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# The dune systems of the Konya Plain (Turkey): their relation to environmental changes in Central Anatolia during the Late Pleistocene and Holocene

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**Abstract**

Several sand flats located on the northern shores of the Late Pleistocene palaeolake of the Konya plain (inner Anatolia, Turkey), are related to changes in lake levels. In this paper, the two main dune systems are mapped according to their geomorphological, sedimentological and dynamic characteristics, and their significance is discussed with regard to the environmental changes since the Late Pleistocene, both at time of the former lake and during the drier periods of the Holocene. Cross-sections show the relationship of the dunes to the topography of the basement. Analyses of the sand fraction show distinct characteristics in size distribution, quartz and shell contents, wind erosion effects on the quartz grains and petrographic composition. Interpretation of the results, coupled with information provided by the geomorphology of the dune systems studied in the field and from aerial photographs and satellite images, highlights the importance and variations in time of local factors such as prevailing winds, sand sources, changes in lake levels and vegetation. A chronology of the main sand fields is proposed, based on the evidence of three main droughts during the Upper Pleistocene. The older one, much eroded (maximum height = 3 m), covers a limestone surface at +50 m above the bottom of the dried lake. An Optical Scanning Luminescence (OSL) date shows a last period of accumulation at 14,328 ± 3220 years. The younger one (maximum height = 12 m) has moved over the emerged Late Pleistocene lacustrine marls. An OSL date gives an age of 5674 ± 988 years for the last accumulation period. Evidence of very recent activation of this younger dune system is apparent as a result of overgrazing and excessive land reclamation. A third period of dominant wind action and dune construction is responsible for the installation of a younger and thin dune field over the Mid-Holocene lacustrine deposits of the Karapinar lake. The success of the stabilization programme of the dunes over the last 30 years shows that the last period of dune movement is not related to climate change but to overpressure on the land due to the needs and activities of an increasing population. © 1998 Elsevier Science B.V. All rights reserved.

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## 1. Introduction

During the Pleistocene and the Holocene, several periods of sand mobilization have been recognized in present day arid and semi-arid areas, and linked to aridification trends (Rognon, 1994). In the present semi-arid climate of the high plateaus of inner Anatolia, some fossil sand dunes related to the lakes occupying the central parts of numerous closed depressions, can be used to study the chronology of Upper Pleistocene and Holocene climate changes in the region (Erinç, 1962; Erol, 1991; Kuzucuoglu, 1993). The strong relationships between the lacustrine systems and the dune fields permit a more comprehensive approach to this chronology. In addition, in the 1960s the moving sand dune system which was threatening the town of Karapinar, situated on the northern border of the Konya plain (Dogan, 1992; Dogan and Kuzucuoglu, 1993) in central Anatolia, was stabilized by planting and by controlling grazing. This programme, started in 1962, has proved a success. One of the questions thus raised is whether the motion of these sands has been determined by a change in the climatic conditions of the area or by the destruction of the vegetation cover by overgrazing and disturbance.

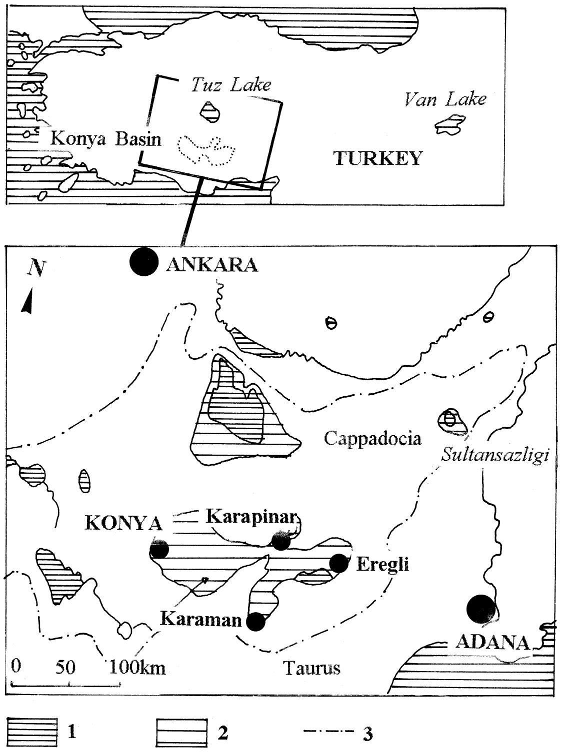



Fig. 1. Location of study area. Legend: *1*. Lakes; *2*. Upper Pleistocene extension of Lakes; *3*. Limits of Anatolian endorheism.

## 2. Setting

The Konya plain is, after the plain of the Salt Lake (Tuz gölü), the largest lacustrine depression of the high plateaus of inner Anatolia (Fig. 1). Its flat bottom has an altitude of 1000 m. Bordered to the south by the Taurus range and surrounded by limestones of either Paleozoic or Neogene ages (Lahn, 1948), the basin contains landscapes dominated by both tectonic and karstic evolution.

Volcanoes of Mio–Pliocene to Late Pleistocene ages are spread along a Southwest/Northeast line in the central part of the plain. These features accompany a topographically higher structure which separates the plain into four cross-shaped sub-basins, the largest being the Konya plain to the west and the Akgöl–Eregli plain to the east. To the south the Karaman sub-basin, and to the north the Karapinar sub-basin, represent smaller lacustrine units (Fig. 2).

During the Late Pleistocene, the 4500 $km^2$ Konya plain was occupied by a 20 m deep sweet-water lake. *Dreissena polymorpha* shells from the sand and gravel beaches of this palaeolake have been dated to 21,000–17,000 BP (Roberts et al., 1979). There are also beach and dune remnants of older lacustrine episodes, preserved on the northern border of the basin (de Meester, 1970; Erol, 1991; Kuzucuoglu, 1993), as yet undated. Younger beach and lacustrine sediments as well as palaeosols show that more recent episodes of lake level variations occurred independently in the four sub-basins temporarily occupied by shallow lakes, marshes or playas during the Holocene (Roberts, 1980, 1982, 1983; Kuzucuoglu et al., 1997).

