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EXTORTED FORMS OF AEOLIAN ACCUMULATION IN THE COUDE DU DRA REGION

Abstract: Two types of the extorted aeolian accumulation forms i.e. nebkhas and Tamarix cones, occur in the Coude du Dra region. The first ones are small sandy forms, usually of the height of several tens of centimetres and a significant elongation accordant to the wind direction. The second ones are forms several metres high, without observable elongation and with distinct layered structure. In the years 2000-2006 the studies comprised two kinds of the nebkhas. One kind was formed by accumulation around the halophyte *arfej* (*Rhantherium suaveolens*) growing in the area of the dried Lake Iriqui. Another kind formed around the grassy plant *drinn* (*Aristida pungens*) growing in numerous pits being the oxbow lakes of the braided bed of Oued (Wadi) Dra. The studied forms show great diversity, although both formed in similar climatic conditions. After a five-hour storm when the wind velocity exceeded 14 m per second, the change of morphology of the nebkhas accumulated behind the grass *drinn* was obserwed. From a uniform morphologically shape new forms developed with a depression caused by deflation directly behind the plant obstacle. Formation of the Tamarix cones is connected with accumulation of sediment around the Tamarix shrubs during low sandy-dusty storms, especially in their final parts, when the finest grains fall. This accumulation is frequently accompanied by rainfall. In the years 2005-2005 both nebkhas and Tamarix cones were significantly degraded. Some of the studied nebkha fields disappeared due to complete degradation of plants, which forced originally the material accumulation. The Tamarix cones were degraded in part as well. This is connected with lowering of the ground water table down to 3-4 m and more below the ground surface (outside the main bed of Oued Dra) and in the region of the Tamarix cones occurrence even deeper than 10 m. Degradation of the extorted forms of the aeolian accumulation caused expansion of the dune fields.

Key words: nebkhas, tamarix cones, textural features, formative process, Coude du Dra region, southern Morocco.

1. Introduction

Among the forms of the extorted aeolian accumulation in the Coude du Dra area two types occur, both connected with vegetation. One of them is nebkhas, ephemeral forms being the effect of aeolian accumulation behind the plant obstacle. They have elongated shape, the maximum height of several tens of centimetres and length of several metres. Accumulation occurs due to decrease of the air stream velocity within the plant obstacle and behind it, when the plant is compact, or only in its shadow, if the plant may be called "airy". Tamarix cone are another extorted accumulation form occurring in the studied region. Development of such forms begins from sand and/or dust accumulation around the obstacle, which is Tamarix shrub. These forms have a cupola shape with convex slopes and the height of several, rarely more than ten metres. They consist of alternating mineral layers of various fraction and admixture of the organic remnants coming from the Tamarix shrub.

2. Characteristic of the extorted aeolian accumulation forms according to literature and the authors' studies

First, characteristic features of the extorted aeolian accumulation forms and their classification should be determined. This classification will be applied next. In the literature three main types of the forms were distinguished, however, their features were not defined clearly. On the basis of the present authors' studies in the areas of Egypt, Tunisia, Morocco and the Cap Verde Archipelago the classification definitions of the three main types of the extorted aeolian accumulation forms were elaborated and they are given below.

Nebkhas *(shadow dune)* are generally small sandy forms of the height of several tens of centimetres and significant elongation, formed in the „shadows" of the plants, i.e. on their leeward sides (Photo 1). Exceptionally they have the height of ca. 2 m and length of 30 m (Khalaf et al. 1995). They are typical of dry areas.

Knob vegetated dune (*nebkhas*, *coppies dunes*, *etc.*) covered in 45-100% by vegetation, are especially typical of the semi-arid areas with precipitation not exceeding 300 mm per year (Langford 2000, Wang et al. 2006). Their height ranges from 0.5 to 2 or even 3 m. They have insignificant elongation according to wind blowing direction (Photo 2).

Tamarix cones are typical of the arid areas. Depending on the degree of their development they have different heights, mostly up to 10 m, without visible elongation. Internal structure has distinct layering (Photo 3, 4).

