THE SOURCE OF THE AEOLIAN SEDIMENTS IN THE COUDE DU DRA REGION

Abstract: Determination of the source of material building the dunes of the Coude du Dra region was the aim of the performed studies. To estimate the source areas, the selected textural features, especially the mineralogical and lithologic composition of the dune sand basement sediments were studied. This composition was determined by means of the microscope analysis of the granular preparations.

On the basis of the obtained results one found that the dunes of the Coude du Dra region have high content of the components of low resistance to the deteriorating factors of transport and weathering processes. Only in the north-eastern part of the area and in the apical parts of the highest dune forms there occur the sediments with high content of the resistant minerals, mainly quartz. The results indicated also the insignificant difference in the mineral and lithologic composition of the sediments of the basement and those of the dunes. This allowed the conclusion that the source of the dune sediments occur in the close neighbourhood of the dunes. This yielded from the presence of numerous components of relatively coarse fraction and low resistance, transported mainly by saltation, which is the mode favouring intensive mechanic abrasion. They are mainly clayey-ferruginous clasts, moreover feldspars and carbonate rock grains. Moreover, the feldspars are well preserved and frequently of automorphic habit and certain feldspars occur as perfect crystals with sharp edges, which could not be preserved during a long transport. The close source of the dune material and short period of the dune formation were confirmed by the analysis of the composition of the heavy mineral fraction.

On the basis of the obtained results one found that first of all the local sediments accumulated in stagnating water were the source of the dune material, mainly the sediments of the Iriqui Lake and numerous pits without water outflow, occurring in the area of the broad there valley of Oued (Wadi) Dra. This is indicated by a very high content of clayey-ferruginous clasts, which formed during the periodic water flow transporting to local, ephemeral basins fine detritic material coloured in red by dispersed iron compounds, forming commonly under strongly oxidizing desert conditions.

Key words: dune fields, source of dune material, mineral and lithologic sediment composition, Coude du Dra region, southern Morocco.
1. Introduction

Analysis of the mineral and lithologic composition is very helpful in determination of the source of the dune sediments, the nature of the sedimentation environment and duration of the aeolian processes. It is connected with the specific features of the dune material, which is submitted to the more intense abrasion due to the aeolian processes, leading simultaneously to the differentiation of the mineral and lithologic composition of the dune sediments (Bagnold 1941). In the sediments undergone to the aeolian processes the prevalence of the minerals resistant to the mechanic abrasion over the poorly resistant ones increases during the development of the process. Moreover, the results of the analysis of the heavy minerals are very helpful in determination of the indicating of the source of the dune material and duration of the aeolian processes. The content of the minerals of a defined resistance to abrasion, the habit of the grains, variation of the specific gravity and resistance to chemical weathering are the main factors indicating the duration of the aeolian processes, thus the degree of alteration the source sediments in the aeolian ones (Barczuk, Dłużewski 2003, Dłużewski 2000, Mycielska-Dowgiało 1995, Racinowski 1995).

Studies of the dune and basement sediments in the area of Coude du Dra (Dłużewski, Krzemień 2008 – Figure 2) were performed in the years 2001-2006. The analyses of the mineral and lithologic composition of 72 samples and additionally the determinations of the heavy mineral compositions in 29 samples were performed.

The determination of the source areas for the sediments building the dune fields in the region of Coude du Dra was the aim of the investigations. This is one of the basic factors allowing the determination and possible constraining of their development in this region.

2. Methods of the studies

The microscope analysis of the granular preparations was the main method of the studies of the sediments in the area of interest that aimed in the determination of their mineral and lithologic composition (including heavy minerals). This method is commonly applied in the sedimentary rocks petrology (Barczuk 1992, Berendsen, Barczuk 1993, Barczuk, Tatur 1999, Barczuk, Wyrwicki 1999, Kosmowska-Ceranowicz, Buhmann 1982), and its especially extensive application is in the studies of the sediments, which were undergone to the aeolian processes (Barczuk, Dłużewski 2005a, 2005b, Chlebowski, Lindner 1975, 1976, 1992, Chlebowski et al. 2002, Mycielska-Dowgiało 1995).

The mineral and lithological composition was analysed in the samples of the sand not separated into individual fractions because of the small variation of the grain size (Dłużewski 2003). The composition of the heavy minerals was determined in the grain fraction 0.2-0.1 mm (2.32-3.32Φ).