Past climates are not only responsible for the appearance and disappearance of lakes in the basin, but also for the construction, erosion and displacement of sand dunes closely related to the lacustrine

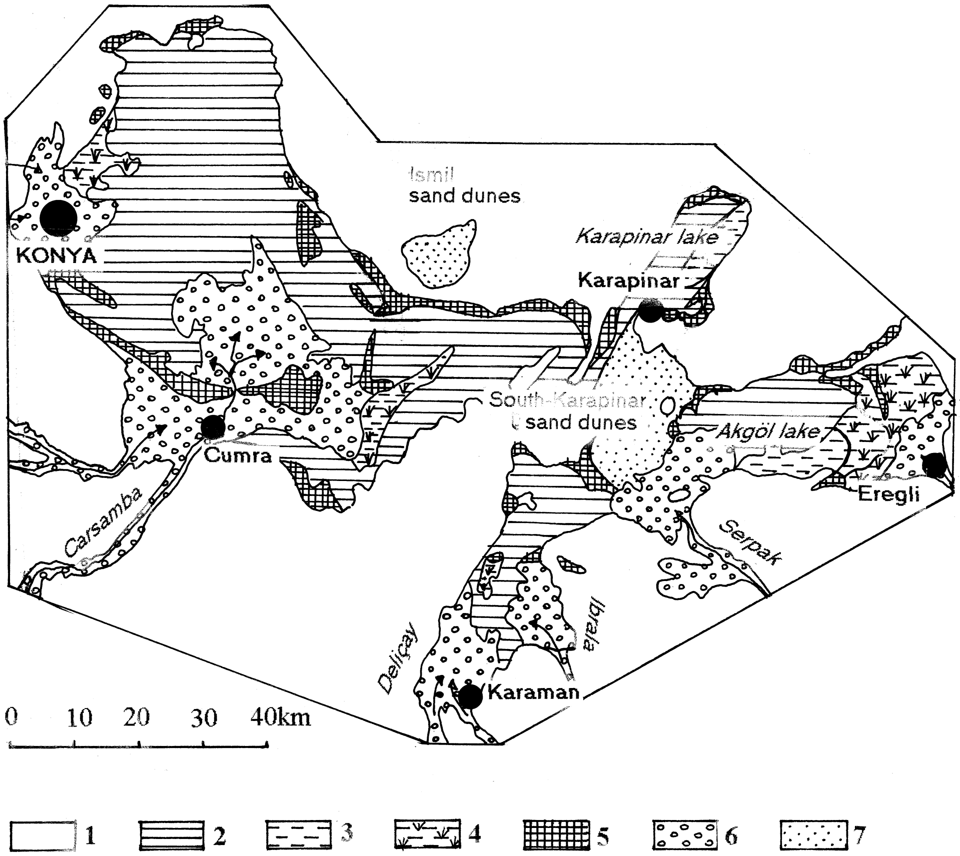



Fig. 2. Main formations of the Konya Plain (after de Meester, 1970 and Roberts, 1983). Legend: *1*. Pre-Quaternary limestones and volcanics; *2*. Limits of the Konya palaeolake; *3*. Pleistocene, lacustrine marls; *4*. Sand and gravel shore deposits; *5*. Alluvial fans; *6*. Dune systems; *7*. Sebkha; *8*. Marshes; *9*. Lakes.

environments. These dunes may be considered fossil when interpreted in view of the Pleistocene and Holocene climatic evolution of the area, or active when considered in the light of the stabilization actions necessitated recently by the invasion of sand within the town of Karapinar.

### *2.1. The present day environment of the Konya plain and Karapinar surroundings*

#### *2.1.1. Hydrology*

The Konya basin as a whole has no surface link to any seaward exit. However, a sink hole in its southern edge directs lake overflow into the Taurus underground network towards the Mediterranean. Other sink holes in the southern and northern parts of the Konya plain, such as Timsa near Cumra, Akçukuru near Ismil, and the depressions in the surface of the northern plateaus (Obruk platosu) are linked to a northwards underground water flow to the basin of the Tuz gölü (Erol, 1991).

Five wetlands still occupy the lowest parts of the four sub-basins of the Konya plain. Three of these wetlands have recently dried but two still exist; the Karapinar playa and the Akgöl lake and marshes. The Karapinar playa is a sebkha-type feature, covered by a salt mantle during summer; the Akgöl lake is a sweet-water lake hosting many bird species.

#### *2.1.2. Climate*

The climate of the Konya plain, and more specifically of the Karapinar area, is semi-arid. Annual mean temperature is 11°C with monthly mean temperature reaching 23°C in July and −2°C in winter. Day temperatures reach 30 to 35°C in summer while winter night temperatures are usually lower than −5°C with extremes below −20°C. The total annual average evaporation is 1189 mm from a free water surface (at the Konya Köy Hizmetleri Research Station).

Precipitation shows a mean annual value of 289 mm/yr at the Karapinar Köy Hizmetleri Research Station with high interannual variability. Forty-five percent of the precipitation falls from December to March and 72% from December to May, sufficient for dry farming cultivation whose success is dependent on the interannual variability and annual distribution of rainfall. This is why, until irrigation techniques were recently introduced and developed, sheep husbandry associated with seasonal nomadism was the main local activity. Summers are very dry, averaging 2 mm per month from the end of June to the end of October.

### *2.1.3. Vegetation cover*

Vegetation is steppic on the plain (with *Artemisia* dominant). Mountain slopes are usually bare, except for the northern slopes of the volcanic Karacadag and Karadag mountains where *Juniperus*, deciduous oak trees and wild almond trees can still be found. Other slopes in the limestone plateaus would probably have been covered by open-forests, as shown by some localised relics, such as at Aktepe north of Karapinar, which have been protected from felling for fuel and construction purposes.

### *2.1.4. Land use*

Prior to 1975, the main activity was sheep grazing by semi-nomadic groups. Summer villages were occupied by enlarged families living otherwise in towns (i.e., Konya, Ismil, Karapinar, Karaman, Eregli) during winter. Until the end of the 1950s, animal husbandry included goats, camels and horses, and long distance migrations from the southern slopes of the Taurus mountains led numerous sheep flocks to graze the inner plateaus of Anatolia (de Planhol, 1958). Today, animal husbandry is declining on the plain (not yet on the plateaus). On the plain, ancient pastures and marshes have been used for dry farming extension. Irrigation is expanding on the soils of the plain for cultivation of cereals and sugar beets. Some pastures not suitable for cultivation (volcanic ashes) show signs of vegetation recovering during wetter summers such as in 1989 and 1992.

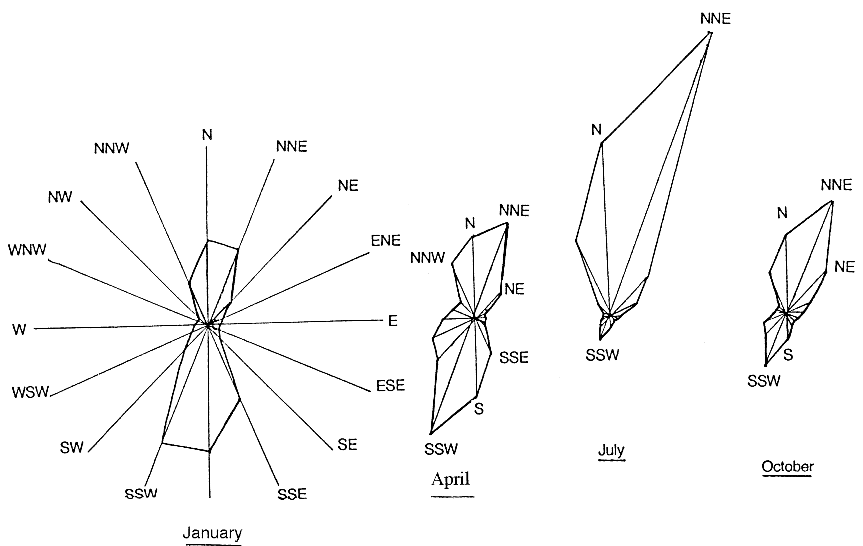



Fig. 3. Wind roses at Karapinar.