In the present publication the authors pay special attention to the forms typical of the Coude du Dra region, i.e. to nebkhas and Tamarix cones. They are immanent component of the surface morphology of the arid areas. In the process of the gradual drying of the terrain, especially of its subsurface layers, the decrease of the vegetation density promotes deflation and facilitates the supply of the material to the discussed forms (Gile 1975, Pietrow 1976). Increase of their dimensions is attributed to the soil degradation caused by more intense land use (Wang et al. 2006). The forms occur most frequently around oases, on the alluvial fans, on the lowermost terraces of the periodic rivers, between the dune fields as well as in the margins of the drying lakes (Coque 1962, Pietrov 1962, Kosmowska-Suffczyńska 1980, Gunatilaka, Mwango 1987, Tengberg 1994, Dłużewski, Woronko 2000, Dłużewski et al. 2002, Qong et al. 2002). Moreover, nebkhas frequently occur in the local terrain depressions, to which rainwater may periodically flow, allowing the growth of small plants. Tamarix shrubs need much more water and reach deeper with their roots, thus they occur mainly along the riverbeds, on the lowest terraces and even in the bed itself, where water appears once every several years. The Tamarix cones may be eroded in part or completely by the flowing water.

Further lowering of the ground water table may cause extinction of the vegetation, leading to disappearance of the discussed forms. In the areas where this process develops, first the nebkhas are degraded and much later degradation affects the Tamarix cones. This is connected with the type of the plants extorting the accumulation. In the case of the nebkhas they are small halophytes or xerophytes with root systems deriving ground waters from the depth of maximum 2 to 3 m. The Tamarix root system reaches ground water even as deep as 20 m. Though halophytes and xerophytes causing origin of the nebkhas need distinctly less water than Tamarix shrubs, when water permanently occurs deeper than 2 to 3 m, these plants extinct, what results in deflation of the nebkhas. In such areas only the Tamarix cones may occur. If the Tamarix shrubs were devastated (e.g. they were cut for fuel or extincted due to watertable lowering), such area may be occupied by shifting sand dunes (Qong et al. 2002).

During formation of the nebkhas the air streams transporting material accumulate it directly behind the plant (Figure 1). where the air pressure and wind speed decrease. The volume of the accumulated sand decreases when the distance from the obstacle increases. Accumulation of sand is caused not only by the air stream flowing directly above the obstacle but also by those moving nearby this obstacle behind which the air movement changes to the rotational one (Figure 2).

It is a common opinion that the dimensions of the nebkhas are strictly related to the kind and size of the plants behind which the material is accumulated (Tengberg 1994, Tengberg, Chen 1998). Supposedly, the important role in formation of these forms is played by textural features of the material, wind force and variability as well as duration of the process (Coque 1962, Tengberg, Chen 1998). Orientations of the long axes of the nebkhas change each time when the wind direction changes.

The studies performed till present show that the ratio of the plant obstacle height to the nebkha length ranges from 1:6 to 1:8 (1:6 after Pietrow 1976, 1:7 or 1:8 after Kosmowska-Suffczyńska 1980). Measurements of the nebkhas from the Chott El Jerid region (Central Tunisia) gave the ratio from 1:10 to 1:23, what may be explained by the presence of the gypsum crust on their surface, which protects the forms from deflation and facilitates an increase of their heights and especially their lengths (Dłużewski, Woronko 2000). Similar height-to-length ratio (1:15) has been noted for the coastal plain in Kuwait (Khalaf et al. 1995).

The Tamarix cones differ from the nebkhas not only by their dimensions but also by their internal structure. In the marginal parts of the Takla Makan Desert they consist of the alternating mineral and organic matter layers – the latter are the fallen

