PALAEOCLIMATIC EVIDENCE FROM EARLY TO MID-HOLOCENE PLAYAS IN THE GILF KEBIR (SOUTHWEST EGYPT)

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SUMMARY

Investigations of the sediments of early to Mid-Holocene playas in valleys of the Gilf Kebir Plateau (c. 23°N/26°E) resulted in new data on the palaeoclimate in the centre of the largest hyperarid region of the earth. From detailed stratigraphic evidence, scanning electron microscopy, more than forty radiocarbon-dates and interpretations of prehistoric floral and faunal remains, the following climatic development was reconstructed: Up to about 9500 years BP an extremely arid climate, similar to the present, prevailed. The period between c. 9500 and 6000 BP had an arid climate with rare heavy rainfalls (approximately four events per 100 years), feeble soil formation and sparse plant growth in the surroundings of the temporary rainpools, and high wind activity. Between 6000 and 5000 BP conditions tended towards moderate aridity with an estimated maximum annual rainfall of 100 mm. This millennium seems to represent the main phase of Neolithic settlement. The playa deposits contain no evidence of the subsequent increase in aridity about 4800 BP. On the whole, there is growing evidence that in this part of the eastern Sahara — in contrary to more southerly regions of the Libyan Desert — the climate was arid during the entire Holocene, with only a slight, sporadic tendency towards semi-arid conditions.

RESUME

Des études au sujet du milieu de sédimentation des playas dans les vallées du plateau de Gilf Kebir (environ 23°N/26°E) ont apporté des données paléoclimatologiques concernant le paléoclimat du centre de la région hyperaride la plus étendue de la terre pendant l'Holocène inférieur et moyen. D'après les résultats microstratigraphiques en rapport avec une quarantaine de datations à radiocarbone jusqu'alors disponibles, des études en microscopie électronique ainsi que des interprétations des restes de la flore et de la faune préhistoriques, il en résulte le déroulement climatique suivant: Jusqu'à environ 9500 BP
régnait un climat extrêmement aride, comparable à celui de nos jours. La période entre environ 9 500 et 6 000 BP semble être caractérisée par un climat aride, accompagné des averses rares (environ quatre événements par 100 ans), avec une formation de sol faible et une végétation modeste dans les environs des playas et une activité éoliene importante. De 6 000 à 5 000 BP les conditions climatiques ont eu une tendance vers le semi-aride avec des précipitations annuelles élimées à 100 mm maximum. C'est à cette époque que la colonisation Néolithique principale à apparemment eu lieu. L'aridification qui suit après environ 4 800 BP n'est plus documentée dans les accumulations de playa. En résumé, il semble que cette région du Sahara oriental était caractérisée par une aridité persistante pendant tout l'Holocène, contrairement à la plus au sud du Désert Libyque.

ZUSAMMENFASSUNG


INTRODUCTION

The results presented here were obtained during several field seasons in SW Egypt and NW Sudan from 1980 onwards. The investigations formed part of the interdisciplinary research project Prehistoric Settlement of the Eastern
Sahara' (BOS) with the title 'Cultural development, landform evolution and life styles in relation to climatic change in the eastern Sahara'. In this connection archaeological evidence has shown that during the early and middle Holocene the playas of the Gilf Kebir were favourite Neolithic settlement sites owing to their temporary water supply in this nowadays totally uninhabited part of Egypt's Western Desert. The objective of the present study was to investigate the sedimentary environments of the playa deposits and thus to clarify the boundary conditions for settlement at the time of deposition. Almost inevitably, this also yielded data contributing to the reconstruction of the palaeoclimate.

**THE GILF KEBIR**

The playas dealt with here are located in two valleys of the Gilf Kebir Plateau, which is situated at the Tropic of Cancer at about 26°E in the SW-Egyptian part of the Libyan Desert. The Gilf Kebir is a sandstone plateau c. 5800 km² in size, dissected by numerous valleys and with steep cuesta-like edges at approximately 1000 m a.s.l. (Fig. 1).
The plateau escarpment was first sighted from a great distance in 1909 (Harding-King 1912), but it was observed at close range and given its name only in 1926 (Gīl el Kebīr = 'great scarp' in Arabic; Ball 1927, Kemal El Dine Hussein 1928). The actual pioneer exploration of the remote plateau during the thirties was motivated by geodetic, archaeological and military factors and is linked with the names of Almási (1936), Bagnold (1939), Clayton (1933), Kádár (1937), Myers (1939), Peel (1939), Penderel (1934), Rhotert (1952), Shaw (1936) and Winkler (1939).