### 2.2. The sand dune systems

#### 2.2.1. Winds

In the Karapinar area, winds blow more often from the north–northeast in summer and autumn (Fig. 3). During winter and spring, winds from the SSW are dominant in frequency and in velocity, their speed sometimes reaching 100 to 120 km/h (20 to 25 m/s). Sand storms, which can be violent, therefore occur primarily from January to March.

#### 2.2.2. Sand sources

The main sand sources are the alluvial fans developed on the southern borders of the plain with, from West to East, the river Çarsamba (forming the Çumra cone Southwest of Ismil), the rivers Karaman, Deliçay, Ibrala and Serpak (forming three cones situated Southwest and South of the Karapinar sand dunes) (Fig. 2). Both the alluvial fans and the lacustrine sediments on beaches and on the floor of the lake provided the sand transported by the strongest winds blowing from SSW, depositing the sand against the topographic obstacles to the North.

#### 2.2.3. The sand dune systems (Fig. 4)

Aeolian depositional landforms can be seen on the northern edges of the Konya basin, from Ismil (midway between Konya to Karapinar) to Akören (midway between Karapinar to Eregli). This location is due to the interception of winds from the SSW by upstanding relief, causing sand deposition on the rising slopes.

During the Upper Pleistocene, sand erosion and accumulation occurred during at least two periods,

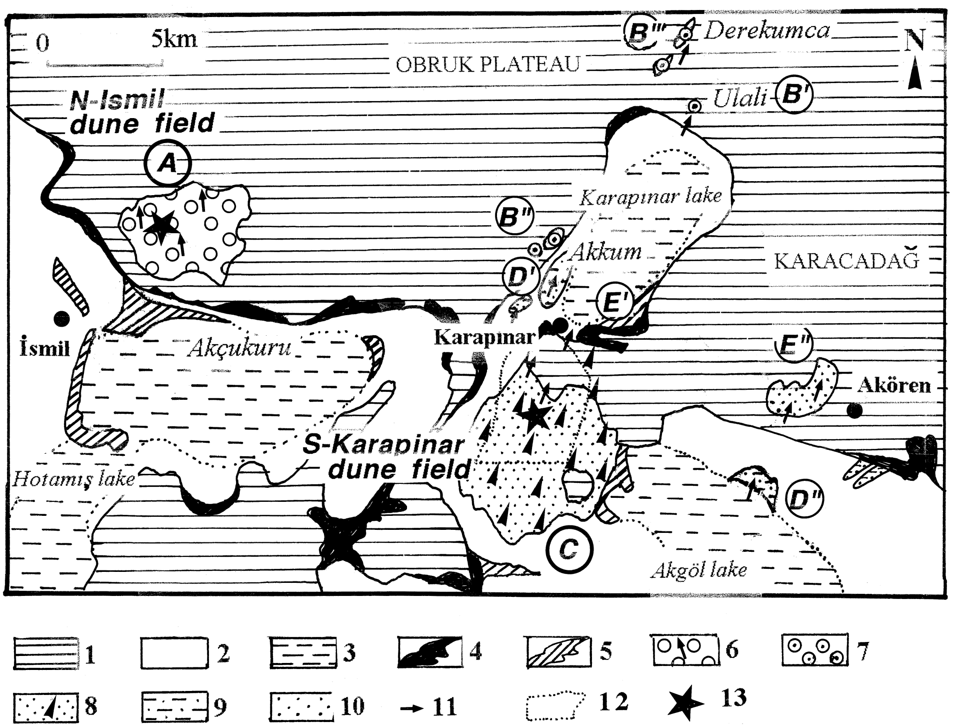



Fig. 4. The sand dune fields on the northern shores of the Konya Plain. Legend: *1*. Anatolian plateaux and highlands (limestone and volcanic rocks); *2*. Upper Pleistocene lacustrine marls; *3*. Holocene extension of lakes; *4*. Upper Pleistocene sand beaches; *5*. Holocene sand beaches; *6*. North-Ismil dune system (*A*); *7*. Old sand dunes west of Karapinar lake (*B*); *8*. South-Karapinar dune system (*C*); *9*. Dunes related to the Holocene lakes (*D*); *10*. Moving dunes (*E*); *11*. Main direction of winds as shown by the dune orientation; *12*. Protected area; *13*. Location of OSL dated sample.

resulting in two parabolic dune systems. These systems cover flat areas, corresponding to two different levels; the older 'North-Ismil dune system', at 1030–1050 m in altitude, covers an erosional surface of the Neogene limestone plateaus; and the younger 'South-Karapinar dune system', at 995–1010 m in altitude, covering the marly bottom surface of the dried Upper Pleistocene lake. The flat surfaces buried by the dune systems correspond to two different levels of the bottom of the Konya palaeolake. Both dune systems were formed during the dry periods which were contemporaneous to or post-dated the shrinking lake.

Other aeolian landforms are also related to the Konya basin and sub-basin lacustrine systems (Fig. 4). Several small, thin aeolian sand sheets can be observed on the western (Büyükkarakuyu) and northern (Ulali, Derekumca) edges of the Karapinar playa, at altitudes of +25 and +50 m above the bottom of the lake. Elsewhere, weathered aeolian deposits cover the marls of the Akgöl sub-basin, and small dunes cover the dried lake bottom to the northwest (Akkum) and northeast of Karapinar town. Aeolian sand is presently being transported and is accumulating at the foot of the volcanic highlands on the northern edge of the Akgöl depression (Akören).

## 3. Methods of study

The study of these dune systems has been based on various methods and techniques. Field reconnaissance has allowed measurement of the heights of the dunes at different places within each dune field, and topographical and geological cross-sections drawn in the field were used to determine the limits and

