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REASONS FOR DEVELOPMENT OF THE DUNE FIELDS IN THE COUDE DU DRA REGION

Abstract: The development of the dune fields in the region of Coude du Dra, occurring to the south of the Antiatlas, along the Moroccan border with Algeria, is described in this paper. The determination of the reasons for expansion of the dune fields was the aim of the studies presented here. The evaluation of the rate of expansion was made on the basis of the analysis of the topographical maps, satellite images and field investigations. Since 1932, the surface of the dune field has increased ca. 30 times. To estimate the causes of such a dynamic development of the dune fields, the source areas of the dune material were determined on the basis of the analyses of the sediment textural features, mainly the mineral and lithologic composition. It was found that local alluvial sediments in the Oued (Wadi) Dra valley and lacustrine beds (mainly of the Iriqui Lake) are the sources of the majority of the dune sediments in the Coude du Dra region. This is evidenced by great mineralogical conformity of the dune and basement sediments, namely the significant contents of the ferruginous-clayey particles forming in local, periodical water reservoirs. Large content of this component in dune sediments, combined with its very low resistance to mechanical abrasion, indicates that the dune material underwent short aeolian process and passed a limited distance from its source.

After recognition of the source areas, the features of the natural environment of these areas were evaluated, taking into account especially those which are of special importance for the deflation process. It was found that the water table lowering is the most important change of the natural environment, which influenced during last several tens of years the distinct increase of the deflation process. Other features of the natural environment like the surface relief, climatic conditions or vegetation did not influence essentially the dynamic development of the dune fields in this region. Only today the distinct morphometric borders, especially in the north and in the south, may limit further expansion of the dune field in these directions.

The construction of the dam system on the Oued Dra supplying water to the described region is the main reason for the ground water table lowering, thus resulting in drying of the surface sediments and making them ready to deflate. Change of the causes of the dune fields development from the factors determined by gradual climate changes to the factors connected with the local human activity influenced essentially the increase of the rate of the dune fields development in the region of Coude du Dra.

Key words: dune field development, dune sediment source, textural features of sediments, Coude du Dra region, southern Morocco.

1. Introduction

Along the northern margin of the Sahara desert during last one hundred years a number of new fast spreading dune fields has developed. Based on current research it is stated that this process does not result from global climate changes but rather from human activity in the area.

In order to assess the dune field development rate, it is necessary to know a rate of mineral material supply to the area and to recognise several environmental factors which influence accumulation of this material (especially the relief and the vegetation cover). In case of an allochthonous source of the mineral material, it is important to determine the type of the source area (e.g. other ergs, fluvial accumulation areas, outcrops of bedrock with weathering material susceptible for deflation, etc.). This will allow to assess the rate of mineral material supply. Precise determination of the allochthonous source area for the dune is quite difficult because it depends on many factors such as: wind speed and its direction, relief, textural features of sediments, especially the mineral-lithological content of the substratum, duration on the aeolian process (Barczuk, Dłużewski 2005). This highly impedes determination of reasons for development of the dune fields, which are linked to supply of the allochthonous mineral material.

Results of current studies undertaken in the Coude du Dra region show that the development of the dunes is usually linked to a local supply of mineral material (Barczuk, Dłużewski 2003). One can therefore infer that the reason for the dune field's development is a change of some factors, which influence increase of deflation susceptibility of local source areas. Among such factors there are: textural features of substratum sediments, relief and substratum cohesion, air and ground humidity, speed and direction of wind and vegetation cover (Bagnold 1941, Chepil 1945, Zingg 1951, Borsy 1972, Tsoar, Illenberger 1998, Lóki 2001, Dubis, Dłużewski 2002). According to several researchers another important factor is susceptibility of bedrock for corrasion – mechanical erosion due to action of wind born mineral grains (Blackwelder 1934). The aim of this study is to determine the factor responsible for the dune fields development in the Coude du Dra region.

