Stefan Kröpelin

The geomorphological and palaeoclimatic framework of prehistoric occupation in the Wadi Bakht area

Abstract

The detailed palaeoclimatic record of Wadi Bakht (Gilf Kebir, Southwest Egypt) and interpretation of associated floral and faunal remains suggest a hyperarid climate similar to the present until 9,300 uncalibrated years bp (8,400 BC). The period between 9,300 and 5,400 bp (8,400 – 4,300 BC) witnessed a moderately arid summer-rain climate with estimated 100-150 mm of annual precipitation and about four major rainfall events per century. With the unique climatic transition at 5,400 bp (4,300 BC), the rainfall regime changed towards a drier winter-rain climate with estimated rainfall below 100 mm per year that lasted until the return of extremely arid conditions at about 4,500 bp (3,300 BC). New geoarchaeological evidence underlines the crucial importance of seasonal rainfall distribution for the vegetation cover and thus for prehistoric settlement and land-use in arid regions.

With few exceptions, the playa lakes have dried out within several weeks or months after the rainy seasons or single major downpours. As a result, the water resources in Wadi Bakht have never been sufficient for permanent settlement in the connotation of years, decades or generations. It may therefore be assumed that the seasonal, periodic or episodic inhabitants of the Gilf Kebir were based at Jebel Ouenat which lies 80 km of its southern tip and which provided permanent water points and lush valleys with optimal conditions for permanent settlement.

Keywords: Eastern Sahara, climate change, Holocene, high-resolution palaeoclimatology, palaeomonsoon, playas, geoarchaeology.

1. The Gilf Kebir

The Gilf Kebir is a huge sandstone plateau in the remote southwest corner of Egypt **[Fig. 1]** (KEMAL EL DINE HUSSEIN 1928). Crossed by the Tropic of Cancer, it represents the core of the Eastern Sahara which today is the largest hyperarid region on earth receiving less than 2 mm of average annual rainfall against a potential evaporation of several metres (HENNING & FLOHN 1977). The increased aridity of this trade wind desert climate half-way between the Mediterranean winter rainfall zone in the north and the summer rainfall zone of the wet-dry tropics in the south is related to the cross circulation of the tropical easterly jet and a strong continentality. Consequently, the Gilf Kebir is virtually inanimate except for some isolated localities with relict vegetation (BACK 1981). Owing to the lack of any surface water or water holes, the area has been void of any human settlement for several millennia.

The Gilf Kebir ("big cliff" in Arabic) consists of two flat-topped plateaus that are connected by a narrow bridge (EMBABI 2004). The northwest part is also known as Abu Ras Plateau (KLITZSCH 1979). The southeast plateau which is treated here, and which is now named Kemal el Din Plateau, has a surface of c. 5,800 km^2, i.e. the size of the Mediterranean island of Corsica. The height of the plateau surface declines from 1,050 m above sea-level at its southern tip to about 900 m a.s.l. in the northern part where it merges with the dune fields of the Great Sand Sea of Egypt. Bounded by steep to vertical cliffs with an approximate