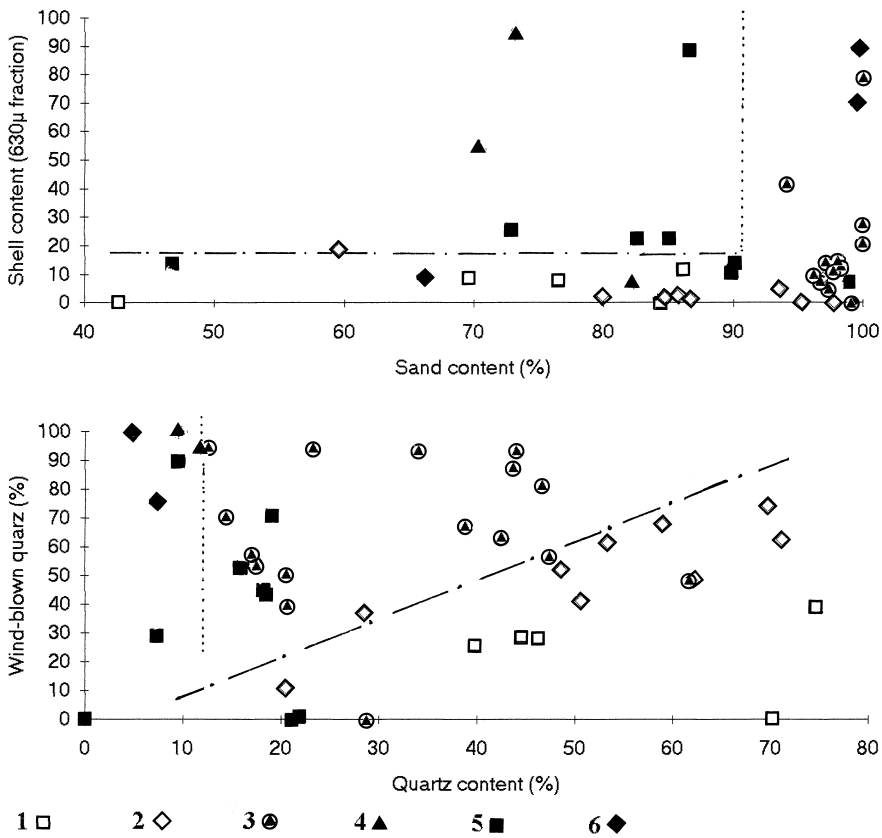



Fig. 5. Sand, shell and wind-blown quartz content of the sand according to the dune field. Legend: North Ismil dunes: *1*. Dune; *2*. Very thin dune cover in the southern part; South-Karapinar dunes: *3*. Dune; *4*. Low dunes from the south-eastern part; Other dunes: *5*. Akgöl; *6*. North-Karapinar.

characteristics of the sand sheets together with the past and present dynamics of the dunes (Fig. 4). Samples from aeolian formations were collected and analysed for grain size distribution, petrographic content, shell content and quartz grain shape.

The field study was complemented by the interpretation of aerial photographs (1960) and satellite imagery (SPOT-XS, 1987) which were partly verified in the field. Finally, sampling for luminescence dating was performed at two sites: one (KP1) 1.70 m deep, in a 12 m high dune, at the foot of the basaltic flow south of Karapinar; the second one (KP2), 1.10 m deep, in a 2 m high eroded dune in the central part of the North-Ismil dune field.

OSL dates were made on the quartz fraction (mean 125 $\mu$m) using green-light stimulation and the additive dose method. The total annual dose, calculated from ppm U and Th and $\%K_20$ and cosmic dose, was 2.6 mGy/yr for KP1 (water content 1.5%) and 3.2 mGy/yr for KP2 (water content 2.5%).

## 4. Characteristics of the sand from the largest dune systems

The sand stocks belonging to the two main dune fields are well differentiated by means of grain analyses (Fig. 5).

### *4.1. The older Ismil sand dunes (A on Fig. 4)*

The grain size distribution curves show a smaller percentage of sand-size fraction in the total sample than in the youngest dune field. The sand fraction is also more poorly sorted than that of the younger dunes. Some sand has been lost by wind exportation northwards, and weathering has transformed the mineral and limestone elements into silt and clay. The coarser alluvial-material lying underneath also influences the results of the analyses when the dune cover is very thin. Other signs of old age are the relative scarcity of shells ($<$ 12%, present only in the finer fractions) and the relative enrichment in quartz (between 10 and 42% of the 630 $\mu$ sand fraction; up to 75% in the 315 $\mu$ fraction).

The presence of shells indicates a lacustrine source for some of the sand. Other sources are nearby beaches and alluvial fans on the northern slopes (a 90 cm thick alluvial deposit is partly covered by the dune sheet), as well as some Neogene sandy material from the bedrock, among which is a 1 m thick volcanic tephra very rich in genuine glass grains. These translucent and tear-shaped glass grains are typical of the sand of the Ismil sheet. The dominance of these local sources is shown by the relatively small proportion of rounded or smoothed grains (15 to 35% in the 630 $\mu$ fraction and 40 to 70% in the 315 $\mu$ fraction).

### *4.2. The younger South-Karapinar sand dunes (C on Fig. 4)*

The sediment comprising these dunes is better sorted and of a different composition to those in the North-Ismil area. The coarser fraction is richer in shells (10–30% and up to 80% in the 630 $\mu$ fraction) but poorer in quartz ($<$ 20%), in contrast to the finer 315 $\mu$ fraction where shells represent only 2 to 20 and 35% of the sand elements, but with a higher quartz content ($<$ 60%). The grains are mainly wind-blown (20 to 100% of all quartz grains are smoothed or rounded). Angular quartz grains are present in the 315 $\mu$ fraction ($<$ 25%), but there are no genuine glass grains such as those found in the Ismil sand dunes. Other elements are carbonate grains, volcanic minerals (feldspars, pyroxenes, olivines, amphiboles), tuffs and scoriae, and rounded rock fragments from the southern alluvial fans.

These results show that the South-Karapinar sand is mainly of lacustrine origin (the nearby beaches have provided shells and angular quartz) enriched with local input from the volcanic area (mainly the Karapinar basaltic scoria cones, falls and laval flows). Input of elements eroded from the Taurus mountains have been either blown up from the southern alluvial fans (the Karaman and Eregli rivers) or transported and preferentially deposited on the high margins of the lake by lacustrine currents and waves loaded with river sediment discharged on the southern edges of the palaeolake.

### *4.3. The North-Karapinar dunes*

There are two main locations of isolated and low sand dune sheets North of Karapinar. Each corresponds to different periods of wind action.

The first is North and West of the catchment basin of the playa. Patches of thin aeolian deposits occur at two main altitudes above the playa floor: +50 m (Ulali; B′ on Fig. 4) and +25 m (Derekumca, Büyükkarakuyu; B‴ on Fig. 4). The shell-poor sand fraction is composed mainly of carbonatic and volcanic rocks from nearby, with a very low quartz content (5 to 10%). When present, the quartz grains always show signs of wind abrasion (rounded shape, smoothed surface). They have been probably reblown from the South-Karapinar sand stock. This sand cover is generally thinner than that of the South-Karapinar system.

Other, younger, aeolian sand dunes, mainly composed of small elongated, whaleback-shaped dunes are spread all over the south-western (Akkum; D′ on Fig. 4) and south-eastern parts (E′ on Fig. 4) of the Holocene bottom floor of the playa. These dunes, covered by steppic vegetation, are sometimes reactivated and may move northwards during winter sand storms. Their sand content is very similar to that of the older dunes, but richer in shells and better sorted.

### 4.4. The North-Akgöl dunes

There are three different dune outcrops and settings. The first is interstratified within the sand-beach deposits and corresponds to a short-term wind deposit. It shows that dunes were being constructed at the same time as beaches and pits.