Granular preparations made from the collected samples were analysed to determine structure, texture and mineral composition by means of various techniques of the optical and scanning electron microscopy (Borkowska, Smulikowski 1973).
Figure 1. Mineral-lithologic composition of the sediments of the selected dune forms (sandy fraction) Coude du Dra region; samples 1-14


Source: Barczuk, Dłużewski 2003, (partly modified).

To achieve the complete identification of the lithoclasts and single mineral grains one analysed such their optical features as habit, cleavage, colour, pleochroism, refractive indices, birefringence, light extinction angle, optic sign etc.

3. Results

A number of the mineral components were distinguished in the studied sediments (quartz, gypsum, feldspars and heavy minerals). The studies revealed also the lithic components i.e. lithoclasts (various limestones, marls and ferruginous-clayey clasts) (Figures 1, 2).
Figure 2. Mineral-lithologic composition of the dune sediments collected along the longitudinal log dune No. 8 (sandy fraction)

Explanations: a – reg (windward side), b – basis of the windward slope, c – middle of the windward slope, d – summit, e – upper part of the leeward slope, f – middle of the leeward slope, g – lower part of the leeward slope, h – reg (leeward side); 1 – quartz (monocrystalline), 2 – quartz (polycrystalline), 3 – gypsum, 4 – fieldspars, 5 – heavy minerals, 6 – ferruginous-clayey clasts, 7 – marls, 8 – chemogenic limestones, 9 – organic limestones.

Source: Barczuk, Dłużewski 2003 (partly modified).
4. Mineral components

Quartz

The percentage of the quartz grains, which increases during the ongoing aeolian process of the sediment due to the great resistance of this mineral to the mechanic abrasion, has the essential importance for the determination of the degree of the sediment aeolization. In the several hundreds years old dune forms occurring in the area of Sahara Desert one found more than 90% and frequently almost 100% quartz component (Coque 1962, Pietrow 1976). Moreover, the variation of the quartz percentage is a good index of the distance of the dune sediments from their source. Decrease of the quartz content during migration of the dunes indicates the delivery of the local material (Barczuk, Dłużewski 2001).

Quartz may be transported for long distances, thus it is a good index of the so-called mineralogical maturity of the sediments. Very high quartz content in the sediment in connection with the characteristic composition of the heavy minerals and other textural features may evidence multiple redeposition of the detritic material. The material of such features might have been passed even several sedimentary-diastrrophic cycles. This results e.g. from the fact that all the poorly resistant components in such processes are removed from the sediment, thus the sediment is enriched in the most resistant minerals, especially in quartz. On the other hand, due to its very uniform mineralogical and geochemical character, quartz is a good index of origin of the detritic material (Barczuk, Dłużewski 2005a).

Quartz is the most common component of the majority of the investigated samples. In the dune sediments the grains of the sandy fraction distinctly prevail, however, many samples contain grains of the dust fraction as well. The characteristic feature of the studied sediments is that the sparse coarse sandy grains are commonly well rounded due to transport by saltation, whereas the fine sand and dust grains are angular, because they are transported in aerosol. Quartz grains are usually clear, without inclusions and flaws. A small part of them contains gas-liquid inclusions and overgrown iron compounds or clay minerals.

Quartz content in the dune sediments ranges from 43 to 55% in the most samples of the studied area, and especially in the longitudinal section of the highest dune forms. Thus, the quartz percentage is relatively low, if compared to the mature Saharian dune forms. This evidences the short period of development of the aeolian processes influencing the material, which builds the studied dune forms.

On the basis of the studies performed in 2005, one found that in the north-eastern margin of the studied area at the foothills of Jebel Beni Selmane the quartz content in the dune sediments was distinctly higher than the value given above, ranging from 75 to 80%.

The sediments of the basement are much more differentiated, if the quartz content is considered. Apparently, this variability should be connected with the local diversity of the accumulation processes, which formed the basement. In the area of the bottom of the episodic lake the quartz content in the basement sediment did not exceed 2%, but in the areas of the episodic riverbeds it increased to 68%. A significant
variety of the dune sediments when compared to the basement sediments may be explained by very large dynamics of the eolian process of the material sorting.