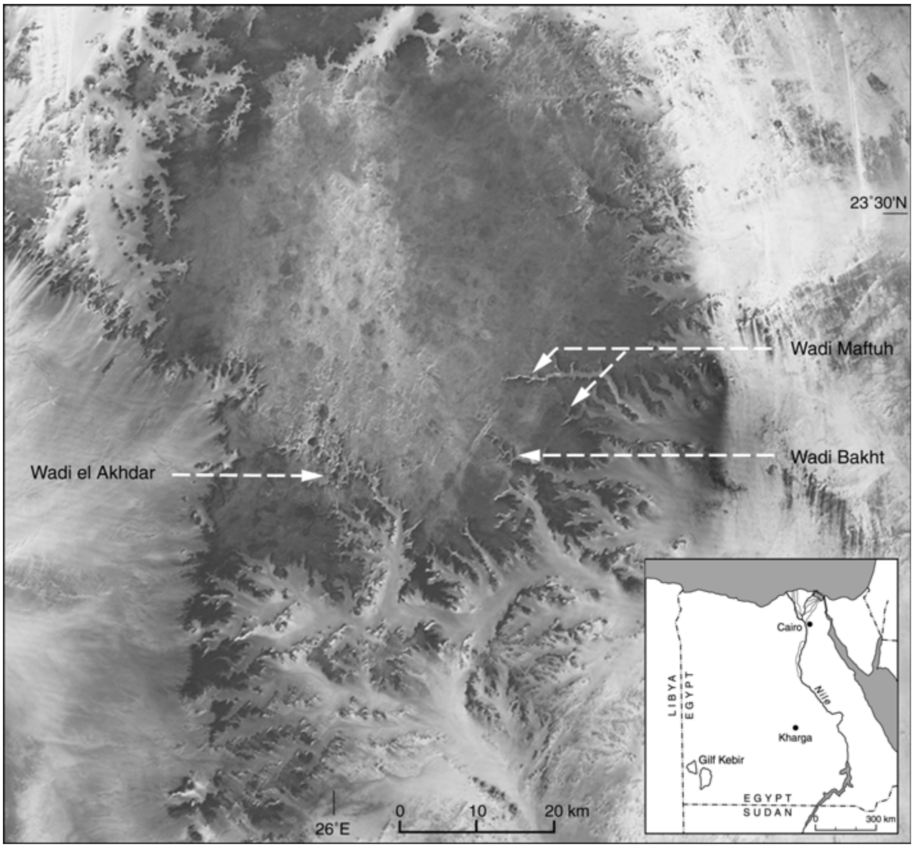


Fig. 1 The southeastern part of the Gilf Kebir plateau with valleys mentioned in text. Inset map shows position in the Western Desert of Egypt. (Apollo VII photograph)

total frontage of 3,000 km, the plateau rises more than 300 m above the surrounding desert plains. The geological structure of the southeast Gilf Kebir consists of horizontally bedded, Jurassic and Cretaceous sandstones, unconformably overlying Pre-Cambrian or Lower Palaeozoic formations (ISSAWI 1971. KLITZSCH & LIST, eds., 1978). Basaltic hills and lava flows, apparently associated with the northwest-southeast, northeast-southwest and north-south striking fault system, indicate intrusive and effusive volcanic activity on the plateau during the Upper Tertiary (FRANZ et al. 1987). Judging on their fresh morphology, some volcanic features possibly even date to the Quaternary (KRÖPELIN 1989).

The existing morphology of the southeast plateau with its box canyons and abrupt headcuts is controlled by the highly resistant ferruginous or silicified cap-rock (PEEL 1939). The initial fluvial dissection probably cut into overlying, less resistant shales which were later completely stripped by deflation (HAYNES 1981). Other processes such as subsurface drainage with undercutting of cliffs and sapping have contributed to the formation of steep valley sides and heads (MAXWELL 1981), just as the aeolian activity during the mainly arid conditions of the Quaternary overprinted the entire landscape (McCAULEY et al. 1981).

The southeast plateau is irregularly dissected by up to 20 km long and up to 4 km wide canyon-like valleys which predominantly trend from west to east. The wadis are flat-floored with remnants of drainage channels in their alluvial fill. As a consequence of the nearly constant northerly trade winds and an almost infinite source of sand in the Great Sand Sea in the north, dune barriers have partly or completely blocked the upper courses of the valleys running at right angles during the arid phases of the Quaternary. This specific set of geomorphologic factors has permitted the accumulation and preservation of fine-grained playa (still-water) deposits during the intervening, relatively short humid periods of the Pleistocene, and in particular during the early and middle Holocene.

2. Wadi Bakht

Wadi Bakht ("lucky valley" in Arabic; BAGNOLD et al. 1939) is one of the longest valleys of the southeast Gilf Kebir **[Fig. 2]**. 12.5 km below the valley head, the typical sandy-pebbly wadi deposits gradually transform to a pelitic facies. This is the location of the pluvial playa which has been singled out for its outstanding potential for the study of late prehistoric palaeoenvironments and cultural adaptation in the area (McHUGH 1980). Its unique palaeoclimatic archive and rich archaeological heritage has attracted scientific missions since the 1970s (WENDORF & SCHILD 1980. KUPER 1981. EL-BAZ & MAXWELL, eds., 1982. PACHUR & RÖPER 1984. KRÖPELIN 1987).

Playas which are not groundwater-fed provide some of the most reliable palaeoclimate archives because their occurrence is solely caused by local rains and drainage, contrary to the palaeolakes in the Sahara which are always dependent on specific conditions such as groundwater-buffering, the effect of which is often difficult to assess. The evidence from Wadi Bakht strongly suggests that the early- to mid-Holocene playas of the Gilf Kebir were such "dry playas", i.e. temporary pools containing water for days, weeks or months only.