The geological structure of the southern Gīl Kebīr consists of horizontally bedded, Jurassic and Cretaceous sandstone, unconformably overlying the Pre-Cambrian or various Lower Palaeozoic formations (Klitzsch & List 1978). Basaltic hills and flows, apparently associated with the NW-SE, NE-SW and N-S striking fault system, point to intrusive and effusive volcanic activity on the plateau during the Tertiary (Klitzsch 1979).

Most likely the existing valley morphology with its box canyons and abrupt headcuts was controlled by the highly resistant quartzitic caprock of the southern plateau (Peel 1939). Haynes (1981) presumed that the initial fluvial dissection of the plateau cut into overlying, less resistant shales which were later completely stripped by aeolian erosion. Other processes such as subsurface drainage with undercutting of cliffs may have contributed to the formation of steep valley sides (Maxwell 1981), just as morphodynamic activity in mainly arid and semiarid conditions during Quaternary times remodelled the entire valley morphology (McCauley, Breed & Grolier 1981).

The region of the Gīl Kebīr is situated in the centre of what is today the vastest hyperarid area of the world (based on the Budyko-Ratio; Henning & Flohn 1977). Half-way between the Mediterranean winter rainfall zone in the north and the summer rainfall zone of the wet-dry tropics an equatorial trade wind desert climate of strong continentality with an estimated mean precipitation of less than 5 mm/year prevails in this part of the eastern Sahara, the increased hyperaridity being due to the cross circulation of the easterly jet (Flohn 1964). Because of the almost complete absence of rainfall and the lack of any waterholes the Gīl Kebīr is virtually inanimate except for a few isolated localities with sparse vegetation (Back 1981).

WADI EL BAKHT

Wadi el Bakht ('lucky valley' in Arabic; Bagnold et al. 1939) is one of the
longest valleys cutting into the Gilf Kebir plateau. About 12.5 km below the valley head the psammitic-pelitic facies of characteristic wadi deposits is gradually succeeded by a pelitic facies. This is the location of the c. 66000 m² pluvial playa (Fig. 1, loc. 1). The importance of this locality was stressed by McHugh (1980: 65) when he wrote: 'This locale has outstanding potential for contributing to the study of the late prehistoric palaeoenvironments and cultural adoption in the area.'

The position of the playa and the thick valley fill up-stream are due to the previous complete blockage of the valley by a still partly preserved fossil dune, covered in part by a recent falling dune (Photo 1). The long profile is almost horizontal over 3 km above the dune barrier, which indicates that the local base level remained stable over a long period. We measured a gradient of only 4.15 m/950.5 m, i.e. 0.0044; Maxwell (1980: 79) gave a gradient of 0.0028 over about 1.775 m.

Mud crack polygons of different orders with diameters between 1 and 10 m cover the playa surface and document the final desiccation. The NE corner of the playa was lowered 3 m by increased deflation probably caused by turbulences at the foot of the falling dune. Here several yardangs about 1 m high are preserved at different levels and provide the best evidence of the presence of old roots, most likely mainly of reed (Phragmites communis). The central part of the fossil playa is covered by a 400 m² sized, 3 cm thick layer of curpled clay flakes, the remains of recent playa deposits.

Similar deposits with a maximum thickness of 10 cm were found 11 km northward, in the 'Winkelwadi', the northern branch of Wadi el Maftuh, as well as in parts of Wadi Wassu (cf. Fig. 1). These pelitic deposits, known as 'Daq' in the Persian deserts, are evidence of secular rainstorms, which occur even during the present hyperarid climate. Field evidence suggests that water columns more than 2 m high can be attained in such short-lived rainpools (Kröpelin 1985). Cemented-in 1930s petrol cans in contemporary 'clay-flake-playas' in the western Wadi Wassu are proof of their recent age.

The prehistoric implements on the slopes of the fossil dune barrier are remarkably abundant (McHugh 1981b, Schön 1984, Wendorf & Schild 1980: 217-222). This dense layer of hundreds of thousands of stone tools and flakes seems to have preserved the fossil dune beyond the consolidated shore zone. However, it is likely that projection or slope processes contributed to the concentration of artifacts. Similar observations were also made at Wadi Howar in NW Sudan where Neolithic implements have stabilized early Holocene parabolic dunes which are surrounded by mobile barchan chains (Gabriel et al. 1985).