The second dune set (D″ on Fig. 4) covers the Upper Pleistocene marls within the Akgöl depression. These sand deposits have been much eroded, so that their surface is flat. Deflation is now deepening large blowouts in the area, exposing sections showing the dune sand overlain by a brownish palaeosol, indicating environmental changes.

Today, wind action creates both smaller transitory aeolian sand deposits on the bottom of the hollowed lacustrine sediments, and sand accumulation climbing on the slopes of the Karacadag mountains near Akören (No. E″ on Fig. 4).

All this stock of sand is shell-poor (0 to 15%) except in the smaller sizes (up to 35%), quartz-poor (< 10–15%), most of which is angular suggesting the source is the nearby alluvial deposits in the lacustrine system.

## 5. Morphology and dynamics

### 5.1. The old ‘Ismil’ dune system (Fig. 6)

North of the Ismil village, the old eroded sand sheet covers the surface of a wide plateau at an altitude of between 30 m and 50 m above the Konya plain. The dunes are rarely thicker than 2 m and most of them are of the parabolic-type. In spite of sheep grazing in summer (from May to end of July), the steppic vegetation cover is relatively dense, except in some areas where present-day wind deflation is opening shallow blowouts in the sand. The western and southern edges of the plateau end with an abrupt scarp some 25 to 30 m high. The straight lines followed by these scarps indicate the probable presence of fault lines along which the lacustrine basin is sinking. The foot of these scarps is partly covered by the Merdivenli sand beaches belonging to the 21,000–17,000 BP dated lake-level; their altitude, relative to the bottom of the lake, is 12 to 20 m.

The chronological position of the Ismil dune sand system is not clear; either it has been nourished by the sand from the Merdivenli beaches during and/or after the full-lake stage or predates this. In fact, high beaches have been identified at an altitude of +50 m on the plateaus east of the Ismil dunes. Radiocarbon dating of shells from these high beaches gave ages 28,000 BP and ≥ 34,000 BP (GIF/LSM 10078; 10079; 10273), indicating an age out of the range of the $^{14}C$ method.

The differences between the mineralogic and lithic compositions of the dune and beach sands (the dune is richer in quartz and poorer in shells; see Fig. 5) do not give any clue to the chronological position of either formation. These differences can be explained either by different processes operating in the construction of these deposits, or by the erosion or selective weathering of the dunes after their construction.

Analysis of SPOT-XS satellite imagery (3 August 1987) permits identification of several areas on the plateau according to degree of wind erosion, transport and accumulation (Fig. 6). External areas to the east are the most deflated ones; westwards there is a roughly square-shaped sand sheet with a first strip of very thin deflated sand cover and a second strip corresponding to a thicker sand sheet where dunes

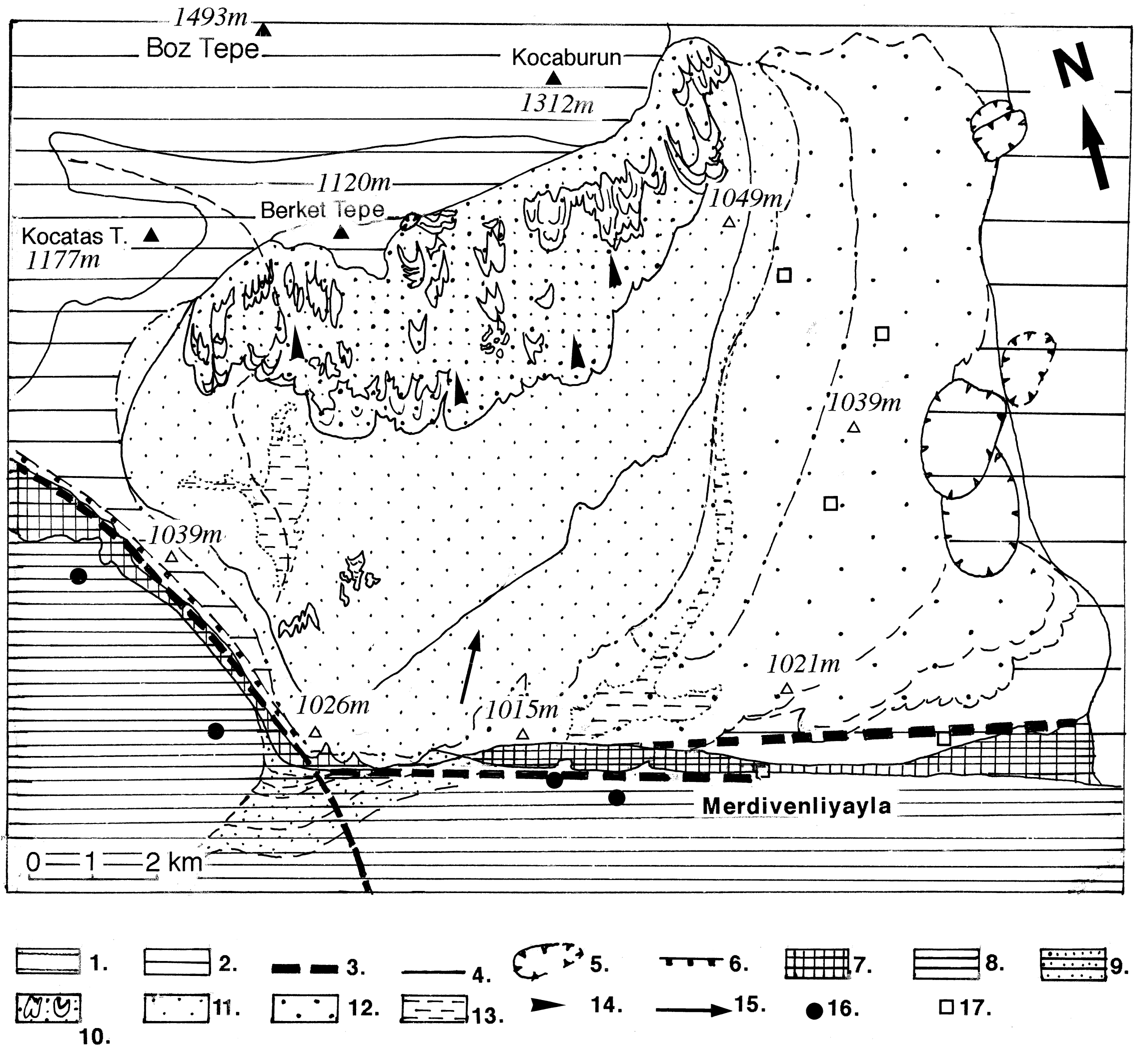



Fig. 6. The old Pleistocene sand dune system north of Ismil in its morphological context (mapping partly based on Spot 1, 110-274/1, copyright CNES and Spot-Image, 1987). Legend: *1*. Paleozoic limestone highlands; *2*. Neogene limestone plateaux; *3*. Major fault line; *4*. Minor structural contacts; *5*. Karstic depressions more or less expressed in the topography; *6*. Subsidence-related scarp; *7*. Upper Pleistocene beaches; *8*. Upper Pleistocene lacustrine marls; *9*. Holocene beaches; *10*. Fossile Pleistocene 2 to 3 m thick wind-deposited sand cover; *11*. Fossil Pleistocene 1 m thick wind-deposited sand cover; *12*. Wind-deflated area with thin sandy cover; *13*. River-type depression in the sand dune system; *14*. Direction of paleowinds; *15*. Direction of present winds; *16*. Prehistoric site (''hüyük); *17*. Modern village.

form a complex accumulation system today largely eroded. At the northern edge of the dune system, two to three rows of parabolic dunes can be clearly identified. This is the part where accumulation has been the most active, because of the obstacle represented by the rising slopes of the Boz Tepe mountains (summit at 1550 m). The orientation of the horns of the dunes indicates palaeowinds blowing northwards (instead of NNE today).