The position of the playa and the thick valley fill are due to the previous complete blockage of the valley by a still partly preserved fossil dune the northern part of which is covered by a recent falling dune **[Fig. 3]**. The longitudinal profile of the talweg is almost horizontal over 3 km above the dune barrier with a gradient of only 4.15 m/ 950 m, i.e. 0.0044 (KRÖPELIN 1989). This indicates that the local base level remained stable over a long period

The playa sediments are exposed over an area of at least 65,000 m^2. Mud crack polygons of different orders with diameters of 1-10 m run through the playa surface and attest to the final desiccation. The northeast corner of the playa was lowered about 3 m by increased deflation caused by turbulences at the foot of the falling dune. Here several metre-high yardangs are preserved at different levels. They provide evidence of roots and stems that indicate small trees and reed belts of *Phragmites communis* along the former shore of the playas.

The central part of the playa is covered by a 400 m^2 sized, 3 cm thick layer of curled clay flakes, the remains of the last noteworthy rains which probably fell during the 1930s. Similar deposits were found 11 km northward, in the so-called "Winkelwadi", the northern branch of Wadi Maftuh (PACHUR & GABRIEL 1980). These clay sediments are evidence of secular downpours which occur even during the present hyperarid climate. Water columns of more than 2 m can be attained in such short-lived rain-pools (KRÖPELIN 1989). Cemented-in petrol cans in contemporary clay flake playas south of Wadi el Akhdar are proof of their recent age.

Prehistoric remains on the slopes of the blocking dune are remarkably rich for the Gilf Kebir area. The dense layer of countless stone artefacts has contributed to its preservation. However, the quantities are not to be compared with the abundance of archaeological material on hundreds of huge dune habitats ("Siedeldünen" in German) along the Lower Wadi Howar in Northwest Sudan that resulted from continuous settlement over centuries or millennia (KRÖPELIN in print).

3. Section Wadi Bakht 82/13

The palaeoclimatologically most significant playa deposits in the Gilf Kebir are exposed in an erosion gap **[Fig. 4]**. This minor channel incision in the eastern edge of the playa deposits and the blocking dune forms a step-like gorge which descends 9 m from the horizontal playa surface to the level of the original valley floor over a horizontal distance of 20 m only. At this site, the dune barrier was breached, thus terminating the former local base level and re-establishing normal wadi flow down the valley.

Even after more than two decades of extensive Quaternary-science field research, the geological main section 82/13 in Wadi Bakht may still be considered the most indicative key section for the climatic evolution of the central Eastern Sahara during the past 12,000 years. It provides the thickest and most detailed sedimentary archive of the entire Western Desert of Egypt (KRÖPELIN 1993a). Such palaeoclimatic data from remote,

Fig. 2 Wadi Bakht. View from the southern rim on the upper course with the residual blocking dune which caused the accumulation of still-water deposits during the early and mid-Holocene. Note the almost horizontal playa surface beyond the former dune barrier and the regular gradient below. Width of valley at the dune: 650 m, difference in elevation between sandstone plateau and playa surface: 110 m. Trucks for scale.

highly continental areas are essential to obtain a comprehensive understanding of past climate systems, without which evaluation and calibration of numeric climate models and reliable forecasting of future conditions are not possible. They also provide the evidence on the climatic and ecological framework of prehistoric occupation in arid areas and enable the comparison of geological and archaeological chronological data to reveal conformities or discrepancies between climatic conditions and human agency.