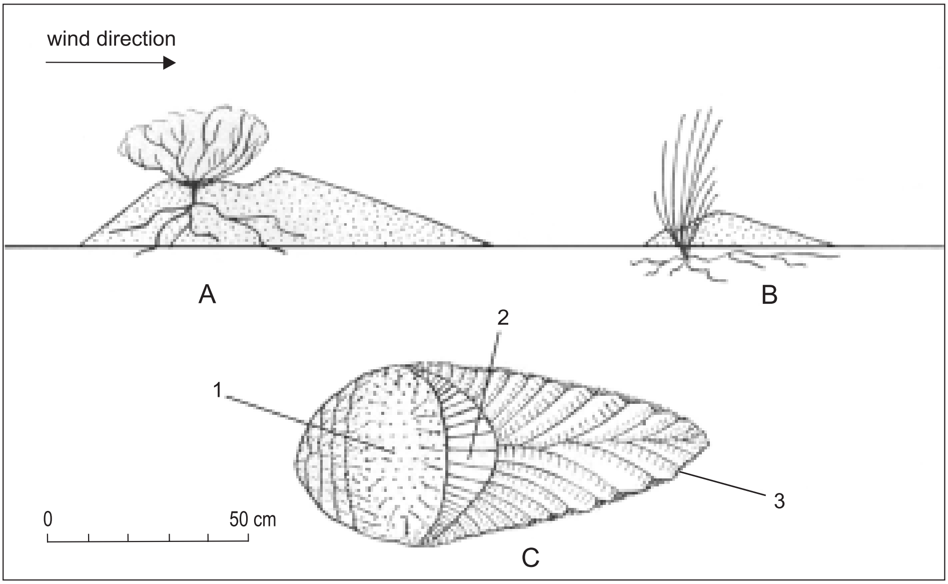

Figure 1. Scheme of a nebkha (after Coque 1962)

Explanations: A – the form behind the plant obstacle of the shrub type of the species *arfej* (*Rhantherium suaveolens*), B – the form behind the plant obstacle of the shrub type of the species *drinn* (*Aristida pungens*), C – parts of a nebkha: 1. apical part, 2. deflation pan, 3. distal part of the nebkha.

needles and branches of the Tamarix shrub. Directly below the ground surface they are fresh and light in colour, but deeper they became decomposed and dark. It is connected with humidity increase in the deeper layers (Qong, Takamura 1997, Qong et al. 2002). Granulometric analysis made in one of the studied cones at the depth of 110 cm showed 67% grains of the 0.2-0.3 mm fraction, 19% grains of the 0.3-0.4 mm fraction and 14% grains of the 0.1-0.2 mm fraction (Qong et al. 2002). Similar values are characteristic for the whole area of the desert: 70% grains are in the ranges from 0.125 to 0.4 mm (Zhu et al. 1986). Wind velocity causing the sand migration in the Takla Makan Desert is evaluated for 4 m per second (Zhu et al. 1986). Between October and December, when the wind velocity is lowest and air humidity is highest, the organic layers accumulate in the cones. Their existence till spring is caused by snowfall and ground freezing in winter. The sandy layers covering the organic sediments form from March till July, during a strongly windy season. Sand transported by wind is accumulated within the Tamarix shrub (Qong et al. 2002). Salt that drops with water from the Tamarix shrub needles and forms a crust causing consolidation of the material saturated with it, is another factor preserving the organic matter from deflation.

In the case of the Tamarix shrub burial, its trunk grows up and the buried part converts into root (Qong et al. 2002). This results in achievement of the height of several metres by the cone.

Dumanowski (1998) found during his studies of the Tamarix cones in the region of the Guira settlement in Libia that the roots decide about the shape of the cone. They change their dimensions from thin branches into roots more than ten centimetres thick. The development of the roots determines the cone stability and its cupola habit.

Dumanowski (1998) recognized the reason of the Tamarix cone formation as the wind velocity decrease caused by the plant obstacle and leading to accumulation of the transported material and, on the other hand, as the accumulation of the organic material. He wrote that the Tamarix needles due to their shape do not deflate, being poorly susceptible to aeolian transport. They are a component initiating the accumulation of the transported mineral material. Accumulation rate depends on the availability of the loose material and frequency of the transporting wind speed appearance.

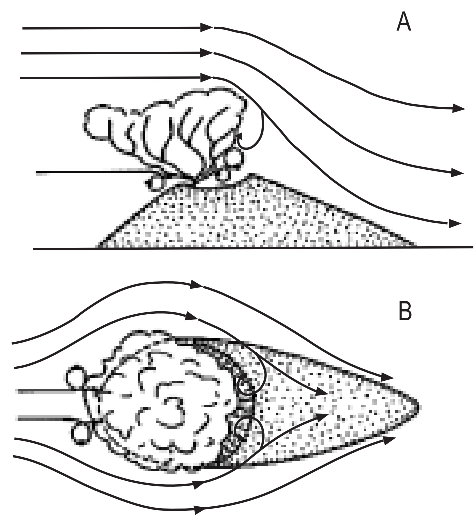

Figure 2. Scheme of the air streams flow around the plant obstacle (after Coque 1962)

Explanations: A – cross-section, B – plane projection.