On the aerial photographs, some lagunal-type and river-type landforms are also recognizable in the western and southwestern margins of the dune sheet, showing the relationship between the fossil coastal dune field and the lake filling the Konya plain (Fig.

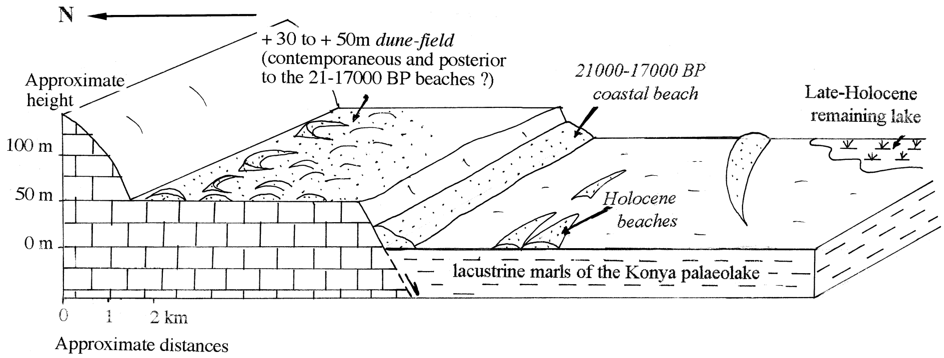



Fig. 7. Morphological setting of the dune system north of Ismil.

7). It was later modified by winds blowing NNE (the present situation) as shown by the erosion of the eastern margins of the dune field.

Luminescence dating of the Ismil dunes on sand sampled at 1.0–1.10 m depth has given an age of 14,328 ± 3220 years. The high error for this sample was due to scatter in the additive growth curve and so this age should be accepted with caution. Given this reservation, this OSL age means that, during a drought following the disappearance of the lake at 17,000 BP, sand was moving on the North-Ismil plateau.

However, the dunes may have been older. They may have been constructed, for example, as coastal dune ridges along the lake shore during the 21–17,000 BP phase. The filling of the lake by 12 m deep water does not directly mean a local increase in precipitation. It was, in fact, probably due to the melting of glaciers and snow in the Taurus mountains in the south. Wind action and arid conditions may have continued during that phase, as well as during the lake recession stage post-17,000 BP.

A period of lake renewal in the sub-basins of the plain has been dated 13–11,000 years BP (Roberts, 1983). The W–E oriented beach deposits (mainly sand spits) remaining on the floor of the plain at the foot of the scarp of the Ismil plateau belong to this period of lower lake level (Fig. 7).

### *5.2. The young 'South-Karapinar' dune system (Fig. 8)*

The town of Karapinar is located at the northern foot of a basaltic fissural lava flow. The steep southern slopes of this basaltic highland, which rise abruptly more than 50 m above the lake floor, represent the obstacle against which SSW winds have deposited a thick sand cover. The protection of the town is not absolute because climbing dunes reach the summit of the basaltic outcrop and lee dunes develop downwind of the obstacle.

There are mainly parabolic dunes within this system. To the west their height reaches 12 m. The thickness and the crescent-shape of the dunes increase northwards, under the influence of winds oriented NNE (as at present). Eastwards the dunes become thinner. Some of these are still moving northwards, separated by shallow active blowouts. The top layer of the lacustrine marls outcropping on the floor between the dunes, is hardened by a thin layer of secondary lime accumulation (Groneman, 1968). This cemented layer is resistant to wind erosion, and forms the bottom of the blowouts. At the easternmost end near the Büyük Meke volcano, signs of temporary inundation (due either to catastrophic flooding of the southern rivers or, more often, to the low infiltration rate of rain water into the impermeable marls) indicates the limits of the dune field.

Unlike the Ismil dune sheet, the South-Karapinar dune system is clearly younger than the 21,000–17,000 year BP palaeolake since all the dunes are moving on the top of the white lacustrine marls which outcrop in the elongated depressions between the dunes. However, some coarser deposits buried under the dunes of the southwestern corner of the Protection Area (Fig. 4) as well as the general location of the dune field suggest that the sand accumulated over a topographically high standpoint, orien-