2. Methods

Field studies in the Coude du Dra region were performed in years 1999-2006 (Figure 1).

In order to determine exact position in the field, GPS and Compulevel were used, the latter allowing for ±3 mm accuracy in measurement of relief altitude. A tape measure and a geological compass were also used. Selected dunes were precisely measured. GPS was used for determination of the current area of dune fields as well as the area between the dune fields. One of the most important factors influencing

the dune fields development – morphometry of substratum was carefully checked. The type of vegetation and its spatial range were also determined in the field in order to assess its influence on aeolian processes.

Changes in the dune fields area were analysed with use of maps from years: 1948 (charting in 1932), 1953, 1989 and Landsat 7 images from the year 2000. Obtained information was supplemented during consecutive field studies.

Degree of aeolisation which can be understood as a measure of a change of substratum sediments into aeolian sediments (Mycielska-Dowgiałło 1993) was checked by analysis of selected textural features of dune material. Selected textural features of substratum were analysed in order to determine the substratum type and its deflation susceptibility and to determine the source of the dune material.

The granulometric analysis was made by the standard set of sieves produced by Fritsch. Fine sediments (<0.063 mm) of substratum were analysed with a use of densimeter (Dobrzański, Uziak 1970). Obtained granulometric curves allowed for calculation of indices according to the Folk and Ward (1957) formulae i.e. the mean grain diameter (M_z), standard deviation (σ_1) and skewness (Sk_1).

The microscope analysis of the granular preparations was the main method of determining the mineral-lithological composition of the dune and the substratum material. This method is commonly applied in the sedimentary rocks petrology (Barczuk 1992). The mineral-lithological composition was analysed in the samples of the sand not separated into individual fractions, because of the small variation of the grain size. The preparations made from taken samples were analysed in the context of their structure, texture and mineral composition by means of various polarizing microscopy techniques (Borkowska, Smulikowski 1973).

3. Characteristics of the dune fields

Contemporary dune fields occupy majority of a flat part of the Coude du Dra region (Figure 1). Most of the dunes are several meters high in the central part of the study area (Photo 1) and from 1 to 3 m in its western margin – in vicinity of the Iriqui Lake (Photo 2) and in its eastern margin – in a vicinity of the Mhamid Oasis (Dłużewski 2003). The dunes are usually of a barchanoidal type (Photo 3), seldom single barchans developed by western winds. Their stoss sides are relatively steep, inclined 10-20°, and up to several dozen of meters long. Their lee sides are typical for Sahara dunes, up to a dozen or so meters long and 33 to 35° inclined. In areas, which have been covered by dune, fields for the longest time (Erg Sedrar, Erg Smer, Erg Mhazil and others) some dunes are several dozen of meters high and maximum height of 111 m (Erg Souar). Such dunes are usually complex barchanoidal dunes. Their winward sides have differentiated inclination and length of up to several hundred meters. Theirs lee sides have constant inclination, the same as little dunes, and length of the lee slopes can exceed one hundred meters.

Sporadically one can find initial star dunes with several crests. Their localization is practically stable. Change in wind direction causes only remodelling of the dune crests.

Recently single dunes frequently combine to create fields of transverse dunes (Photo 4). Their development is linked with a major increase in supply of mineral material to the dune field sand and also with periodical winds of the opposite direction or local denser vegetation. Such variability in wind directions and also increased moisture content in the ground along the Oued Dra (which was the case in the near past) are responsible for a pendulum-like forward movement of dunes with a limited resultant. Such a way of movement can create a characteristic shape of dunes, which have changeable inclination of slopes within both stoss and lee sides. Additional factor limiting speed of dune migration and also influencing shape of the dunes is a relatively small area between the dunes (Photo 5).

Textural features of sediments building dunes in the Coude du Dra region are highly differentiated for several reasons: duration of aeolian processes has been varied, dunes are of different size and local source areas are of different lithology.