**Polycrystalline quartz**

Polycrystalline quartz is a separate group of the clasts in the fine to coarse sand fraction. It has typically mosaic structure of the grains. The presence of the polycrystalline quartz in the sediment has similar importance in the context of the genetic-environmental considerations, like the monocrystalline quartz. The both varieties of the quartz grains have similar resistance to the destroying factors of weathering and transport. Only certain types of the polycrystalline quartz are slightly less resistant than monocrystalline quartz, however, the difference is small. Recognition of the alimentation area of this component is possible only in the case of the correct recognition of its genesis, i.e. the distinguishing of the metamorphic and vein (hydrothermal) quartz (Barczuk, Dłużewski 2005b).

The percentage of the polycrystalline quartz in the dune sediments is from 10% to 14% and only in few samples one found its decrease to several percent. The content of the polycrystalline quartz in the sediments of the basement is distinctly lower, mostly being at the trace level, and only occasionally achieving a few percent.

This large differentiation in the dune sediments and in the basement ones is connected with the origin of this kind of quartz. High contents of the polycrystalline quartz may result from the local outcrops of quartzite or vein quartz. Though this component has the resistance to mechanic abrasion comparable with that one of the monocrystalline quartz, its percentage in the studied sediments cannot be an index of the duration of the aeolian processes because of the above indicated great variability of the occurrence of the polycrystalline quartz in the source sediments.

**Gypsum**

Gypsum is a typical evaporate mineral. It forms in periodic, frequently drying and highly saline water reservoirs. It is susceptible to the physical factors, transport and chemical weathering, thus it is a good indicator of the proximity of the alimentation areas. Its presence indicates erosion of the nearby specific evaporate sediments, which should form in quite recent past. Occurrence of gypsum in the dune sediments is an evidence of their relatively young age (Barczuk, Dłużewski 2005a).

In a significant part of the investigated dune sediments the gypsum content does not exceed a few percent. It is connected with its poor stability and low resistance to the mechanical abrasion and chemical weathering. Due to low content of gypsum in the dune sediments it is difficult to accept this mineral as an indicator of the environment of the studied area.

**Feldspars**

Feldspars are relatively susceptible to the destroying factors of transport, thus they are considered as indicators of not very distant alimentation areas (Photo 1). However, like gypsum, they occur in the studied dune sediments in small amounts. They are most commonly represented by microcline, rarely by orthoclase perthite and very rarely by acid plagioclase. These feldspars are usually slightly altered by ka-
olinization and sericitization, though completely fresh grains were found in the studied sediments as well.

**Lithic components**

**Ferruginous-clayey clasts**

Small ephemeral water reservoirs are the most probable sources of these components (Photo 2). Such reservoirs origin episodically due to very rare but abundant and sudden rainfalls. Water flowing to local terrain hollows carry fine detritic material, coloured in red by disseminated iron compounds forming commonly in strongly oxidizing desert environment. The ferruginous-clayey clasts forming this way are very good indicators of the conditions in the places of their formation as well as short transport of the considered sediment because of their poor resistance to mechanic abrasion (Barczuk, Dłużewski 2005a).

The ferruginous-clayey clasts occur in the studied sediments as brown aggregates, frequently with parallel shaly texture, rarely with the random one (Photo 3). Most of these clasts may be determined as iron-bearing clayey shale and the remaining part is ferruginous claystone. Rarely the clasts have observable features indicating their origin by strong weathering and decomposition of the glauconite or biotite grains.

Average content of the ferruginous-clayey clasts in the studied dune sediments is about 30%. The dune sediments in the northern and northeastern parts of the studied area, i.e. near the foothills of the mountains, have lower contents of these clasts (19-28%). The dune sediments occurring in the bottoms of the episodic lakes and oxbow lakes in the episodic river valleys (35-38%).

The basement sediments are especially rich in the ferruginous-clay clasts, for instance in the bottom sediments of the Iriqui Lake their content achieves 97%.

**Marls**

Marls have typically very low mechanic and chemical resistance. They probably come from the limestone formations occurring in the close neighbourhood of the studied area, in its northern margin. However it cannot be excluded, that their small, light grains are brought from the more distant terrains (Barczuk, Dłużewski 2005a).

Marls occurring in the studied sediments form diverse groups of lithoclasts. Relatively well-rounded grains of the sandy fraction of grey or grey-brown colour prevail; they consist of a mixture of fine-crystalline or micrite carbonates and clay minerals. Proportions of the above-given components are difficult to establish on the basis of the microscope analysis. Most of these clasts have parallel, shaly texture and may be determined as marly shale. The remaining part consists of the typical marls of random texture.