The minor channel incision of the upstream portion of the wadi floor also continues into the playa deposits. At its eastern edge it turns into a step-like gorge which descends 9 m down to the original valley floor over a horizontal distance of only 20 m (Photo 2). At this site the dune barrier was breached, thus terminating the former local base level.
Stratigraphy

The smoothened outcrop at the former playa-lake shore gives an excellent insight into the sequence of sedimentary processes (Photo 2). As already established by Peel (1939: 306), the deposits consist of thin alternating layers of mud and partially cemented red sand, overlain by a 6 ft (= 183 cm) thick mud cover (Peel mentions 6 inches = 15.24 cm; as this is obviously a slip of the pen, the correct value of 6 ft has been given here). Maxwell (1980) called for detailed stratigraphic investigations in order to clarify sedimentary conditions. These studies were carried out during our stay in January/February 1982. Figure 2 shows the micro-stratigraphic column of section 82/13. Both the scale and the few symbols demonstrate that it is a sequence of homogeneous clastic sediments with no indications of erosional disconformities.

The underlying bed is the former western slope of the fossil blocking dune and consists of cross-bedded medium sand with sharp grain-size differences between individual laminae and is undoubtedly aeolian in origin. The internal structure strikes 170° and dips 12°W on average. The fossil dune sands are orange (Munsell 5 YR 6/8 dry) and show numerous calcified root casts in
their upper parts. Between 810 and 790 cm below the surface the underlying dune sands interfinger with the overlying psammites, which will be referred to here as 'playa sands' in the sense of sands that have been deposited in a playa area. This is the first occurrence here of the reddish yellow playa sands (Munsell 5 YR 6/6-8 dry). Due to a non-calcareous pelitic matrix, the medium to coarse grained sands are well consolidated.

At 788 cm the first clayey silty deposit occurs, a layer of 5 mm thick. Up to the top these deposits recur 89 times, with thicknesses up to a maximum of more than 1 m (Fig. 2). Pechar & Roper (1984: 254) quote a grain size distribution from the opposite wall of 54% silt, 45% clay and 1% sand, classifying the sediments as very clayey silts. 77% of these strata are less than 2 cm thick, 22% are 2-7 cm thick, and only the near-surface layer is 116 cm thick. Disregarding this top layer, the mean thickness is 1.43 cm with a standard deviation of 1.26 cm. On the whole, the pelites form 30% (242 cm) of the vertical thickness of the profile above the fossil dune sands.

An important argument in favour of the playa sands having been deposited in a wet environment is that load casts (Kuenen 1953) occur at almost all the basal sides of the sand layers. These pressure marks are evidence of plasticity of the still saturated pelitic layers during or shortly after sedimentation. Curled clay flakes, on the other hand, which would be evidence of complete surficial desiccation, were not found at all, although the clay content of the fossil pelites is somewhat lower than in the recent playa deposits mentioned above.

What is remarkable, however, is the total lack of signs of 'anthropoturbation'. If either humans or animals had walked over the wet, unconsolidated mud at or after playa deposition the thinly interbedded layers would have been disrupted to a greater extent. Possibly the reeds hindered entry to the swampy environment.

Of particular interest are several finds of pottery up to depths of approximately 5 m in the playa deposits. One sherd was found in the profile 82/13 at about 4 m below the surface. It is of the same type as that of a vessel found in the main profile 80/7-1 in bed D at Wadi Ard el Akhdar which was dated at about 8000 BP (R. Kuper, pers. comm. 1982; cf. Fig. 3).

Scanning electron microscopy and energy-dispersive analysis of playa sediments

Analogous to what has been described by Walker (1979) the consolidation of parts of the fossil dune is attributed to mechanically infiltrated clay minerals (cf. Crone 1975) and extremely finely distributed iron oxides. The playa sands and pelites were analysed, taking into account results by El-Baz & Prestel (1981) who investigated the coatings of loose dune sand from Wadi el Bakht, and by Potter & Rossman (1979) who established the significance of clay minerals in the Mn-Fe-oxide deposition. Scanning electron microscopy and semi-quantitative energy-dispersive X-ray microanalysis (EDAX) of the
playa sands and pelites yielded the following results:

a. Both the coatings and matrix of fossil dune and playa sands seem to consist of the same material.

b. Both coatings and matrix consist of detritic aluminosilicates, mainly kaolinite, and hematite. The latter is evidence of oxidization during and after formation.

c. The water necessary for redistributing both clay minerals and iron oxides originated from the playa and not (as Walker (1979) proposes for similar features in Libya) directly from rainfall, as consolidation of fossil dune sands and playa sands only occurs in the intake area of the playa; fossil dune sands outside the shore zone of the former playa lake are still loose today. This may be a further variant in the formation of red beds, i.e. in the vicinity of playa.