Analysis of granulometric frequency curves for dune sediments in the research area (Dłużewski 2003) showed that small dunes (up to 3 m) are composed mostly of grains 0.25-0.2 mm (2-2.32Φ). Finer material and less sorted: 0.25-0.08 mm (2-3.64Φ) builds dunes at the foot of the Jebel Bani mountain, localised in a vicinity of mouths of episodic streams. A shift of the maximal frequency peaks to finer fractions reflects finer material found in local source areas – basins episodically filled with water. Dunes lying in the western part of the region, within a dry lake of Iriqui, are characterised by sediments which are lesser sorted and have more finer fractions: 0.315-0.045 mm (1.67-4.47Φ). Differentiated granulometry within a single form can only be found in the highest dunes. The higher such dunes are the higher share constitutes the prevailing fraction 0.2 mm (2.32Φ). Finer material – 0.1 mm (3.32Φ) is found at bases of the dunes and results from aeolian supply of sediments directly from the dune forefields (Dłużewski 2003).

Relatively small mean grain diameter (M_z) of dunes in the Coude du Dra region (Table 1) suggests that the dunes are composed of finer material in comparison with

Table 1. Granulation indices of selected dune sediments

a)

Number of dune	2	4	5	7	8B	9	11	12	13	14	16	17	19	20	21	22
Height of dune [m]	3	3	2	2	1	4	2.5	1	4	0.3	2.5	8	1	2.5	3	4
σ1	0.47	0.69	0.49	0.46	0.52	0.65	0.45	0.81	0.43	0.43	0.72	0.49	0.63	0.47	0.63	0.51
Mz	2.22	2.06	2.38	2.65	2.29	2.16	2.13	2.41	2.70	3.23	2.44	1.95	2.07	2.03	2.14	2.22
Sk1	0.36	0.32	0.23	0.09	0.09	0.42	0.36	-0.07	0.12	0.05	0.53	0.24	0.20	0.23	0.41	0.66

b)

Number of dune	1	3	6	8	10	15	18
Height of dune [m]	20	30	30	111	33	12	10
σ1	0.61	0.42	0.49	0.31	0.37	0.60	0.36
Mz	2.09	1.83	2.11	2.29	2.49	2.21	2.00
Sk1	0.45	0.23	0.30	0.25	0.17	0.54	0.50

Explanations: Mz – average grain diameter, σ_1 – standard deviation, Sk_1 – skewness; according to Folk and Ward's formulas (1975). a – dunes lower than 10 m; b – dunes higher than 10 m

Source: Dłużewski 2003.

Table 2. Granulation indices of selected bedrock sediments

Number of sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
σ1	1.03	1.54	0.53	1.00	1.04	0.82	0.48	0.58	0.68	0.95	1.37	1.16	0.92	1.02	0.92	0.74
Mz	4.11	3.11	1.18	4.26	2.42	1.93	5.06	1.67	4.64	2.96	2.41	1.30	2.40	1.84	1.62	2.86
Sk1	-0.62	0.14	0.01	-0.91	0.20	0.21	-0.39	-0.07	-0.89	-0.04	0.34	0.64	0.04	0.32	0.18	-0.22

Explanations: M_z – average grain diameter, σ_1 – standard deviation, Sk_1 – skewness; according to Folk and Ward's formulas (1975).

Source: Dłużewski 2003.

dunes from other Sahara regions (Pietrow 1976, Coque 1962, Barczuk, Dłużewski 2001). It testifies that the dynamics of the local aeolian transport is limited but also that the dunes are composed of material derived from the local substratum, which is built of fine material (Table 2).

Analysis of granulometric cumulative curves drawn in a probability scale (Dłużewski 2003) allowed to infer that majority of the dune material was transported in saltation. Rolling and sliding plays a relatively important role only in case of smallest dunes. Grains transported in suspension are recognised only on lee sides of the highest dunes. They were accumulated probably due to a rapid decrease in transporting power of wind on the lee sides of dunes.