Percentage of marls in the dune sediments is very variable, but the maximum content does not exceed 6%.

Distinct enrichment in marls (up to 13%) was noted only at the foot of the leeward slope of the highest dune forms. It seems that it is connected with the kind of transport typical of this type of clasts with small mass. Contrary to the grains of the higher volumetric gravity and different structure, e.g. the grains of quartz, the discussed
ones are transported by floating and when the wind speed is low – by rolling or dragging. However, due to their structure and low mass they are not subject of saltation. On the leeward side of the dunes the wind speed and thus the moving force decreases rapidly, what causes the falling of the marl grains immediately behind the top edge of the dune and their spilling down the leeward slope to its base.

In the sediments of the basement the variation of the marly clasts content is even higher, up to 11%, being related to the supply of the material by episodic fluvial transport.

**Chemogenic limestones**

Chemogenic limestones are represented by sand size clasts formed from subhedral to anhedral sparry calcite. Sometimes single euhedral or globular grains of colourless calcite are found. Rarely in the dune sands there occur lithoclasts of micrite limestones and exceptionally – typical euhedral zoned rhombohedrons with calcite inner core and dolomite coat (Barczuk, Dłużewski 2005 a, b).

The percentage of the chemogenic limestones in the studied dune sediments equals up to 4% Like in the case of marls, the percentage increases (to 8%) at the foot of the leeward slope of the highest dunes. Special structure and small volumetric gravity of the chemogenic limestones indicate that this relative increase of percentage results from the mechanism similar to the one described for marls.

**Organogenic limestones**

Organogenic limestones occur in trace amounts or they are absent at all. If they do, they are represented by sparse and poorly variable group of micrite and fine sparry lithoclasts, containing remnants of different calcareous organisms recrystallised in various degree. Most of the organisms are very difficult to identification because of poor preservation and strong crushing. Few recognisable forms include poorly preserved radiolaria and snails, and elongated forms resembling remnants of the mollusc shells. Unfortunately, because of the strong recrystallization it is difficult to recognise their more exact classificational attribution. Single clasts of other carbonate rocks are probably recrystallized algae limestones. Another, relatively numerous group of the bioclasts is so strongly altered that their more precise identification is not possible.

In the sediments forming the highest dunes (Figure 2), single grains of the following rocks were found: quartz-graphite schist, chalcedony and agate aggregates with typical laminar texture, formed of thin alternating chalcedony laminae coloured by variable amount of the iron pigment.

**Heavy minerals**

Microscope analysis evidenced that in certain samples taken from the dune sediments there occur exceptionally high amounts of the heavy minerals with prevalence of the opaque ones (Figure 3). Among the minerals resistant to erosion, especially epidote is abundant 15-29%) (Photo 4), moreover staurolite (4-11%) and tourmaline (3-7%) are the constant components. Noteworthy is the low content or absence
of the most resistant minerals as zircon (0-1%) and rutile (0-1%) (Photo 5), as well as garnet (0-2%), the mineral of relatively high resistance to mechanic abrasion and moderate resistance to chemical weathering.

Among the minerals poorly resistant to the mechanic abrasion and chemical weathering amphiboles (8-13%) and pyroxenes (7-9%) prevail. Relatively high abundance is typical of the heavy minerals with flaky habits (biotite, chlorite and muscovite) – maximum 34% at the leeward slopes and up to 19% in the apical parts of the highest

Figure 3. Composition of the selected heavy minerals of the sediments from the selected dune forms, fraction 0.2-0.1 mm (2.32 φ-3.32 φ) Coude du Dra region; samples 1-14

Explanations: 1 – staurolite, 2 – tourmalines, 3 – epidotes, 4 – carbonates, 5 – amphiboles, 6 – pyroxenes, 7 – mica groups, 8 – others.

Source: Barczuk, Dłużewski 2003 (partly modified).
dunes. Among the minerals of the mica group biotite distinctly prevails, occupying 11 to 21% of the total content.

Some samples contain trace amounts of glauconite, which is weathered in various degrees. Occasionally andalusite (Photo 6a, 6b), apatite, carbonates (other than the above described), kyanite (Photo 7), phosphorite and sillimanite were found. Neither monazite nor sphene were found.