d. The clay minerals and matrix of aeolianite and playa sands originated in the fluvially deposited pelites of the playa which in turn came from the cementing material of the surrounding 'Nubian' sandstone. Hence the material forming the matrix does not consist of aeolian dust, contrary to the findings of Walker (1979) in Libya.

e. Evidence of authigenic mineral formation (Halloysite) within the porous playa sands is proof of distinctly higher humidity, as under the recent and subrecent hyperarid conditions such clay mineral formation would be impossible.

f. The micromorphological comparison between playa sands and aeolianite

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indicates that the playa sands were deposited in a humid environment thus confirming the conclusions drawn from the load casts mentioned above and related microstratigraphic features. The playa sands are therefore not to be interpreted as wind-blown sand deposited after total desiccation of the playa-lake.

g. The pelites have the typical structure of elastic silicate mud deposits with a high kaolinite content.

h. Furthermore the total absence of any micro- and nanofossils emphasizes that the environment within the playa was hostile to life.

WADI ARD EL AKHDAR

In the upper reaches of Wadi Ard el Akhdar ('wadi with the green floor'; Bagnold et al. 1939) the valley widens out in several places, as the satellite image interpretation map shows (Fig. 1). The playa is located in a depression which is 2.200 m long, 750 to 500 m wide, with a total area of about 3 km², and lies about 35 km upvalley from the junction with Wadi Wassa. In the eastern part the playa surface of about 160,000 m² is covered with a network of small channels. They run more or less radially from the edges into a 50-80 m wide main channel which cuts up to 8 m into the playa deposits. The narrow mouth of the depression is situated at the eastern end of the main channel, below a basaltic intrusion recently dated at 38 ± 2 Ma (Franz, Puchelt & Pasteels 1986; cf. Fig. 1, dotted signature E of loc. 2). This constriction is about 600 m long and only 50 m wide, and the valley floor is reduced to about 10 m width by a recent, N-S striking dune.

The complete blockage of this constriction in earlier times was due to a dune barrier formed in the lee of the basaltic hill, as the present situation suggests (McCauley, Breed & Grolier 1981, Pachur & Braun 1982). This blockage which seems to have been initiated by an apparently sudden fall of metre-size boulders from the southern slope (Kröpelin 1985) caused the depression to fill with thick, loose sediments over a considerable span of time.

Stratigraphy

The most significant section 80/7-1 is located 640 m upvalley from the fossil dune barrier on the north side of the main channel. Here, pottery sherds were found about 2 m below the surface. Associated charcoal was dated at 8,460 ± 520 BP (Hv 8311) so that the fragments are among the oldest pottery in the entire Sahara (Pachur & Gabriel 1980). Figure 3 shows seven alternating of pale and dark layers. The darker strata, marked A to G, mostly contain root structures and bioturbational features, and have distinctly more coarse sand and fine, angular gravels than the comparatively homogeneous paler layers (Kuper 1981: 232).

Detailed chemical analyses and grain-size distributions of this profile have
been published by Pachur & Röper (1984: 253). They confirm the predominantly psammitic nature of all the layers which show a content of sand between 41.4 and 81.5% (X = 63.2%), silt between 3.4 and 31.6% (X = 19.1%) and clay between 6.7 and 25.3% (X = 13.5%) with poor sorting and, in part, bimodal distribution. Higher gravel contents of 20.8% and 8.4% were found only in the two samples from the top, the others have less than 3.3%. The organic carbon content varies between 0.03% and 0.09%. As the radiocarbon dates in Figure 3 show, section 80/7-1 reflects the course of sedimentation in part of the depression from about 9 400 to 5 000 BP; an erosion-induced unconformity is only perceptible above the A layer.

The material was probably washed by sheetfloods or rill erosion over a short distance only from the margins into the deeper, central part of the depression, a process which has been verified in other sections by corresponding sediments (basalt and quartzite particles; W. Schön 1984 in litt.). Both the poor sorting and the high degree of consolidation are typical of such conglomerates. Better sorting occurs only in a position further downvalley, where there are few or no psamphite components in the over-9-m-thick, fine sand-size deposits which represent the core of the playa and occupy c. 12 000 m². This means that at the time of deposition site 80/7-1 was situated at the periphery of the former playa lake. This interpretation, based on independent evidence, corresponds in the main to the conclusions drawn by Pachur & Röper (1984: 252) from this profile: that it is a sedimentary environment characterized by short and heavily loaded sediment transport, with no features of genuine limnic sedimentation.