Standard deviation (σ_1) calculated according to Folk and Ward (1957) is 0.43-0.81 (Dłużewski 2003) and shows that sediments building majority of the dunes are medium or well sorted (Table 1). Such sorting is relatively small in comparison with material building other dunes in hot deserts: in the Western Desert (Egypt) – from 0.28 to 0.39 (El-Baz et al. 1982), the northern margin of the Great Eastern Erg (Tunisia) – from 0.35 to 0.53 (Dłużewski 2000, 2002), deserts of south-west Asia – from 0.2 to 0.45 (Dymowska et al. 1984). Only material found in the highest parts of the highest dunes in the Coude du Dra region displays good or very good sorting (σ_1 = 0.31-0.42) – comparable with sorting of sediments of mature dunes, which have been created for at least several hundred years (Coque 1962). Mean sorting of dunes which have relative height of less that 10 m (σ_1 = 0.55) is worse than sorting of dunes higher than 10 m (σ_1 = 0.45). Analysis of sorting index along longitudinal profiles of highest dunes in the region shows that the index increases upward on both stoss and lee sides of the dunes (Table 3).

Skewness (Sk_1) of sediments building the researched dunes is positive (Table 1) (Dłużewski 2003). This shows prevalence of finer fraction regarding the fraction of maximum frequency. Such skewness results from additional supply of silts from the atmosphere during the last stage of accumulation of dune sands, which is typical in hot deserts. Sknewness increases with increase of altitude on stoss sides of the highest dunes (Table 3). This index has highest values for the whole dune on its lee side because here, the transporting power of wind decreases.

Mineral-lithological composition of dunes in the Coude du Dra region is complex. The dune sediments are rich in minerals, which are poorly resistant to transportation

Table 3. Granulation indices of the dune sediments collected in the longitudinal log – the dune No. 8

Location	Reg-stoss side	Base of stoss side	Middle part of stoss side	Upper surface	Upper part of lee side	Middle part of lee side	Lower part of lee side	Reg-lee side
σ1	0.83	0.54	0.39	0.33	0.37	0.37	0.62	1.27
Mz	2.30	2.02	2.54	2.32	2.39	2.58	1.84	1.74
Sk1	0.00	-0.12	0.20	0.26	0.33	0.26	0.33	-0.39

Explanations: M_z – average grain diameter, σ_1 – standard deviation, Sk_1 – skewness; according to Folk and Ward's formulas (1975).

Source: Dłużewski 2003.

and weathering processes. There is a lot of ferruginous-clayey particles, feldspars, debris of carbonate rocks including small fossils. Feldspars are well preserved and often automorphic, some carbonates are developed into crystals of sharp edges (Barczuk, Dłużewski 2003). This shows that the transport of the material was limited and the source area was not far away. Sediments of relatively homogenous composition are rare and can be found mainly in the north-east part of the region. They include more minerals resistant to mechanical and chemical processes – mainly quartz. Such sediments inherit their composition from lithology of local substratum. Numerous channels of contemporary episodic rivers in this part of the region constitute source for dune material. The river channels include sediments which underwent sorting, and depletion of poorly resistant minerals in the fluvial environment. Higher share of minerals resistant to mechanical abrasion is also found in summit parts of the highest dunes. This is a result of higher aeolisation of the sediments which were subject for this process for a longer time.

Analysis of heavy minerals composition provides further argument that the source area was near the accumulation zone and that the dunes were created relatively quickly. This is shown by little differences between heavy minerals composition of the dune material and the substratum and a high share of mica in the dunes. This mineral has a lamellar structure and is very susceptible for deflation (Barczuk, Dłużewski 2003).

Textural features of the dune sediments in the Coude du Dra region show that the source area is local and degree of aeolisation of the dune sediments is low.