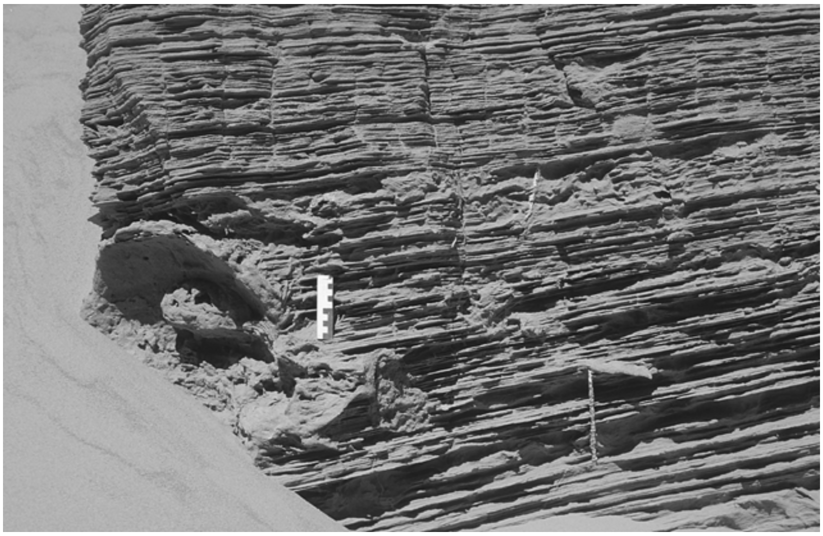
The base of the section consists of wind-blown sands which formed the western slope of the fossil blocking dune. They consist of thinly laminated cross-bedded medium sand with distinct grain-size differences between individual lamina which point to varying wind speeds at the moment of deposition. Along the former shore, the aeolian sands are slightly consolidated by bonding agents infiltrated during the later lake phases **[Fig. 5a]**. The dune sands are succeeded by reddish yellow sands which are referred to as "playa sands" in the sense of sands that have been deposited in the playa area (KRÖPELIN 1987). The medium to coarse grained sands are well consolidated due to a pelitic matrix.

The following deposits are composed of thin alternating layers of siliceous mud and partly cemented playa sands. Microstratigraphical features and the thinness of the clayey-silty mud layers indicate the event-controlled character of the pelitic layers as well as their generally short duration of sedimentation **[Fig. 5b]**. Both the mud deposits and the intermediate playa sands are non-calcareous and biologically virtually sterile, with the exception of rare unspecific grass phytoliths. This is contrast to the carbonatic, highly fossiliferous sediments that are typical of the permanent palaeolakes in the more southerly regions of the Eastern Sahara (GABRIEL & KRÖPELIN 1983. KRÖPELIN & SOULIE-MÄRSCHE 1991. KRÖPELIN 1999. HOELZMANN et al. 2001).

Load casts are an important argument in favour of the playa sands having been deposited in a wet environment. The pressure marks are evidence of the plasticity of the still water-saturated pelitic layers during or shortly after sedimentation. Curled clay flakes, on the other hand, which would be evidence of complete desiccation, do not occur at all. Therefore, the playa sands can not be interpreted as wind-blown sand sheets that were

Fig. 3 The recent sharp-crested falling dune below the northern rim is superposed on the ancient blocking dune; elsewhere, its upper parts have been deflated. The site of section Wadi Bakht 82/13 is located in the centre. The light patch on the playa surface results from thin curled clay flakes, which probably date from the last rains worth mentioning during the 1930s.

Fig. 4 Wadi Bakht, site of section 82/13. The gorge exposing the outstanding natural outcrop was caused by the breaching of the ancient dune barrier at about 4800 bp (3300 BC) and subsequent fluvial erosion. The playa sediments dip up-valley near the former shore of the playa lakes and are more than 8 m thick here.



a **Fig. 5a** Close-up of the aeolian layers of the Terminal Pleistocene blocking dune showing calcareous stem and root casts of reed and termite burrow that date from the early Holocene. The finely laminated structure is partly disturbed by bioturbational features. Scale: 10 cm.

b **Fig. 5b** Detail of playa layers, each of which records a single major rainfall event. Load casts at the basal sides of the intermediate sandy layers indicate that they have been deposited on the still water-saturated mud layers. Scale: 10 cm.

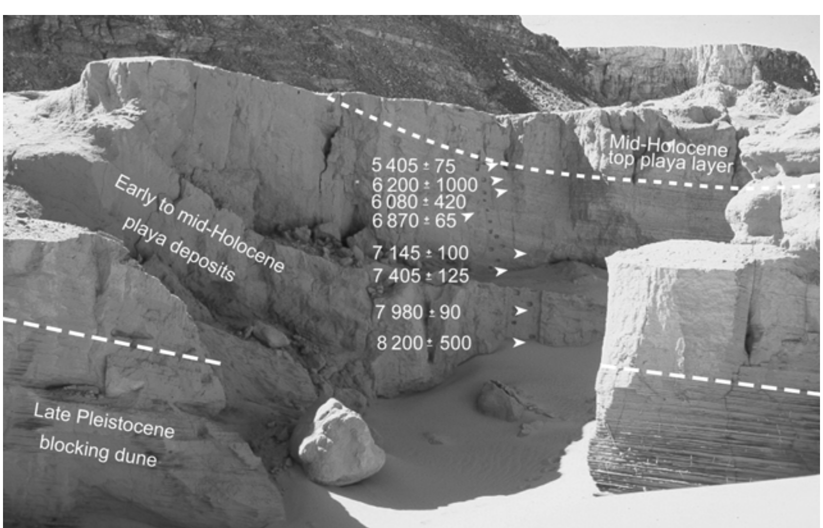


Fig. 6 Section Wadi Bakht 82/13 with uncalibrated charcoal radiocarbon dates and main stratigraphic units.