In fact, the upper Wadi Ard el Akhdar contains almost no purely pelitic stillwater deposits, i.e. playa sediments in the narrow sense (with grain sizes < 63 μm), comparable to the pelitic layers in Wadi el Bakht. This is the main facies difference to the accumulations there. Several sections and test pits confirmed the predominantly lateral-coluvial character of the Holocene deposits, which reveal a comparatively high energy level.

PREHISTORIC FAUNA AND FLORA

The faunal remains obtained from Wadi el Bakht and Wadi Ard el Akhdar suggest a meagre palaeofauna and, indirectly, as well a poor palaeoflora (Table 1). They were found mainly on or in surface layers at some distance from the playas and belong exclusively to non-aquatic organisms. Since it is by no means certain that the bone only tentatively identified as ?Elephas did in fact come from Wadi el Bakht or Giff Kebir (see note to Table 1), the only significant palaeoecological evidence of wild fauna consists of two finds of giraffe bones (Pachur & Röper 1984; this chapter). Since giraffes subsist on the leaves, buds and twigs of trees, mainly acacias, these scanty relics are the only faunal indications of tree vegetation. The other wild mammals found here are desert animals accustomed to extreme aridity rather than typical
<table>
<thead>
<tr>
<th>Name</th>
<th>Specific name</th>
<th>Source</th>
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<tr>
<td>Wadi el Bakht</td>
<td></td>
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<tr>
<td>? Elephant</td>
<td>? <em>Elephas</em> sp.</td>
<td>McHugh 1975*</td>
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<tr>
<td>Big bovide</td>
<td><em>Bos</em> sp.</td>
<td>McHugh 1975*</td>
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<td>Addax</td>
<td><em>Addax</em> sp. <em>nasomaculatus</em></td>
<td>McHugh 1975*</td>
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<td>Damaliscus</td>
<td><em>Damaliscus</em> sp.</td>
<td>McHugh 1975*</td>
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<tr>
<td>Gazelle</td>
<td><em>Gazella</em> sp.</td>
<td>McHugh 1975*</td>
</tr>
<tr>
<td>? Goat</td>
<td>? <em>Capra</em> sp.</td>
<td>McHugh 1975*</td>
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<td>Jackal, ? dog</td>
<td><em>Canis</em> cf. <em>anthus</em></td>
<td>McHugh 1975*</td>
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<td>Ostrich</td>
<td><em>Struthio camelus</em></td>
<td>McHugh 1975*</td>
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<tr>
<td>Wild donkey</td>
<td><em>Equus</em> atinus</td>
<td>McHugh 1975*</td>
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<tr>
<td>Ostrich</td>
<td><em>Struthio camelus</em></td>
<td>Gautier 1980</td>
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<tr>
<td>Big dog</td>
<td><em>Canis lupus</em> f. <em>familiaris</em></td>
<td>Gautier 1980</td>
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<td>Dorcas gazelle</td>
<td><em>Gazella dorcas</em></td>
<td>Gautier 1980</td>
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<tr>
<td>Sheep or goat</td>
<td><em>Ovis aries</em> f. <em>aeron</em> or <em>Capra aegagrus</em> f. <em>hiricus</em></td>
<td>Gautier 1980</td>
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<tr>
<td>Domestic cattle</td>
<td><em>Bos primigenius</em> f. <em>taurus</em></td>
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<td>Big bovides</td>
<td><em>Bos</em> sp.</td>
<td>Gautier 1981</td>
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<tr>
<td>Giraffe</td>
<td><em>Giraffa camelopardalis</em></td>
<td>Pachur &amp; Röper 1984 (det. Uerpmann, Tübingen)</td>
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<tr>
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<td><em>Bubalus</em> sp.</td>
<td>Uerpmann, Tübingen</td>
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<td>Gazelle</td>
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<tr>
<td>Giraffe</td>
<td><em>Giraffa camelopardalis</em></td>
<td>This chapter (det. Uerpmann, Kuper 1984 in Tübingen; Kuper 1984 in litt.)</td>
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<tr>
<td>Cattle</td>
<td><em>Bos</em> sp.</td>
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<td>Mice</td>
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<td>Wadi Ard el Akhdar</td>
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<td>Rock rabbit</td>
<td><em>Procavia capensis</em></td>
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<td>Bovide</td>
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<td>Big buffalo</td>
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<td>Capride</td>
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<td>See above</td>
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<td>McHugh 1975*</td>
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*These faunal remains were collected by O.H. Myers in 1938 (Myers 1939) and only preliminarily identified by D.M.A. Bate & J. Johnson, London. Their provenance from Wadi el Bakht or Wadi Ard el Akhdar or even from the Gilf Kebir is not ascertained though it is likely that some of them were associated with artifact assemblages recorded by Myers in the upstream portions of these valleys (Gautier 1981). Therefore parts of the material listed under Wadi el Bakht could possibly have come from Wadi Ard el Akhdar.