4. Characteristics of selected factors influencing development of the dune fields

The substratum of the Coude du Dra region, which occupies a depression between the Jebel Bani and the upland surface of the Hamada du Dra, is mostly built of poorly cohesive material of various grain size accumulated during Pleistocene and Holocene as fluvial fans. Increased erosion in mountains during pluvial periods removed poorly resistant rocks. This eroded material was transported to the forefield of the Jebel Bani and accumulated in a form of several alluvial fans which now constitute a wide plain (Dłużewski, Krzemień 2003).

The substratum of the central part of the researched region, the wide Oued Dra valley, is built with fluvial sediments constituting terraces and accumulated during pluvial periods. Sediments of various grain sizes, sometimes only stones and gravel were deposited on the valley floor by braided rivers of a very dynamic discharge. The Dra River originating in the High Atlas had such characteristics in the past. Granulometric cumulative curves elaborated for fine-grained flood sediments, which constitute a potential source of aeolian material, exhibit much worse sorting in comparison with the dune sediments. The curves point at deposition from saltation and, for a majority of samples, also from suspension.

Granulometric indices calculated for the substratum sediments according to Folk and Ward (1957) significantly differ from the corresponding indices for the dune sediments. Mean grain size of the substratum sediments is usually much smaller, sorting is poor or medium and skewness is usually negative. Differences in values of the granulometric indices between the substratum and the dunes are an effect of the aeolian transport.

Mineral-lithological composition of the substratum sediments is highly differentiated which results from accumulation in water environment of various dynamics. Sediments accumulated in fluvial environment consist mostly of quartz grains and different admixtures are linked to fluvial erosion of certain rock outcrops, e.g. limestone. Substratum sediments accumulated in standing water consists mostly of ferruginous-clayey particles. Their share in lacustrine sediments of the Iriqui Lake is up to 97% (Barczuk, Dłużewski 2003).

Major part of the substratum in the researched region constitutes a flat plain lying at an altitude of 450 to 550 m a.s.l. The northern boarder of the plain coincides with southern slopes of the Jebel Bani and erosional edges of Pleistocene alluvial fans. The southern boarder is constituted by several-hundred-meters high edge of the Hamada Dra. The eastern part of the plain is limited by the Beni Selmane range and the western part by the edge of Mejehm hills.

The ground water table significantly decreased especially during last dozen or so years (Dłużewski, Krzemień 2003). Contemporary ground water table in the Coude du Dra region, in the Mhamid oasis, can be found 10-15 m below the ground level (Sobczak 2006). This results from rare water supply from the Oued Dra. In the northern part of the region the ground water table is the highest – only 4-7 m below the ground level (Dłużewski, Krzemień 2003). This is probably linked to ground water supply from the Jebel Bani. Nevertheless, it seems that such deep ground water cannot influence moisture of superficial sediments. Relatively fast lowering of the ground water table causes degradation of vegetation, which is clearly visible even on the example of drought-resistant tamarisk plants.

The vegetation cover in the researched region is relatively scant. Only a few fragments of the dune fields are covered by sparse grass. On salty ground individual halophytes find their habitats. Slightly more dense vegetation grows in the episodic river channels where apart from the grass one can sometimes see acacia trees. Such vegetation cover is typical for the Oued Dra area and for foot slopes of the Jebel Bani. Dense vegetation can only be found within the Mhamid oasis, which is artificially irrigated (Dłużewski, Krzemień 2003).

Among climatic factors the most relevant to the dune fields development are: speed and direction of wind together with precipitation and evaporation which determines ground moisture – one of the most important factors determining the process of deflation. The researched region has an arid continental climate. Limited precipitation results from western winds bringing humid air masses from the Atlantic Ocean. Nevertheless rainfall occurs very rarely because the Atlas Mountains constitute a major barier for the humid air (Dłużewski, Krzemień 2003). Rainfall occurs only during cyclones, which due to its large vertical dimension allow humid air to pass over southwestern part of the High Atlas. Amounts and intensity of the rainfalls varies a lot (6-180 mm per year). This causes very limited moisture content of the ground though majority of the year. During summer, rain-bringing wind is replaced by a constant northeastern trade wind which make the unprotected by mountains Coude du Dra region very dry. Annual potential evaporation in the region is assessed to be even 2500 mm per year (Benmohammadi 2001, Dłużewski, Krzemień 2003). Such climatic conditions determine exceptionally little moisture content of the ground and allow form the deflation process.

