10 (2c), 13 (2d) according to the Krumbein (1941) scale

of very well rounding (exceeding 0.7) (Figure 2). Grains of poor or medium rounding (0.2-0.6) dominate. Sediments building the dune number 1 (Figure 2a) are exceptional. The dune is localised in the most north-western part of the Coude du Dra erg (Dłużewski, Krzemień 2008– Figure 2). These sediments include small amount of grains lacking any traces of rounding (0.1 in the Krumbein scale) and also grains which are very well rounded (exceeding 0.7). In both cases, the share of such untypical grains is 4% (Figure 2a).

Regardless of the degree of rounding, the dune sand grains are crusted. In majority of cases the crust has a character of a precipitation silica sheet and it is observed in microdepressions and also on grain edges (Photo 4). There are no traces of eaching on grain surfaces, which can be a result of a lesser aggressiveness of pore solutions. Oval microfractures are visible on surfaces of depressions in a little share of grains (Photo 5). Less that 10% of grains exhibit microstructures called „raindrops" solution (Photo 6). They created a characteristic pockmarked surface. They originate from dulling any mechanical destruction of primary original structure, but also chemical eaching (Pell, Chivas 1995). Such structures are present on most protruding fragments of the grains, but also on flat surfaces (Photo 5a, 5b). They are more characteristic of larger grains.

Aeolian abrasion is visible on most protruding parts of only 10% of analysed grains (Photo 7) (Woronko 2003, 2006). This pertains only to the crusting of grains. The aeolian action is recorded on the grains by smoothing of edges and corners and more smooth and homogenous crust in places directly exposed to abrasion (Photo 8). It is worth noting that in a case of grains with aeolian abrasion, there are no great differences between abraded edges and depressions (Photo 9a, 9b). Grains smaller than 0.3 mm do not have any traces of aeolian action.

5. Discussion

The results of the research proved that dunes of the Coude du Dra region are built with sands which texture is little spatially differentiated. The degree of rounding of the grains varies a lot. There are grains of extremely bad rounding with sharp edges and corners (Photo 7). Such grains neighbour with very well rounded grains. Sub-angular or sub-rounded grains dominate. It proves that commonly acknowledged theories of poor rounding of aeolian grains from hot deserts are true (Folk 1978, Pye, Tsoar 1990). It also testifies for a very short-distance aeolian transport of these grains. The sand which was subject of long-distance aeolian transport, exhibit a very high share (up to 80%) of very well rounded grains. Mechanical abrasion acting on angular grains during aeolian transport makes them rounded very quickly (Kuenen 1960, Wright et al. 1998). Ph. H. Kuenen (1960) suggests, that aeolian rounding of grains is 100-1000 times more effective comparing with fluvial environment. Intensity of the process decreases as rounding of the grains increases (Kuenen 1960). The degree of rounding also depends on duration of the process. E. Mycielska-Dowgiałło (1993) studied dunes in southern Sweden which were 200 years old. The dunes appeared to consist almost entirely of angular grains. On the other hand, sands from dunes in middle Europe, where aeolian processes during the end of the last glaciation lasted for 1000 years, include well rounded grains and no angular ones.

A differentiated degree of rounding of sand grains from the Coude du Dra erg reflects a constant supply of fresh, angular grains which most probably originate from weathering of surrounding bedrock. This is proven by the presence of angular grains in dunes in outermost places of the erg (dunes 1 and 4) (Dłużewski, Krzemień 20087 – Figure 2). In more central parts of the erg the angular grains are absent (Figure 2). Grains which are very well rounded (over 0.7 in the Krumbein scale) may be originated in a remote source area or duration of aeolian transport may be long. According to A. Goudie and A. Watson (1981) well rounded grains in aeolian sediments of hot deserts are rather rare (about 8%). Some of such grains inherited well rounding from other, not aeolian environment (Goudie, Watson 1981). In the aeolian environment the surface of such grains become only slightly modified. Moreover there is no clear relationship between the degree of rounding and the size of the grains (Figure 3). Nevertheless it seems that the bigger the grain, the higher the degree of rounding is. This characteristic is linked to the type of transport (Pye, Tsoar 1990).

All analysed grains are crusted (Woronko 2003, 2006). The crust mainly consists of amorphous silica with little share of other ions (Pell, Chivas 1995). The process of crusting acts on the whole grain surface and it is not limited to concave parts, like it is emphasised by D.H. Krinsley and J.C. Doornkamp (1973). It may indicate that the thickness of the crust is relatively large. Such features of the grains show that