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savanna species. Addax, Dorcas gazelle and Damaliscus live on grass and herbs only and can exist for months, years or even entirely without water other than the fluid intake from plants and dew (Haltenorth & Diller 1977). Furthermore, Almáy (1936: 45) mentions finding the fresh carcass of an *Addax nasomaculatus* on the western side of the Gif Kbir as late as 1933.

Owing to the absence of pollen, diatoms and identifiable opal phytoliths, until recently the only direct palaeofloral evidence consisted of root structures (Fig. 3), a few root and stem fillings with diameters up to 10 cm, and the close-set stone casts of roots and stalks, which were identified as reeds (*Phragmites communis*) by their position, cross-sections, and diameters of about 1 cm. In addition, grass steppe fires were deduced from the widespread minuscule traces of charcoal found well away from hearth sites.

Recently, however, the results of extensive palaeoxylotomic studies of charcoal remains with the aid of scanning electron microscopy have been presented (Neumann, this volume, and 1986), the great majority of which have been dated by radiocarbon. They provide independent confirmation of conclusions on palaeoflora and early and mid-Holocene rainfall drawn from sediment facies, electric conductivity logging, the absence of micro- and nanofossils, geomorphological mapping and other evidence (Kröpelin 1985). Relicts of almost all the identified genera and species, mainly acacia (*Acacia tortilis* subsp. *raddiana* and *Acacia ehrenbergiana*), *Maerua crassifolia* and *Balantites aegyptica*, still occur in Gif Kbir; *Tamarix articulata* is found in the neighbouring Jebel Uweinat. Only *Acacia albida* and *Ziziphus lotus* no longer occur here today, but are found in the mountains of the central Sahara (Neumann 1986).

**DISCUSSION AND PALAEOCLIMATIC CONCLUSIONS**

Playas which are not groundwater-fed represent valuable indicators of climate because their occurrence is due only to surficial run-off, contrary to lakes in the Sahara which are always dependent on specific conditions in which local, non-climatic factors may play a major part (Rognon 1980). The evidence presented above strongly suggests that the early to mid-Holocene playas in the Gif Kbir were such ‘dry playas’ (Motts 1965), i.e. temporary pools containing water for days, weeks or months only.

Of course, local factors are also important to a certain degree in the formation of both fossil and recent playas in the Gif Kbir. The necessary conditions for the origin of basins and thus for the accumulation of playa sediments are the result of a combination of W-E trending valleys with constant winds blowing roughly N-S (trade winds), and a source of sand in the north (Great Sand Sea). Additional factors were residual terraces ('Winkel-wadi') or valley constrictions (Wadi Ard el Akhdar). On the other hand, such special local influences would not have had any great effect had they not been accompanied by climatic parameters considerably different from the present day.
Photo 1. Wadi el Bakht. View WNW upvalley with residual fossil dune responsible for damming the valley and causing the accumulation of stillwater sediments between c. 9000 and 5000 BP. Valley width: 650 m. Difference in elevation between plateau edge and playa surface: 110 m. Two Unimogs show scale of photo. (Photo by S.Kröpelim, 29/1/1982)

Photo 2. Wadi el Bakht, section 82/13. Natural outcrop in the gorge breaching the fossil dune barrier (see centre of Photo 1). Date of breach probably about 4800 BP. The playa sediments dip W upvalley and are over 8 m thick at this site near the former playa lake shore. (Photo by S.Kröpelim, 5/1/1982)
The sections of Wadi el Bakht and Wadi Ard el Akhdar (82/13 and 80/7-1) show the following climatic development: Blockage of the valleys, which created the conditions necessary for playa accumulation must have occurred, or at least begun, before 9370 ± 215 or 8200 ± 500 BP (cf. Table 2); the latter seems to be the case in Wadi Ard el Akhdar. An age of about 9400 BP is more likely to be correct since the date from Wadi el Bakht is from material overlying the earliest deposits in the playa centre. The climate seems to have been even more arid than today, since actual dunes are not able to cause total blockage of the valleys of Wadi el Bakht and Wadi Ard el Akhdar. However, different non-climatic boundary conditions may have prevailed, causing for example an increased supply of sand.