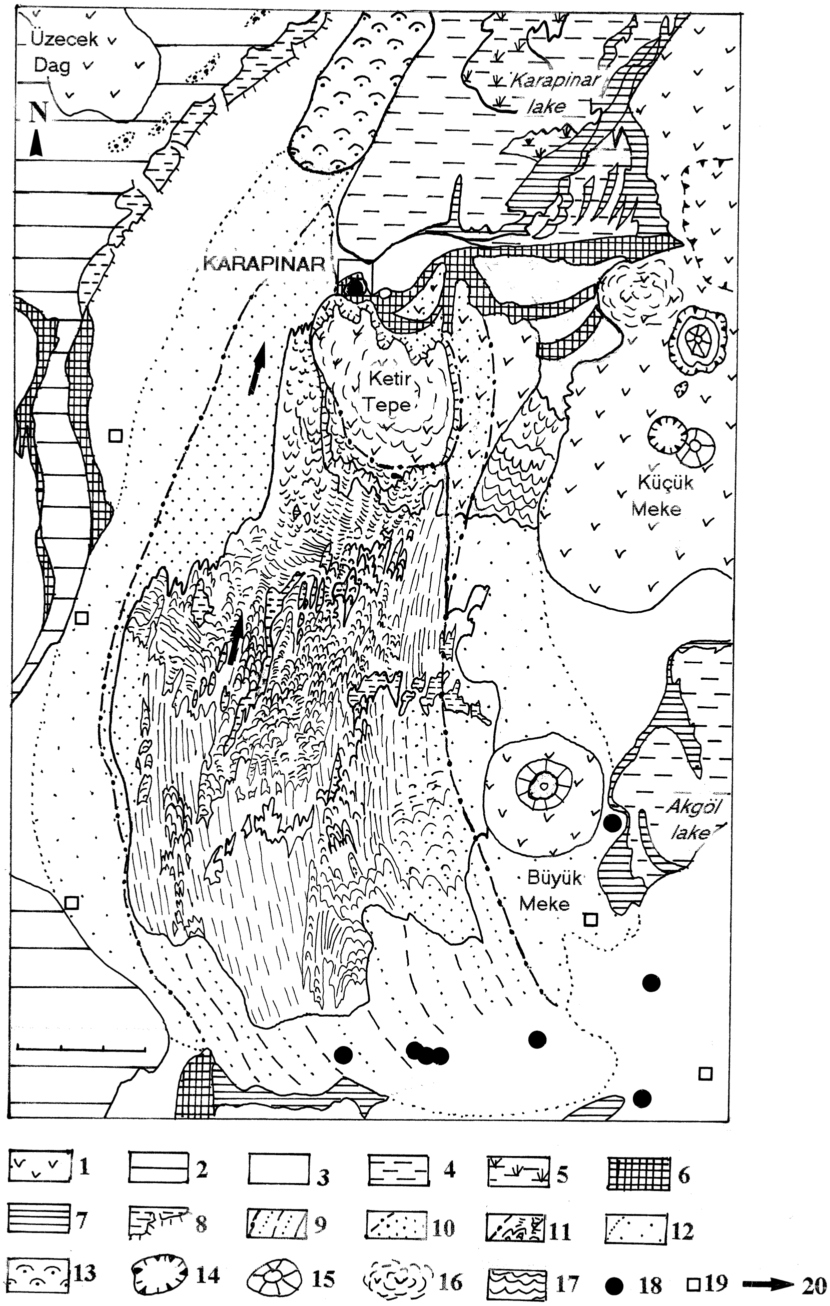
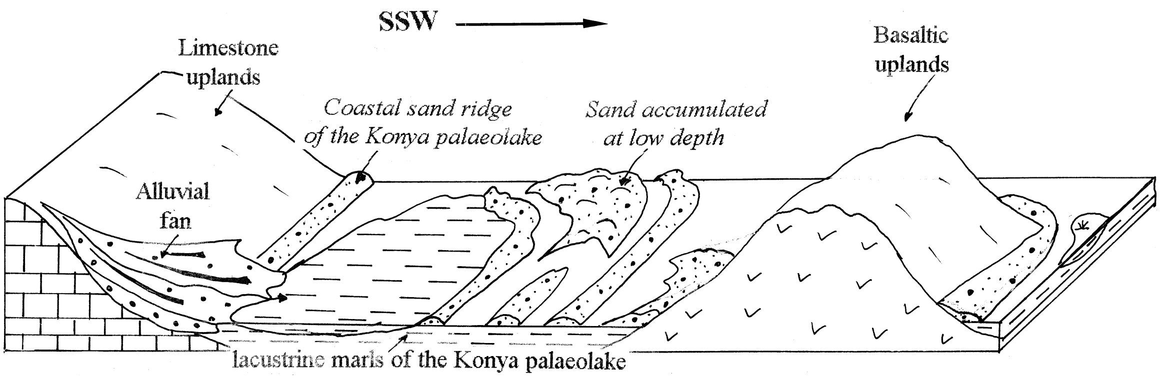


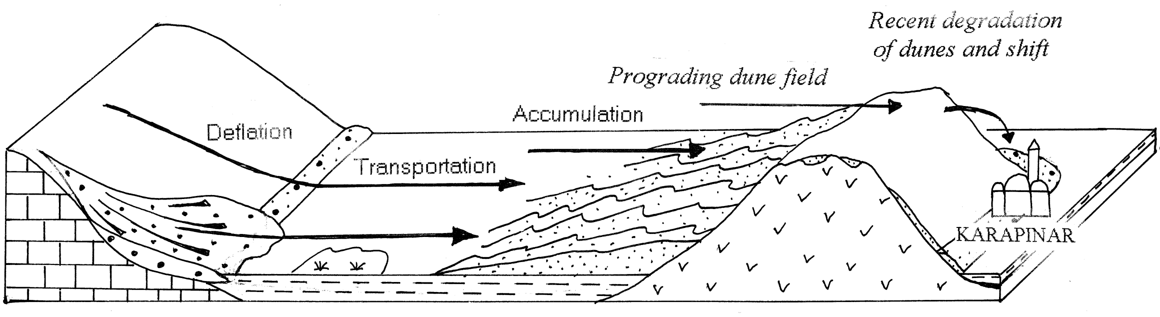

Fig. 8. The Pleistocene sand dune system south of Karapinar in its morphological context (mapping partly based on Spot 1, 110-274/1, copyright CNES and Spot-Image, 1987. Legend: *1*. Volcanic outcrops (up to 1200 m altitude); *2*. Limestone plateaux (1060 m altitude); *3*. Upper Pleistocene lacustrine marls (1000 m altitude); *4*. Holocene lake extension; *5*. Modern extension of lakes; *6*. Upper Pleistocene sand beaches; *7*. Holocene sand beaches; *8*. Holocene erosion level; *9*. Wind deflated area; *10*. Sand accumulation area; *11*. Moving dune field; *12*. Side extension of wind action; *13*. Hummocky-like subrecent dune fields down-wind; *14*. Maar; *15*. Volcanic scoriae cone; *16*. Fissural lava flow; *17*. Wind blown scoriae cover of a basaltic lava flow; *18*. Prehistoric site (''hüyük''); *19*. Summer village; *20*. Direction of present winds.

tated roughly SW–NE, and linking the southern limestones to the Karapinar volcanic outcrops (possibly linear mounds partly made of lava flow). It has, however, been covered partly by lacustrine marls (in the eastern part) and partly by alluvial and lacustrine sand and gravel (western part). These latter deposits may be related to the contracting beaches of the sub-basins when the general level of the 21,000–17,000 BP Konya palaeolake dropped and when the shorelines moved gradually inward to lower places in the sub-basins of Konya and Akgöl (Fig. 9). There must have been sufficient vegetation at that time to trap the sand and to keep it from being transported further north.

OSL dating of sand sampled here at 1.60–1.68 m depth shows an age of 5674 ± 988 years. The sampled dune is about 12 m high; the sample was taken close to the foot of the obstacle formed by the basaltic highland, as the best location for sampling the sand trapped at the beginning of the sand accumulation. As for the Ismil dune sheet, the age obtained probably belongs to the last period of drought after 5000 BP (Sanlaville, 1992; Issar, 1994). This drought is also indicated by the sedimentological




**1. Situation during the contraction of the Konya paleolake post-17000 BP**
Sand is made available for the wind to construct dunes.




**2. Situation during the droughts following the disappearances of (including the drought post-6000 BP) and during the overpasture of the sand areas.**
Sand is wind transported. Dunes are built against the topographic obstacle. But insufficient sand input causes the parabolic dunes to be wind eroded. The sand is transported leewards where it constructs sand sheets and very small dunes moving on the dried lake floors.

Fig. 9. Morphological setting of the dune system south of Karapinar.

study of some young Holocene lacustrine sequences in the Karapinar lake sub-basin (Kuzucuoglu et al., 1997).