deposited after total desiccation of the playa lakes. Even close to the former lake shore, the overall thickness of the playa strata exceeds 8 m **[Fig. 6]**. These pelitic layers occur 89 times within the section and have an average thickness of only 14 mm, disregarding the singular, more than 1 m thick top layer **[Fig. 7]**.

The rain pools or playa lakes in which the fine particles of the incoming were deposited under still-water sedimentary environments were fed exclusively by local rainfall and run-off (KRÖPELIN 1987. 1989). These were ephemeral lakes that contained water for weeks or months at most. Evidence for this interpretation includes sedimentological parameters such as the thinness of the mud layers, the lack of any aquatic organisms or plant remains requiring permanent water, the extremely high rates of potential evaporation at this geographical position, and the exclusion of groundwater-buffering because of the enormous depth of the regional aquifer. According to the topography of the valleys and information from the bore hole at "Eight Bells" 40 km southwest – the only drill site in the Gilf Kebir region –, the regional groundwater level appears to lie several hundred meters below the playa surface.

4. Chronology

In agreement with all available palaeoclimate data, it is beyond any doubt that at least the lower parts of the dune which hydrologically blocked the entire valley of Wadi Bakht can be attributed to the terminal Pleistocene hyperarid phase, even if there are still no direct thermoluminescence dates.

Considering the onset of playa sedimentation in the neighbouring Wadi el Akhdar (KRÖPELIN 1989) and the general onset of humid conditions over the entire Eastern Sahara at approximately 9,300 bp (8,400 BC – KRÖPELIN 1993b. HAYNES 2001) there are strong arguments to place the beginning of aquatic sedimentation in Wadi Bakht to the same stage. It is obvious that the earliest playa sediments must have been deposited in the central and deepest part of the playa basin. Therefore they are not exposed in the natural outcrop which is situated at least several decametres east of the presumed centre. This inference is in accordance with the estimated thickness of the hidden sediments in view of the swiftly decreasing dip of the strata towards the bottom of the playa basin, the mapped extent of the playa surface, and the average sedimentation rate.

Tiny pieces of charcoal can be observed in many of the exposed pelitic layers. They are from former human activities at the lake shore, or from wind-blown burned material resulting from natural or anthropogenic shrub or grass fires on the surrounding plateau or in the valley. Due to the lack of appropriate charcoal samples and restraints in dating techniques on small quantities of carbon by conventional methods, the first established chronology included long chronological gaps and high sigma values (KRÖPELIN 1987. 1989). New Accelerator Mass Spectrometry (AMS) dates of very small charcoal fragments from the most interesting stratigraphical positions substantially improved the temporal resolution in the middle part and particularly the top of the section 82/13 (LINSTÄDTER & KRÖPELIN 2004).

Many more and bigger charcoal samples could be retrieved for high-resolution dating at sub-century or even decadal scale by gradually cutting back the exposed section by aid of a mechanical excavator. This would have meant, however, the partial destruction of this outstanding locality, which is a candidate for the nomination as a "Geological Monument" in the Global Indicative List of Geologically Relevant Sites of UNESCO (KRÖPELIN 1996). The location may even become one of the highlights of a proposed protected area within UNESCO's recent "GeoParks" initiative (KRÖPELIN 2000). For all future geological work in fragile sites like the Wadi Bakht, it will be important to find a well-balanced compromise between scientific interest and the preservation of natural heritage.