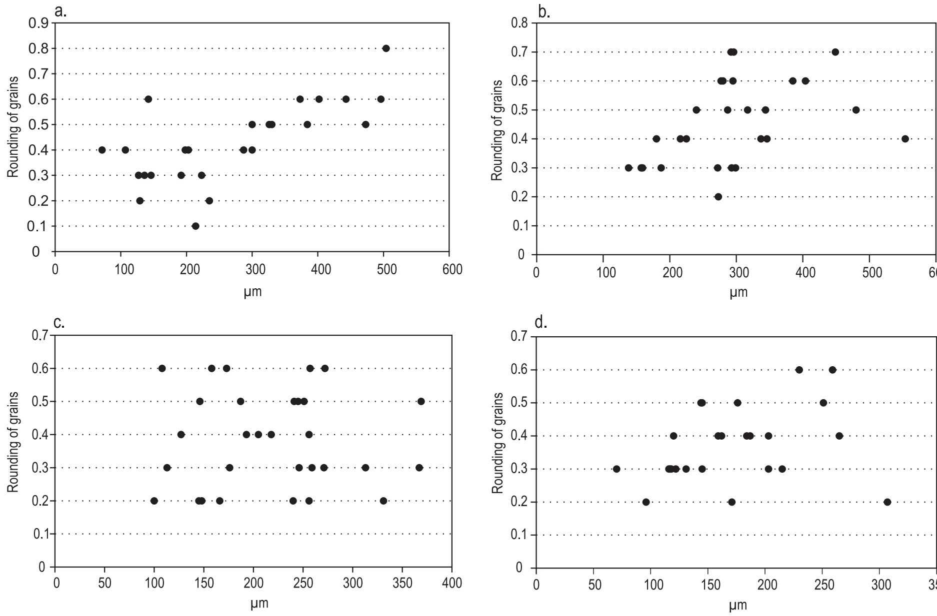

Figure 3. Relationship between the grain size and the degree of rounding from dunes: 1 (3a), 5 (3b), 10 (3c), 13 (3d)

the crusting process was fast and intensive which is proved by numerous studies (Mycielska-Dowgiałło 1992, Pell, Chivas 1995). It seems that the grains upon entering the aeolian environment are already crusted but not abraded. This may be supported by the fact that majority of grains lack traces of aeolian abrasion on their edges and corners – the most susceptible parts for abrasion. On the other hand, the process of crusting may be much faster than aeolian abrasion (Mycielska-Dowgiałło 1992, Woronko 2000). Such a hypothesis can be supported by the fact that microstructures of upturned plates type which are diagnostic for aeolian abrasion (Kaldi et al. 1978) are recognised only few times on the analysed grains. According to experimental studies, 5 hours of continuous saltation is enough to create traces of aeolian abrasion on quartz grains (Kaldi et al. 1978). D.H. Krinsley and I.J. Smalley (1972) emphasise that the aeolian abrasion is more effective on grains which previously underwent processes of solution and reprecipitation. On the other hand the process of solution is more active on newly abraded grains.

Silica solutes when pH is high (Lucchi, Casa 1968, Krinsley, Doornkamp 1973, Krinsley, McCoy 1978). In dry climatic conditions pH is usually very high. The processes of solution and reprecipitation act on the day-and-night bases (Krinsley, McCoy 1978). During the day, when temperature increases, pore water evaporates and density of pore solution increases together with an increase of pH. Little amount of silica gets dissolved on the grain surface (Krinsley, Doornkamp 1978). In the case of the Coude du Dra region potential evaporation is very high. According to different sources it is estimated to be from 2900 to 5042.7 mm per year wchich results from a very high air temperature (Dłużewski, Krzemień 2003). Such conditions favour creation of grain crusting.

Within microdepressions on grain surfaces there are oval or polygonal micro-fractures (*circular* or *polygonal cracking*). S.D. Pell and A.R. Chivas (1995) suggest that such structures result from dehydration of clay minerals located below the amorphous silica layer. Most probable sources of such grains are floors of dry salt lakes (Coudé--Gaussen 1991) e.g. the Iriqui Lake. Clay particles constitute a high percentage in such sediments (Dłużewski 2003).

According to S.D. Pell and A.R. Chivas (1995), grain surfaces with „raindrop" solution microstructures are produced under climatic conditions (hot and humid) which are different from contemporary climate in this part of Morocco. Such structures occur on convex part of surfaces as well as in microdepressions in the grain surface. They usually create regular polygonal network of oval microdepressions, 5μm in diameter. There are no traces of eaching within already existing crusting. According to S.D. Pell and A.R. Chivas (1995) it is probable that the crusting overlies previously created microrelief especially when such microstructures occur in microdepressions. When the „raindrop" solution microstructures occur only on most protruding fragments of well rounded grains, it is likely that they develop from aeolian abrasion which destroys small fragments of the crust and from the process of reprecipitation (Mycielska-Dowgiałło 1992, Woronko 2000). They represent most probably other than local source of sediments.

Taking under consideration north-eastern direction of prevailing winds (Dłużewski, Krzemień 2003), there is no correlation between the degree of rounding and distance of aeolian transport. It can result from the fact that the sediment supply to the fast growing erg (Dłużewski 2003) is from different directions. Sediment source for the Coude du Dra dunes is local and the grains are derived from nearest neighbourhood – the dry floor of the Iriqui Lake, wide alluvial fans at the base of the Jebel Bani and alluvial sediments found in the floor of the Oued Dra (Woronko 2003, 2006). Only little percentage of the grains (about 10%) is probably derived from sources outside the Coude du Dra region. Such grains have the "raindrop" solution microstructures on their surfaces.

6. Conclusions

Surfaces of grains building the dunes in the Coude du Dra region are mostly shaped by processes of solution and re-precipitation of silica on grain surfaces. This results in intensive grain surface crusting. The effects of aeolian abrasion are visible only on little percentage of grains. Majority of the grains is angular or sub-angular and only few grain are well and very well rounded. Such features indicate that the sediments were not transported for a long distance. Sediment source for the fast growing erg is local and consists of dry lake floors, alluvial fans and sediments supplied by the Oued Dra. Only very well rounded grains which constitute a small share of the analysed sediments can represent a different, remote source.

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