According to Dumanowski (1998) that structure of the cones is complex: the subsurface part is layered but in the inner part at relatively great depth the layering disappears. He distinguished two parts: the external one *a* and the internal one *b*. The part *a* containing more organic matter (needles and small branches) reaches the depth of 40 to 60 cm in the higher part of the cone, and in its lower part (i.e. on the slopes) even to 1 m. In some of the cones studied by him the layers of the plant remnants are separated by clayey-sandy layers of the thickness from 0.5 to 2 cm. Layered structure in places disappears and one may observe a mixture of the organic remnants with clayey-sandy material. The colour of the level *a* changes from pale yellow to gray-brown, depending on the content of the organic matter. The cone inner core, the part *b*, is built from sand with admixture of the finer fractions of the yellow-brown colour with low content of the fine organic remnants, usually below 2 mm in size.

3. Location of the study area

Two nebkhas fields (number 1 and 2) in the Coude du Dra region were the objects of investigations in the years 2000-2006 (Dłużewski, Krzemień 2008 – Figure 2). The field 1 is located in the western part of the Coude du Dra region, in the eastern part of the dried Lake Iriqui, and the field 2 – in the central part of the Coude du Dra area, in one of the numerous pans without outlet which formed as Pleistocene and

Early Holocene oxbow lakes within the more than ten kilometres broad braided bed of Oued Dra.

Moreover, two areas were investigated, in which the Tamarix cones occur – one on the lowest terrace of Oued Dra, and the other in a oued bed being the tributary of Oued Dra.

4. Investigation methods

Length, height and width of each investigated nebkha, and the height and width of pertinent plant causing material accumulation were measured. Azimuth of the forms and direction and velocity of wind blowing during the measurements were noted as well. Among the measured forms there were distinguished such ones, which were of simple accumulation type and the others which morphology was related to the eroding activity of wind. Special attention was paid to the relation between the nebkhas and their substratum.

In the case of the Tamarix cones the measurements of their heights, base widths and slope inclinations were made for eighteen objects. Within the research pits the measurements of the structural features of the sediments were performed.

In the cases of the both investigated forms the granulometric analysis of the material building the forms and the basic granulation indices were calculated according to the formulae of Folk and Ward (1957).

5. Forms of the extorted aeolian accumulation in the Coude du Dra region

Nebkhas

Accumulation of the sediments in the field 1 developed around the *arfej* halophyte (*Rhantherium suaveolens*) (Dłużewski, Krzemień 2008 – Figure 2). This plant grows on compact, clayey soil with small polygons of drying of the surface of more than ten square centimetres (Dłużewski et al. 2003). Deflation forms of the shapes of "negative" nebkhas were found in this clayey substratum (Photo 5). It happened that two or three such pits were connected with one plant, indicating slightly different directions of wind. The present authors explain these forms by deflation caused by extremely strong winds. Within these pits the sandy nebkhas occur, however, of distinctly smaller size than the outline of the deflation forms. Sometimes the long axes of the accumulation and deflation forms were not coincident (Table 1a), what indicates the slightly different directions of winds, which had different forces.

During performing of the measurements in March 2001, the nebkhas in the field 1 were formed by NE wind. Azimuth of the long axis of the nebkhas ranged from 45 to 75^{o} (Tables 1a, 1b). These nebkhas are small with the average height ca. 15 cm, reaching the maximum value of 41 cm (Photo 5). They were accumulated behind the *arfej* halophytes of the height from 4 to 50 cm. It appears from the measurements that there is a high correlation between the heights of the plant and those of the nebkha.