### 5.3. *The youngest aeolian landforms (E on Fig. 4)*

The very recent dunes around Karapinar cover about 1500 ha. These dunes are being eroded and are moving. They cover the top layer of the Mid-Holocene lacustrine sequence in the area of Karapinar. The thickness of these dunes reaches a maximum of 1 m although the depth of the aeolian silts reaches 2 m in sections. These superficial dunes have been overgrazed in recent times and have consequently been eroded.

Today the landscape of the South-Karapinar dune field illustrates reworking and activation of fossil landscape features. According to Groneman (1968) stating local information, the present reactivation of the sand field started after the 1940s when migrants arrived, whose herds accentuated pressure on the local pastures and ranges. Overgrazing and the consequent destruction of the steppic vegetation protecting the fossil sand dunes led to the reactivation of the system with new blowouts and movement of sand dunes. This northward movement soon threatened the town of Karapinar itself. In order to stop the sand invading the town and the roads, a stabilization programme was started in the 1960s which included tree, shrub and grass planting on the elongated parabolic dunes in the area SW of the basaltic obstacle where the dunes are highest and the sand cover is thickest. Irrigated orchards and fields were cultivated on the western lowest margins whilst the central and eastern parts were left to recover naturally. Grazing interdiction affected a controlled area of 15,000 ha (Fig. 4). The spectacular effect of this enclosure is clearly visible today in the field and on the satellite imagery where significant changes in vegetation cover and in colour define the limits of the controlled area.

## 6. Interpretation and relative chronology

At least three stages of sand accumulation and dune field construction related to fluctuating lake levels and periods of drought can be identified in the region of Karapinar.

The Ismil dune field appears to be the oldest system of the region. It covers an erosional surface which overlooks the bottom of the 21–17,000 BP Upper Pleistocene lake with a 35 to 40 m high scarp cut into Neogene formations (Fig. 7). Either it is older than 21,000 BP and could thus be related to a higher level stand of the former Konya palaeolake, or it is related to the deflation of the sand beaches, during the Upper Pleistocene lake stage or during the following recession stage. It may be of the same age as the other shell-rich aeolian formations identified on the plateaus near the Karapinar playa, at an altitude of 30 to 50 m above the present playa floor.

The shapes of the vegetated horns of the parabolic dunes of this field are orientated to a N wind direction, slightly different to the NNE winds which constructed the South-Karapinar dunes. A change in wind direction, opposite to that of today, has been suggested by Erol (1978) based on the stratigraphy of the Merdivenli coastal beach deposits. The shapes of the old Ismil parabolic dunes demonstrate that there has been a distinct, although smaller change in wind direction from N to the present NNE.

Radiocarbon dating of shells from the main beaches on the shores of the last stage of the lake when it covered the whole Konya plain (Roberts et al., 1979) and other dating in Fontugne et al. (in press) confirm the ages of 19,600–17,000 BP for this high lake level stand. After the start of the contraction of this lake, around 17,000 BP, the South-Karapinar sand field was constructed by winds blowing from the SSW. A field of parabolic dunes is now piled at the foot of the Karapinar basaltic highlands. In order for this dune field to have developed, we must assume an arid environment where the vegetation cover is mainly absent, with coastal sand left unprotected (Fig. 9).

Drought conditions increased during or after the lake recession, i.e., from 17,000 to 13,000 BP. After 13,000 BP, marshes developed in the sub-basins until 11,000 BP (Roberts, 1980, 1983; Fontugne et al., in press; Kuzucuoglu et al., in press), showing a change in the water balance of the basin, although vegetation remained steppic (Bottema and Woldring, 1984).

In more recent periods, the youngest dunes NW and NE of Karapinar, made of very fine, carbonaceous sand derived from the underlying marls, shells and smooth sands, are Mid-Holocene or younger, according to dated marshy and soil layers buried in sequences underneath (Kuzucuoglu et al., 1997; Kuzucuoglu et al., in press).

## 7. Conclusion

The dune systems of the northern shores of the Konya plain are the result of climatic changes during the Upper Pleistocene and the Holocene. There are three main stages of dune formation. First, the South-Karapinar dune field which is mainly related to a post-17,000 BP drought although it was wind-reworked during the 6th to 5th millenium BC drought. Secondly, the Ismil dune field which is older (tectonics may explain its good preservation and its distinct disconnection from the plain floor) and last reworked in relation to the drought which followed the disappearance of the 17,000 BP lake. Finally, the thin sand cover and small dunes located at Akkum (North-Karapinar) and at the northern edge of Akgöl are related to a Late Holocene drought which is also evident in the upper silts of some lacustrine sequences.

All three sand dune systems have been eroded. The most eroded is the oldest one north of Ismil although the parabolic shapes can still be clearly seen on the satellite images. The height of the dunes never exceeds 2.5 m and weathering and wind deflation have also significantly modified the petrographic composition of these sands. By comparison, the aeolian dune cover south of Karapinar appears to be much better preserved, in dune shapes as well as in sand composition. However, many dunes have been eroded and moved northwards, the southern part of the sand sheet decreasing while wind blowouts widened the interdune and interhorn corridors. The youngest dunes have also been subject to linear wind erosion, although to a lesser extent. In conclusion, it seems that the effect of wind erosion is cumulative over time on the various sand dune fields, the oldest being the most deflated and diminished.

Since they are closely related to lake-level high stands and to the following lake-contracting stages, the dune fields can also indicate the environmental conditions during and following the lake periods. The presence of some vegetation is probable on the shores of the lake, in order to fix the sand and prevent its continuous exportation by the winds. The lake shrank with the continuation of the drought, thus allowing the wind to build the sand dunes. This scenario occurred three or four times during Upper Pleistocene and Holocene. The drought periods can be identified as being during the last glacial (Ismil dune field c. 45–35,000 BP), from 17,000 BP to 13,000 BP (South-Karapinar dune field and reworking of the Ismil dune field), some time around the Mid-Holocene (Akkum dunes and aeolian deposits reworking of the South-Karapinar dune field in the 6th to 5th millenium BP), and during historic times (isolated and elongated dunes on the floor of the Karapinar playa), including the present-day dune activity.

The question of a climatic cause of the increasing wind erosion features encountered in recent decades can be addressed using the high contrast between the fenced protected area and the grazed surrounding pastures and rangelands. Although no plantation was done in the eastern part of the protected area, most of the dunes are now covered with grass and shrubs and some trees whose seeds were brought by exceptional river flooding from the South. On the other side of the enclosure, where grazing is allowed, the vegetation cover is scarce, with patches of wind deflated large and shallow blowouts, with sand tongues moving northwards toward the protected area, burying the fence in places.

This observation suggests that the present renewal of sand motion is due to land use. Present climatic conditions would normally allow the dune field to stabilized. The Karapinar area has a mean annual precipitation of 289 mm/yr which is the uppermost limit for sand dune formation in semi-arid regions (Pye and Tsoar, 1990). Activation of dunes, whether occurring at Ismil, Karapinar, Kumdere, Akkum, Akören or Akgöl, is due to the destruction of the protecting natural grass cover by grazing or by field ploughing, and is a process of degradation and not desertification (Mainguet, 1994).

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