Lacking any stratigraphical unconformities, the sedimentary sequence of playa section 82/13 has recorded every major rainfall event in the Gilf Kebir during the entire early and mid-Holocene, i.e. over a period of 5,500 calendar years (KRÖPELIN 1989). The AMS date of 5,405 ± 75 bp (4,210 ± 110 BC; Erl-2873) marks the onset of the compact, 120 cm thick near-top layer, that differs from the much thinner layers below because of its thickness and the lack of interlayering sand. This sharp

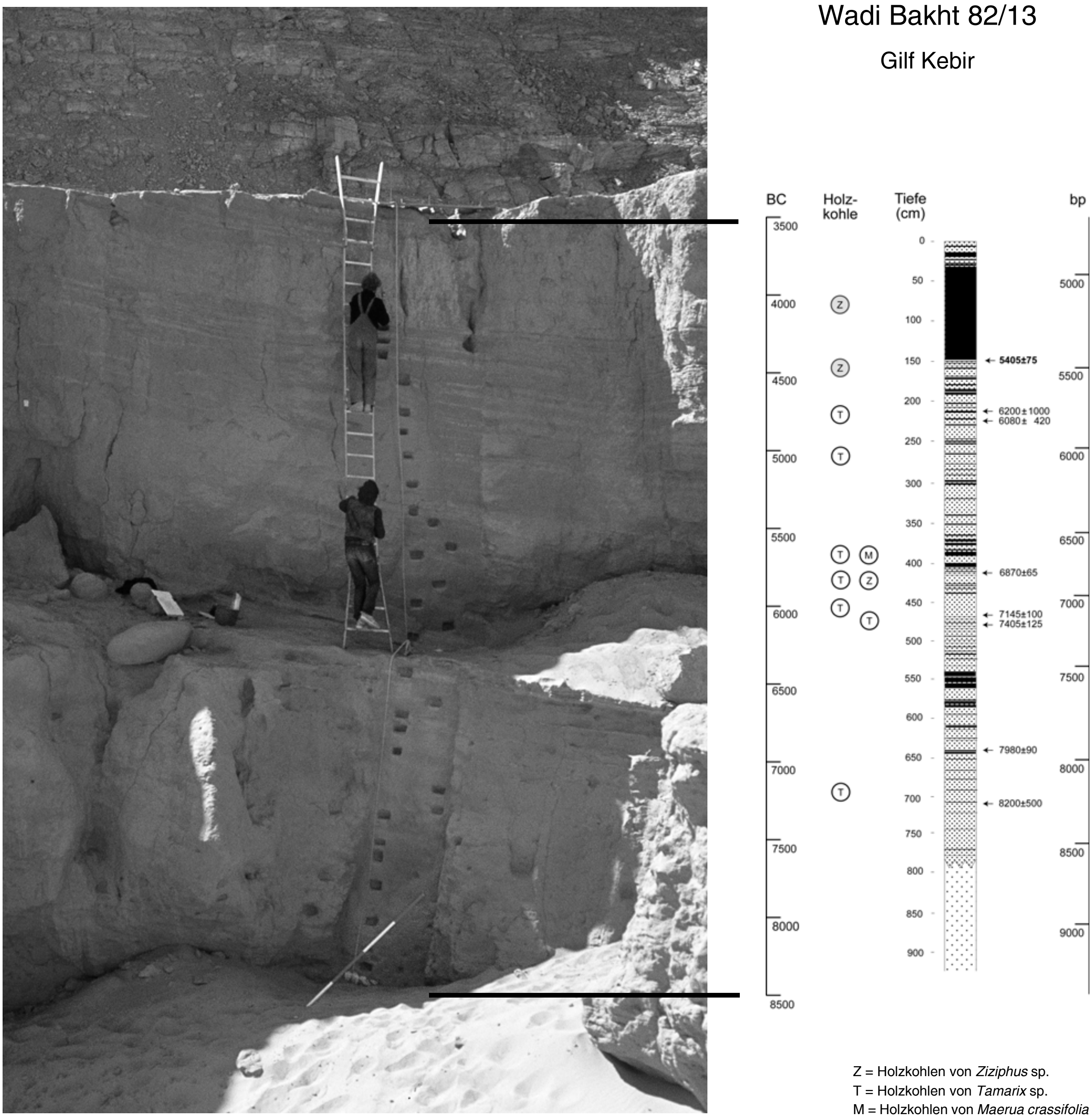


Fig. 7 Section Wadi Bakht 82/13 during sampling in January 1982 (left) and its stratigraphy with radiocarbon dates and identified plant remains (right). Black signatures designate playa mud deposits, dotted patterns indicate sandy layers.

boundary clearly indicates a major change in the precipitation regime (KRÖPELIN 1987).