Table 1a. Measurable features of the nebkhas, plant obstacles and concave forms, field 2 (Dłużewski, Krzemień 2008 – Figure 2)

Azimuth of the long axis [degree]	Nebkha length [m]	Nebkha width [m]	Nebkha height [m]	Plant obstacle height [m]	Plant obstacle width [m]	Nebkha width at its base [m]	Length of the concave form [m]	Width of the concave form [m]	Azimuth of the long axis of the concave form [degree]
54	2.02	1.00	0.32	0.36	0.95	0.69	1.96	0.75	352
58	2.94	1.00	0.34	0.48	0.95	0.80	1.45	0.68	351
58	1.70	0.56	0.16	0.30	0.56	0.56	1.08	0.40	342
61	2.56	1.00	0.21	0.39	0.83	0.86	1.71	0.80	4
65	2.23	0.85	0.24	0.48	0.75	0.77	1.90	0.53	352
63	3.30	1.60	0.41	0.55	1.31	1.20	2.50	1.11	355
54	2.24	1.30	0.28	0.34	1.06	1.07	2.17	1.21	0
58	2.55	1.30	0.27	0.42	0.9	0.96	1.91	0.90	351
58	2.35	1.20	0.21	0.50	0.75	0.77	1.90	0.80	355
58	2.11	1.40	0.26	0.40	0.71	0.80	1.83	0.80	358
60	2.32	1.25	0.21	0.61	0.73	0.94	1.74	0.70	342
63	1.60	0.77	0.25	0.33	0.70	0.61	1.61	0.61	354
54	1.38	0.60	0.33	0.36	0.50	0.50	1.30	1.01	357
62	2.44	1.10	0.29	0.39	0.83	0.96	1.88	0.70	352
55	1.72	0.71	0.19	0.50	0.54	0.63	1.57	0.84	352
55	1.58	0.76	0.23	0.28	0.62	.60	1.35	0.62	349
58	4.09	1.37	0.40	0.50	1.18	1.20	2.82	0.70	354
57	2.2	0.91	0.25	0.36	0.78	0.65	1.56	0.98	347
58	2.6	1.50	0.32	0.48	1.14	1.07	2.73	0.92	334
56	1.54	0.63	0.21	0.35	0.51	0.62	1.32	0.52	333

Source: Dłużewski et al. 2003.

The length of the studied forms did not exceed 4.0 m, with two dominant length classes: ca. 1.5 m and ca. 2.5 m. The length of the studied forms was influenced both by the height and by the width of the plant obstacle. For the studied forms the height--to-width ratio varied from 1:4 to 1:28 (average 1:15). Similar results were obtained in the case of the nebkhas occurring in the central Tunisia in the margins of Chott El Jerid (Dłużewski et al. 2004). The width of the studied forms in the considered Coude du Dra region (dominating 0.7 to 0.1 m; maximal 1.60 m) indicates a very high dependence on the width of the plant obstacle (Dłużewski et al. 2003).

Nebkhas are built from the material characterised by a distinct similarity to the material of the dunes occurring in the western part of the investigated area. They are loose medium- and fine-grained sands with average grain diameter (M_z) equal 2.88 Φ, moderately

Table 1b. Measurable features of the nebkhas and plant obstacles field 1 (Dłużewski, Krzemień 2008 – Figure 2)