On the basis of the obtained data one concluded, that the percentages of the individual heavy minerals in the dune sediments within the investigated area are relatively little variable. However, the results indicate that in the cases of the highest dunes the variation increases within the single object (Figure 4). In the apical part the contents

![Diagram](image-url)

Figure 4. Composition of the selected heavy minerals of the sediments collected along the longitudinal log dune No. 8, fraction 0.2-0.1 mm (2.32 \( \Phi \)-3.32 \( \Phi \))

*Explanations:* a – reg (windward side), b – basis of the windward slope, c – middle of the windward slope, d – summit, e – upper part of the leeward slope, f – middle of the leeward slope, g – lower part of the leeward slope, h – reg (leeward side); 1 – quartz (monocrystalline), 2 – quartz (polycrystalline), 3 – gypsum, 4 – fieldspars, 5 – heavy minerals, 6 – ferruginous-clayey clasts, 7 – marls, 8 – chemogenic limestones.

*Source:* Barczuk, Dłużewski 2003 (partly modified).
of the minerals resistant to the mechanic abrasion is apparent, whereas on the leeward slope and at its foot the minerals poorly resistant to the mechanic abrasion, especially the ones of the flaky habits, are more abundant. It is connected with the significant increase of the wind speed in the apical part of the high dunes, being the evident obstacle for the moving near-surface air masses.

Results of the analysis of the heavy minerals in the basement sediments did not display important differences with respect to the above shown results pertinent to the dune sediments. It was found that the amounts of the individual mineral species relatively resistant to the mechanic abrasion are few percent or exceptionally more than ten percent lower than in the dune sediments, and amounts of the minerals of low resistance are respectively few percent higher.

4. Conclusions

On the basis of the performed mineralogical analyses of the dune sediments in the region of Coude du Dra it was found that the mineralogical and lithological compositions of these sediments are relatively diversified. They are rich in the components, which are poorly resistant to transport, and weathering processes. Rarer, especially in the north-eastern part of the region and in the apical parts of the highest dunes the sediments with more uniform composition, bearing higher amounts of the physically and chemically resistant minerals, mainly quartz.

Detailed recognition of the mineral and lithologic composition allows to conclude that the source of the sediments forming the accumulation aeolian forms developed in the investigated area occurs in short distance from these forms. This is indicated by the presence in the dune sediments numerous poorly resistant components in coarse fraction, which are transported mainly by saltation – a process accompanied by intense mechanic abrasion. The dune sediments contain high percentage of the ferruginous-clayey clasts, moreover feldspars, clasts of various carbonate rocks, fine organisms remnants inclusively. Habit and the state of preservation of certain components are additional evidence indicating relatively short transport of the material composing the studied dunes, namely feldspars are usually well preserved and frequently euhedral, certain carbonates occur as perfect crystals with sharp apices, which could not be preserved during long transport.

Results of the mineral composition analysis of the heavy fraction confirm the nearby source of the dune material and short time of formation of the dunes. This is indicated by small difference of mineral compositions of the basement and dune sediments. Large amount of the heavy minerals in the studied dune sediments and even relative abundance of the minerals which are resistant to mechanical abrasion is connected with their common occurrence in the basement rocks, but not with the duration of the aeolian processes. High percentage of the heavy minerals of the mica group in the dune sediments is an important evidence confirming a local supply of the material, because these minerals of flaky habits are susceptible to deflation.

Concluding, one may indicate the proximity of the sediment source and low degree of aeolization of the dune sediments of the studied region of Coude du Dra
are indicated by insignificant change (or its absence) of the mineral and lithologic composition of the dune sediment when compared to the basement sediments as well as presence of the components poorly resistive to the destroying action of the transport factors. Local lake sediments as the prevailing source of the dune material are evidenced by high contents of the ferruginous-clayey clasts in the dune material. An elevated presence of the minerals resistant to mechanic abrasion in the apical parts of the highest dunes is connected with the higher degree of aeolization of these sediments resulting from a longer process, which affected the material building these dunes. Higher content of the abrasion-resistant minerals in the northeastern part of the considered area is connected with the type of the local basement. Numerous beds of the presently episodic rivers occurring in this part of the region yield to the dune forms the material, which has been earlier sorted in the fluvial environment. This process was the reason for the increase of the percentage of the abrasion-resistant minerals in the basement, which next became the alimentation area for the dunes in the considered part of the investigated region.

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