For the subsequent period up to about 6200 BP the section 82/13 (Fig. 2) is more instructive because the playa in Wadi el Bakht had a larger catchment area and therefore, due to the amplifying effect, provides more information on the course of sedimentation than the Wadi Ard el Akhdar playa where lateral influences dominated. The number of pelitic strata documented in section 82/13 between 8200 ± 500 BP and 6080 ± 420 or 6200 ± 1000 BP (cf. Fig. 2) could be explained by the fact that rainfall events were only twice as frequent (approximately 70 events/2000 years) as in the present hyperarid climate (approximately 2 events/100 years = 40 events/2000 years). Likewise the thicknesses of fossil deposits (less than 2 cm on average) roughly correspond to recent rates of sedimentation in the ‘Winkelwadi’ or in Wadi Wassal. Nevertheless, neither the spatial extent and volume of the deposits, nor the composition of the sediments are conceivable under the actual climatic regime. This suggests that there must have been both heavier or lengthier rainfall and, above all, different conditions for material supply. Particularly the texture of the pelites can only be explained by more intense weathering or soil formation in the source area. There are signs of pedogenesis at numerous outcrops especially in the surroundings of the playa in Wadi Ard el Akhdar where there are root structures, bioturbation features, still measurable organic carbon, higher proportions of clay, at least some of which probably formed in situ, and red beds in various stratigraphic positions.

Hence, the strata A to G in section 80/7-1 (Fig. 3) cannot be interpreted as representing pluvial phases of climate, since they probably resulted from single fluvial deposits after exceptional rainfall. However, they contain pedogenetic features which provide palaeoeccological evidence for the entire phase between two depositional events. At any rate, this period, roughly lasting from 9000 to 6000 BP, was characterised by uneven, discontinuous sedimentation, which points to an arid climate with single heavy showers of rain.

Only after 6200 ± 1000 or 6080 ± 420 BP does the series of pelitic layers in section 82/13 become denser, and there is a more or less continuous deposition of the thick pelitic top, lasting up to about 5000 BP (cf. Fig. 2). Some evidence of earlier human occupation exists; however, radiocarbon dates
<table>
<thead>
<tr>
<th>No.</th>
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<th>Material</th>
<th>Source</th>
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<tr>
<td>Hv 11644</td>
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<td>Section 82/13, 720 cm below top</td>
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<tr>
<td>Hv 11648</td>
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<td>Site 82/22, ditch</td>
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<tr>
<td>KN 3149</td>
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<td>Site 82/15, hearth</td>
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<tr>
<td>KN 3182</td>
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<td>Site 82/19, hearth</td>
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Wadi Ard el Akhdar:

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<tr>
<th>No.</th>
<th>Age BP</th>
<th>Site/Stratigraphic level</th>
<th>Material</th>
<th>Source</th>
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<td>KN 2879</td>
<td>9370 ± 215</td>
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<td>KN 2934</td>
<td>7670 ± 75</td>
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<tr>
<td>KN 3191</td>
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<td>KN 3176</td>
<td>5940 ± 230</td>
<td>Site 81/8, surface artifact layer</td>
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<td>KN 3358</td>
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<td>KN 2935</td>
<td>5780 ± 80</td>
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<td>KN 2882</td>
<td>5670 ± 75</td>
<td>Section 80/1, layer A</td>
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<td>KN 3016</td>
<td>5670 ± 65</td>
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<td>Hv 8242</td>
<td>3830 ± 365</td>
<td>Hearth</td>
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<td>Pachur &amp; Gabrieli 1980</td>
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calc. rt. = calcified root casts; ostr. = ostrich egg-shells; p = preliminary date
show that the main settlement phases occurred between 6000 and 5000 BP, both in Wadi el Bakht and Wadi Ard el Akhdar (Cziesla 1986, Schönb 1984; cf. Table 2). This could also be evidence of comparatively favourable climatic conditions.

Not long after c. 5000 BP the deposition of playa sediments stopped in both valleys, as the two main sections 82/13 and 80/7-1 (Figs. 2 and 3) and numerous surface dates show, even if a certain amount of deflation is taken into account. This suggests that the dunes blocking Wadi el Bakht and Wadi Ard el Akhdar were breached during this period. There are two possible explanations: Either the breaches were due to an unprecedented, exceptionally high water pressure or level, pointing to a climatic optimum with comparatively high precipitation or a unique millennial rainfall event. Or the sediments had reached the same height as the dune barriers so that overflow and breaching were inevitable. The fact that the occurrence of thick pelitic deposits (section 82/13) coincides with the cessation of playa sedimentation 'shortly afterwards' and the roughly contemporary breaching of the blockages in both valleys makes the first explanation more likely.