Azimuth of the long axis [degree]	Nebkha length [m]	Nebkha width [m]	Nebkha height [m]	Plant obstacle height [m]	Plant obstacle width [m]	Inclination of the NW slope [degree]	Inclination of the SE slope [degree]
54	3.05	0.92	0.14	0.40	0.60	-	-
54	1.52	0.32	0.06	0.14	0.30	-	-
61	2.00	0.75	0.15	0.25	0.61	19	27
58	1.00	0.28	0.04	0.15	0.28	27	16
61	2.47	1.16	0.25	0.40	0.90	27	17
67	2.00	1.00	0.20	0.25	0.85	18	29
54	1.75	0.83	0.20	0.28	0.75	27	27
58	2.00	0.65	0.15	0.32	0.60	10	14
58	1.80	0.70	0.14	0.38	0.55	10	27
57	1.55	0.62	0.08	0.28	0.55	16	16
57	1.35	0.63	0.10	0.15	0.55	14	19
54	1.62	0.70	0.15	0.24	0.65	34	30
55	1.42	0.45	0.13	0.23	0.52	28	29
49	1.44	0.62	0.08	0.25	0.55	10	18
54	1.44	0.50	0.10	0.18	0.42	6	16
55	1.90	1.02	0.15	0.19	0.67	10	16
57	2.12	0.88	0.22	0.43	0.75	24	28
57	1.60	0.85	0.17	0.24	0.50	10	22
63	2.84	0.87	0.15	0.27	0.83	24	23
75	2.85	1.50	0.29	0.50	1.05	19	16
59	2.25	1.08	0.22	0.36	0.95	12	27
67	2.62	1.22	0.18	0.33	1.02	16	20
58	1.97	0.86	0.17	0.35	0.68	18	26
54	2.44	1.14	0.14	0.33	0.80	10	20
57	2.60	1.40	0.32	0.42	1.11	8	19
45	2.10	1.07	0.14	0.32	0.80	7	18
61	2.35	1.20	0.14	0.34	0.72	9	18
61	0.68	0.92	0.15	0.23	0.70	18	27
61	2.00	0.60	0.11	0.28	0.54	14	21
54	1.71	0.68	0.15	0.30	0.75	10	18
63	1.69	0.49	0.10	0.30	0.36	27	21
62	1.29	0.46	0.95	0.20	0.32	35	24
64	1.20	0.53	0.09	0.27	0.35	15	18
54	1.40	0.56	0.12	0.22	0.70	3	16

Source: Dłużewski et al. 2003.

or well-sorted (σ_1 from 0.40 to 0.51) and uniform grain distribution (Sk_1 from -0.01 to 0.05). Similar values for the sediments forming nebkhas are given by Tengberg (1994). The transport of the material was mainly by means of saltation, as is indicated by the cumulative granulation curves (Dłużewski et al. 2003).

Measurements of the slope inclination of the nebkhas yielded slight asymmetry of the studied forms. Slopes exposed to NW have generally lower inclination than those exposed to SE. The differences reach even 10° and are probably connected with erosion of the SE slope and accumulation on the NW slope, caused by the south-eastern wind perpendicular to the long axis of the nebkha. However, the wind force was low enough to prevent the former orientation of the nebkha without any change. In the place where the thickness of the wind is lowest the bending of the nebkha according to the direction of the wind was observed. However, in the central part of the nebkha and directly behind the plant, where the sand thickness is highest, the form was deflated and the slope inclination increased. Kosmowska-Suffczyńska (1980) found similar slope asymmetry in the Palmyra valley of the Syrian Desert and she linked it to the aeolian erosion as well. Nebkha slopes asymmetry was also observed in the gypsum crust fixed nebkhas in Chott El Jerid in Tunisia (Dłużewski et al. 2004). In the latter case it is, however, the result of accumulation on the windward slope during blowing of wind perpendicular to the nebkha long axis i.e. it comes from the decrease of the slope inclination angle by widening of the nebkha on the windward side.

The substratum of the nebkhas in the field 2 (Dłużewski, Krzemień 2008 – Figure 2), is built from poorly cemented sandy-dusty sediments. On such soil the grassy vegetation of the *drinn* plants (*Aristida pungens)* developed, behind which the sandy sediments accumulated. During the studies quick changes of the nebkhas morphology were observed. During a five-hour-lasting sand storm when the NE wind velocity reached 14 $m \cdot s^{-1}$, the morphologically uniform nebkhas altered to the new ones with deflation depression directly behind the plant (Photo 6). This resulted from a specific wind flow with whirls behind the obstacle caused by strong wind (Tsoar, Yaalon 1983, Tsoar et al. 1985, Walker, Nickling 2002). The depth of these deflation pans ranged from 3 to 8 cm, their length – from 0.59 to 2.15 m. (Table 2). The length of the pans has distinct connection with the length of the parent nebkhas, but it poorly depends on the plant height and width. One may conclude that the origin and dimensions of the deflation pans result mainly from the dynamics and velocity of wind. The studies performed till present indicated that the material transport starts when the wind has speed from 4 to 6 $m \cdot s^{-1}$ (Bagnold 1941, Zhu et al. 1986, Wang et al. 2002).Thus one may conclude that the sand storm had essential influence on the morphometry of the studied forms.