In the Coude du Dra region western winds predominate during most of the year. This is a relatively weak wind but it occurs frequently due to specific atmospheric pressure systems over the Atlantic Ocean. Irrespectively of the season of the year, before the noon the direction of the wind is WNW and in the after noon WSW-SW (Benmohammadi 2001). During summer this region lies within the range of the Saharan low pressure (sometimes on its northern margin). In such situations, seasonal wind is from northeast (Chergui). This is a result of the trade wind influence. The southern wind (Sirocco) occurs relatively seldom, but its importance for moisture content of the ground is profound due to hot air brought by the wind.

In the nearest meteorological station in Tagounite, 30 km north-east of the Mhamid oasis, during 10.6% of the year the wind had a speed below 1, during 40.6% of the year the wind was 1-4 $m \cdot s^{-1}$, during 29.8% of the year 4-6 $m \cdot s^{-1}$ and during 19% of the year wind speed exceeded 6 $m \cdot s^{-1}$ (Benmohammadi 2001). One should bear in mind that the minimal wind speed necessary for aeolian transport of mineral grains in this region is about 4 $m \cdot s^{-1}$, but the wind speed necessary for deflation is at least 5 $m \cdot s^{-1}$, depending on lithology. Such frequency of wind speed allows for deflation. The strongest wind in the Coude du Dra region occurs during spring and summers – from April to September. The highest wind speed is in June and August that is during the time when the ground is very dry. During the twenty-four hour period, occurrence of stronger wind also favors deflation regardless of the season. Wind speed increases from the morning hours and reaches maximum in the afternoon. During the night weak wind or calm predominates (Benmohammadi 2001).

5. Development of the dune fields

The area occupied by the dune fields shown on maps from 1932 is about 30 times smaller comparing with nowadays situation. This allows inferring that the dunes expand in the Coude du Dra region very quickly. Increase in dynamics of

Table 4. Area of dune fields in the Coude du Dra region in years 1932, 1954, 1989, 1999/2006

Year	Area of the dune fields [km^2]	Source
1932	85	Carte Topographique du Maroc 1 : 200 000. Institut Géographique National – l'Annexe du Maroc, Rabat 1948 (based on measurements in 1932). The Coude du Dra sheet.
1954	873	Carte Générale du Maroc 1 : 500 000. Elaborated with co-operation of: Service Géologique du Maroc and l'Annexe de l'Institut Géographique National, Rabat 1953, Institut Géographique National, Paris 1954. The Ouarzazate sheet.
1989	1291	Carte Géologique du Maroc 1 : 200 000. Ministère de l'Energie et des Mines. Direction de la Géologie, Rabat 1989. The Zagora – Coude du Dra – Hamada du Dra sheet.
1999/2006	2625	Satelite images (Landsat 7), 31 March 2000 year. Own field research performed between 1999 and 2006.

Source: Dłużewski 2003, partly modified.

the dune expansion was seen especially during the third and fourth decade of the 20th c. and since 1980 until now (Figure 2, Table 4).