We have now reached the open question of whether accumulation or erosion was the prevailing process during the Saharan pluvials (cf. Butzer 1963, Chavaillon 1964, Hagedorn 1980, and, with reference to Wadi el Bakht, Pahur & Röper 1984). However, it would be going too far here to equate playa formation in the Giff Kebir with arid phases and fluvial erosion with humid conditions. A possible approach to solving this apparent contradiction may be to consider the distribution of rainfall rather than its annual mean, i.e. the rainfall regime, as Gabriel (1977) suggested in the case of the Tibesti mountains. Thus a west-wind-induced type of occasional winter rainfall with steady rains could have alternated with a regime of secular monsoonal-convective summer rainstorms triggered by exceptional northward surges of the surface inter-tropical convergence zone (cf. Pedgley 1974). The former is more likely in the case of the more or less continuous pelitic deposits at the top of section 82/13, and the latter in the case of the preceding and subsequent 'wet' phases. At any rate, after about 5000 BP no more playa sediments were deposited and hence, there is no evidence of the renewed climatic deterioration which is underlined by the fact that the following fluvial erosion obviously had no significant effect on their degradation, at least in Wadi el Bakht. However, this interpretation of events implies that the main gully in the upper Wadi Ard el Akhdar already existed during the late settlement phase around 4000 BP.

In attempting to estimate the approximate rainfall level we do not intend to repeat the above mentioned conclusions which were drawn from the sedimentary structure of the playa deposits, the absence of micro- and nannofossils, the faunal remains of non-aquatic organisms and palaeofloral evidence. Nevertheless, botanical results established by Walther (1979: 124) will be quoted which bear on the question of palaeovegetation — and thus indirectly of the palaeofauna — in the valleys from the desert near Helwan with rainfall
about 25 mm/year. Given that 40% of the rainfall flows down into the deepest parts of the relief which cover about 2% of the whole area there, the plants at these favourable sites would receive the same amount of water as those in the plain with a rainfall of 500 mm/year. Yet we do not have to go that far to explain the occurrence of reeds and resistant species of acacia in the Gilf Kebir valleys. The fact that the vegetation in the valleys was apparently not abundant, suggests that the plant cover on the surrounding plateau was very sparse.

It is true that Neolithic implements in this nowadays completely uninhabited area are surprisingly frequent. However, they are few compared with the abundance of archaeological remains found in the more elevated Tibesti mountains (Gabriel 1977) or in the Wadi Howar (Gabriel & Kröpelin 1986, Kuper 1981). Thus it seems unlikely that the area was permanently occupied even during the most favourable periods.

On the basis of the evidence described above and compared to the conditions under the present Sahel climate (cf. Ibrahim 1980, Mensching 1984, Rózska 1961, Wickens 1976, and others), the amount of rainfall in the Gilf Kebir during the 'Neolithic' pluvials more likely lay within the lower range of 50-100 mm/year estimated by Butzer (1959: 77) and Hester & Hobler (1969: 164) on general considerations for the area. Here, the higher values should be restricted to the mid-Holocene period approximately between 6 000 and 4 500 BP, lasting from the onset of the top pelitic layer at Wadi el Bakht to the time after the barrier breaches.

McHugh (1974: 13) based his estimate of 200-800 mm/year rainfall mainly on the normal ecological requirements of the giraffe, ostrich, oryx and domestic cattle depicted by rock art (cf. Rhotert 1952, Winkler 1939). However, it is not necessary to postulate such a high maximum to account for Neolithic pastoralists migrating seasonally or sporadically at times of good grazing with their herds from the climatically more favourable Jebel Uweint with its waterholes to the southern Gilf Kebir, 150 km away. At the beginning of this century cattle were still being driven 200 km from Kufra oasis to graze in the northwestern Gilf Kebir (now known as Abu Ras Plateau) after exceptional summer rainfall (Almasy 1939: 131 f.). Thus, the conclusions drawn here lie even somewhat below the palaeoclimatic inferences drawn by Paechter & Gabriel (1980) and Paechter & Köpe (1984) from the 'montane variant of pelitic sediments' in the Libyan desert, according to which a semi-arid climate with high wind activity and rainfall around 200 mm/year prevailed at the Gilf Kebir between 8 000 and 4 000 BP.

On the whole, it becomes more evident that climatic conditions during the entire Holocene in this central part of the eastern Sahara were arid, with only a sporadic tendency towards semi-aridity (cf. Cour & Duzer 1976, Meckelein 1982, Wendt & Hassan 1980). It seems possible that such wetter phases may be over-interpreted in some cases.
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