The studied nebkhas, like the previously described ones, belong to the low forms with the height of 16 to 45 cm; however, they are very long – from 1.90 to 5.50 m (Table 2). The average height-to-length ratio is 1:16. They were generally accumulated behind larger plant obstacles (height from 21 to 78 cm, width from 51 to 187 cm) than those described above. It seems that in the case of the analysed forms the larger length of the nebkhas id connected with significant width of the plant, which caused accumulation (Dłużewski et al. 2003).

Table 2. Measurable features of the nebkhas and plant obstacles, field 2 (Dłużewski, Krzemień 2008 – Figure 2)

Azimuth of the long axis [degree]	Nebkha length [m]	Nebkha width [m]	Nebkha height [m]	Plant obstacle height [m]	Plant obstacle width [m]	Length of the deflation pan [m]	Width of the deflation pan [m]	Depth of the deflation pan [m]
36	4.47	1.18	0.27	0.21	0.51	1.49	0.68	0.06
39	5.50	1.69	0.40	0.58	0.79	2.15	1.04	0.03
38	4.98	1.08	0.29	0.33	0.66	1.77	0.48	0.04
32	1.90	0.66	0.16	0.30	0.67	0.59	0.32	0.03
33	3.30	1.50	0.20	0.40	1.49	1.43	0.84	0.04
39	3.15	1.20	0.19	0.59	1.41	1.30	0.74	0.05
36	5.40	1.65	0.26	0.54	1.31	1.83	0.75	0.08
35	3.02	1.08	0.30	0.49	1.16	0.98	0.46	0.03
37	4.38	1.98	0.45	0.64	1.65	1.25	1.07	0.06
38	5.30	1.82	0.38	0.78	1.87	1.20	0.75	0.03

Source: Dłużewski et al. 2003.

Nebkhas occurring in this part of the Coude du Dra region are built from slightly coarser material (M_z = 2.49 Φ) with better sorting (σ_1 = 0.37) and with insignificant prevalence of the finer fraction amount with respect to the fraction of maximum frequency (Sk_1 = 0.18), than the forms of this type in the field 1.

Tamarix cones

Studies of the Tamarix cones occurring in the Coude du Dra region indicated that the rate of their expansion depends on the parent plant growth. The smallest investigated cone was grown by a little shrub, whereas on the large forms the Tamarix plants reached sizes of big shrubs or trees. The maximum height of the cones in the studied region rarely exceeded 5 m (Radwańska 2003).

The Tamarix cones occurring in the area under the present study have quite uniform structure and texture of their sediments. In most cones in their apical parts (to 30-40 cm) and in the subsurface strata (to 20-30 cm) an appreciable content of the organic remnants (needles and little branches of Tamarix) was noted (Photo 7). Deeper the mineral sediment with lamination coincident in shape with the cone habit (Photo 8), locally with fragments of the diagonal lamination. The Tamarix cones are built most frequently from slightly finer material (0.125-0.063 mm, 3-4 Φ) than the dune forms occurring in the same area (2.5 Φ). Moreover, the medium- to fine-grained sandy material forming the Tamarix cones bears from several to more than 10% of coarse dust. The material building the cones is poorer sorted (σ_1 from 0.42 to 0.64) than that of the neighbouring dunes (σ_1 from 0.39 to 0.42, as published by Radwańska 2003).

The cumulative curves indicate that the material forming the Tamarix cones was transported mainly by saltation, with a distinct increase of the suspension transport in the subsurface layers (Radwańska 2003). The descriptions of the sand-dusty storms in the region of the Lake Chad area evidenced that sand (1-2 Φ) is transported exclusively close to the ground surface by saltation, but the finer fraction (3-4 Φ) may be transported in suspension, though also in the near-surface space and for the distance not exceeding 100 km (Evans et al. 2004). The shown difference in the mode of the transport of the sandy fraction 3-4 Φ between the two areas apparently indicates lower dynamics of wind in the Coude du Dra region than in the Lake Chad area, and simultaneously the greater participation of the near-ground transport in the first region.