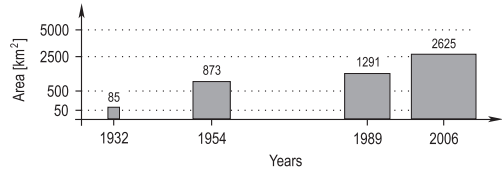

Figure 2. Area growth of dune fields in the Coude du Dra region in years 1932, 1954, 1989, 1999/2006

The area occupied by dunes mapped in 1932 shows beginning of aeolian accumulation in the region (Figure 3). This is supported by geomorphological field research performer in the second decade of the 20th c. (Piegot 1929).The area of the dunes in the fifth decade of the 20th c. was already much larger. The dunes developed on Holocene alluvial fans north of the Dra Valley and on upper river terraces on both sides of the oued. The floor of the valley was generally free of aeolian accumulation. It could result from limited deflation of local material due to relatively high ground water table and therefore denser vegetation. Until the eighth decade of the 20th c. there were no dunes on the river flood plain and this could result from removal of the loose aeolian sand by episodic floodwaters, which used to happen every couple of years. Such floods ceased due to erection of the Mansur ad Dahabi dam in 1972 south of Ouarzazate and this allowed expansion of the dunes on the flood plan. This is clearly visible on the map elaborated based on mapping in the eight decades of the 20th c. Northern limit of the dune fields moved closer to clear morphological edges produced by Pleistocene incisions into alluvial fans. In the southern part of the researched region, dune fields were situated in forefields