Studies of the texture and structure of the sediments evidenced that the mineral sediments building the Tamarix cones are accumulated during the low sand-dusty storms, especially in their final periods when the finest mineral grains fall down. Sometimes the final dust accumulation occurs during rain. The authors observed effects of such process on the Tamarix cones on the sea shore of the Mayo Island in the Cap Verde Archipelago. The seasonal rains occurring there cause formation of the erosion furrows on the surface of the Tamarix cones, and in the inner structure – sediment fluction disturbances or diagonal lamination between the parallel one coincident with the cone shape. The activity of the rainfall in the final period of the sand-dusty storms in formation of the sediments may be indirectly evidenced by absence of lamination in the Tamarix cones in the central Sahara, the region of the Kharga oasis in Egypt. In that area the average annual precipitation does not exceed 1 mm.

The performed studies of the measurable features of the Tamarix cones evidenced, that the dimensions of the cone are directly proportional to the height and spread of the plant. The smallest observed cone had the height of ca. 40 cm with the Tamarix shrub 80 cm high, and this cone was found in an old watering channel abandoned since several years. As it was stated earlier, the plants of the genus Tamarix influence directly the development of the cones by accumulation of the organic matter in the cone body, strengthening of the cone by the root system and by stimulation of the mineral material accumulation from the sand-dusty mass transported during the desert storms. The peculiar feature of these plants, namely the ability to grow up after they are largely sand-covered explains why they do not extinct after covering the accumulated sediment.

5. Conclusions

On the basis of the performed studies of the extorted aeolian accumulation forms one may conclude that such forms occurring in the Coude du Dra area are very differentiated, though the both considered types developed in the similar conditions of the natural environment. These differences manifest in different origin and measurable features. First, it is connected with the type of the plant obstacle and with the kind and humidity of the substratum, wind force and variability of its direction and textural features of the accumulating material.

The nebkhas, which are not fixed e.g. by the gypsum crust, are the least stable forms from all the bodies developing due to aeolian accumulation. The change of wind direction lasting few hours is sufficient to cause complete change of the nebkha location. This results from small height of these forms and absence of any protection against deflation in the case of the wind direction change. Tamarix cones are distinctly more stable. Organic matter and salt forming crusts inside the cone yield better compactness of the material, making the aeolian erosion more difficult.

On the basis of the studies performed in the years 2005-2006, i.e. five years after the previous detailed measurements, one found significant degradation of the forms of the extorted aeolian accumulation. The nebkhas fields occurring in the terrain depressions in the Coude du Dra area disappeared due to complete degradation of the vegetation, which originally extorted the material accumulation. The forms from the marginal parts of the Lake Iriqui area were completely or in part degraded as well, because most of the plants in this region extinct. The Tamarix cones were degraded significantly as well due to partial necrosis of the Tamarix branches causing next easier deflation.

Distinct lowering of the ground water table is the cause of so rapid degradation of the investigated forms. The current depth of the water table is always greater than 3-4 m beside the main bed of Oued Dra, thus resulting in degradation of the plants of the species both *arfej* and *drinn*, whose root system may take water from the depth not exceeding 2 m. Although these plants may survive without water even two or three years, recently they could use only rain water which in the hot arid climate of that area appears very irregularly and for short time only. The plants of the genus Tamarix may take water from the depth up to 20 m, but they need much more water than it is currently available. The studies showed that the water table in the region of occurrence of the Tamarix cones lowered distinctly and during the major part of the year is at the depth of 10 m and lower (Sobczak 2006). That is why the so-called first root system of the Tamarix plants, normally active at the depth of ca. 2 m, presently does not work. This results in decrease of water supply to the plants and thus in distinct slowing of their growth or even their partial degradation. The decreasing water supply in the Coude du Dra region causes continuous increase of the water and soil salinity, what is another factor limiting the development of the Tamarix vegetation.

The current studies confirmed the influence of the functioning of the extorted accumulation forms on the process of the dune field's expansion in the Coude du Dra area. Degradation of these forms, especially in the case of the nebkhas, resulted in absence of the aeolian material accumulation and its free migration. In the area where in 2001 the nebkhas measurements were made, in 2005 one found formation of new dunes, which were already the part of the expanding dune field. Moreover, in the area of the tributary beds of Oued Dra, where formerly the measurements of the Tamarix cones were performed, a dynamic development of single forms of the free accumulation i.e. barchans was observed.

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