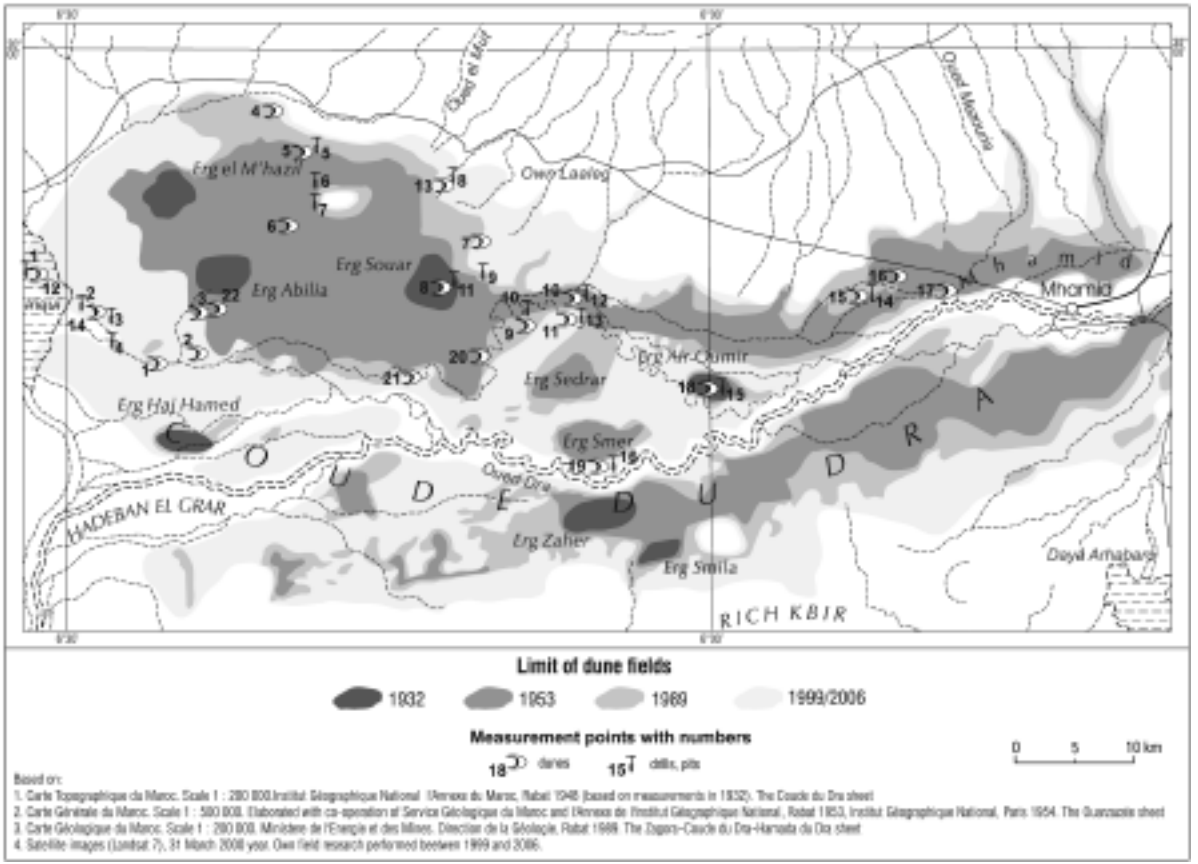

Figure 3. The map of the dune fields limits in the Coude du Dra region in years 1932, 1953, 1989 and 2006 (Dłużewski 2003, partly modified)

of the Hamada du Dra. Only the Iriqui Lake, episodic during the eight-decade period of the 20th c., and mouth of the Oued Dra were free of dunes.

Contemporary area occupied by the dune fields is twice as large as the one from the eighties testifying that there is a very high increase in dynamics of the dune field expansion (Figure 3). Nowadays northern limit of the dune fields is constituted in the northwestern part of the researched region by southern foot slopes of the Jebel Bani and by edges of the Pleistocene alluvial fans in the northeastern part. Additionally, in the northeastern part, aeolian sands fill mouths of episodic rivers, which originate from the Jebel Bani.

The dune fields are limited from east by southwestern sloped of the Jebel Beni Selmane and by the Mhamid Oasis. It is worth emphasizing that the oasis does not constitute any barrier for dunes migration any more. During field studies numerous dunes or groups of dunes were observed which encroached on cultivated fields (Photo 6) and even directly threatened households (Photo 7). Singular dunes 2-4 m high are even found in the river channel of the Oued Dra, because there are no significant discharges since 1995.

From the south, the dune fields are limited by a clear, several hundred high structural edge of the Hamada du Dra.

Significant increase of the area occupied by dunes during last dozen or so years is recorded in the western part of the researched region. Dunes do not exist only in small mountain range of the Hadeban El Grar, in a channel of episodic river originating in the Iriqui Lake and in a part of a flat plain of this lake.

It seems that from the northern and southern side of the researched region expansion of the dune fields is nowadays limited by morphological barriers constituted by slopes of the Jebel Bani and clear edges of alluvial fans in the north and the edge of the Hamada du Dra in the south. Expansion of the dune fields is partly limited from the east also by morphology of the region (Jebel Beni Selmane). The Mhamid Oasis, despite efforts of local society, does not constitute any effective barrier for the dune field's expansion (Photo 8). From the western side, the expansion of the dune fields is practically not limited. Flat surface of the lake, vegetation free and dry for several years, favors intensification of deflation and also the expansion of the dunes.

6. Conclusions

Analysis of relevant cartographic material allows stating that in the Coude du Dra region the expansion of the dune fields is very fast. Textural features of sediment building the dunes show that the source of the aeolian material is local.

Direct reason for the dune fields development is the intensification of deflation in the Coude du Dra region during last dozen or so years. It mostly pertains to contemporary, weakly consolidated fluvial sediments accumulated in river channels of terraces and relict lakes. Such forms dominate in the researched region. Reasons for this process are conected with contemporary local drying of superficial layers of the ground. This, in turn, is a reason of lowering of the ground water table. The process directly influences susceptibility of source areas for deflation. It seems

that other factors do not play an important role in the dune field development. Scanty vegetation cover or flat surface of the ground did not cause significant changes in expansion of the dunes. Only nowadays clear morphological barriers, especially in the south and in the north of the researched region can limit further expansion of the dune fields in these directions.

Summing up, it can be stated that the main reason of the dune field's development in the Coud du Dra region is the construction of dams on the Oued Dra, which used to supply ground waters. Human activity in the area plays a more important role in the development of the dune fields in comparison with climatic factors.

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