The definite end of playa-type accumulation can be put to about 4,800 bp (3,300 BC). This estimate is based on charcoal samples from the three most recent hearths on the playa surface, located very close to the section, that yielded dates of 4,880 ± 390 bp (3,590 ± 480 BC; KN-3182), 4,820 ± 60 bp (3,590 ± 70 BC; KN-3098) and 4,770 ± 130 bp (3,530 ± 140 BC; KN-3184) (KUPER 1989. KRÖPELIN 1989. See also LINSTÄDTER Feuerstellen, this volume).

5. Artefact and plant content

Stone artefacts, mainly unmodified flakes, have been retrieved in section Wadi Bakht 82/13 and adjacent strata down to the base at 8 m depth. Of particular interest are fragments of pottery at depths up to 5 m (KRÖPELIN 1989). They indicate the presence of humans around the playa throughout the millennia which is in agreement with the occupation history of the neighbouring Wadi el Akhdar (see **Fig. 1**), where similar pottery (KUPER 1981) has been dated by associated charcoal to 7,670 ± 75 bp (6,520 ± 70 BC; KN-2934) and 7,700 ± 60 bp (6,530 ± 70 BC; KN-2878. The fresh edges of most of the lithic artefacts from section 82/13 indicate their short duration of exposure after production and their fast deposition within the playa mud.

Owing to the absence of pollen, diatoms and identifiable opal phytoliths, small pieces of charcoal provide the essential information on the past wooden vegetation in Wadi Bakht. Even if most samples of the recent collection from section 82/13 can not be identified to the species because of their very small size (≪ 1 mm), there is evidence of *Tamarix* sp., *Ziziphus* sp. and *Maerua crassifolia* at different levels (determination: St. Nußbaum/Köln). These species fit into the taxonomic composition of earlier anthracological identifications (NEUMANN 1989). Remarkably, *Tamarix* is found throughout the section from a depth of 700 cm (c. 8,200 bp / 7,200 BC) up to 160 cm below the top (c. 5,700 bp / 4,600 BC; see **Fig. 7**). The new find dates back to c. 6,900 bp (5,750 BC) while the previously undated find of *Ziziphus* can now be put to about 5,500 bp (4,400 BC) based on their stratigraphical position.

Tamarix is typical for saline positions on clayey soils and close to open water where it usually inhabits the banks. *Tamarix articulata* which can survive periods of drought is the most likely species for the locality. Today, the sahelian species *Ziziphus mauritiana* densely covers the wadi channels of the Ennedi plateau in Northeast-Chad. This remote plateau situated about 700 km to the southwest still receives monsoonal summer rains of 50-150 mm/year and morphologically resembles the Gilf Kebir. It may therefore be considered a "living Gilf Kebir" and serve as the best modern analogue to the early to mid-Holocene climatic and environmental conditions in southwest Egypt (GEORGE & KRÖPELIN 2000).

The joint occurrence of *Ziziphus*, *Maerua* and *Tamarix* in 380-430 cm depth indicates somewhat wetter conditions around 6,870 ± 65 bp (5,750 ± 60 BC; Erl-2874). *Maerua crassifolia* probably has populated the slopes in low density (comm. St. Nußbaum/Köln). In this context, however, observations in the desert south of Cairo with an annual precipitation of 25 mm have to be taken into account (WALTER 1979). Given that 40 % of the rainfall there collects in the deepest parts of the terrain which make up about 2 % of the area, the plants at these privileged sites receive the same amount of water as those on the plain would only obtain with a rainfall of 500 mm/year. The fact that the vegetation on the bottom of Wadi Bakht was rather limited thus indirectly suggests that the wooden plant cover on the surrounding plateau was very sparse.

6. Palaeoclimatic inferences

The stratigraphic and sedimentological evidence from section Wadi Bakht 82/13 in combination with the previously reported conventional radiocarbon dates on charcoal has been used to develop the following climatic model (KRÖPELIN 1987. 1989). Until about 9,300 bp (8,400 BC) a hyperarid climate, similar to the present one, must have prevailed because of the complete lack of any sedimentological or biological indicators. The period between 9,300 bp (8,400 BC) and approximately 5,400 bp (4,300 BC) had an arid climate with rare heavy rainfalls (on an average four events per 100 years) enabling incipient soil formation and sparse plant growth in the areas around the temporary rain pools. Between 5,400 and c. 4,500 bp (4,300 – 3,300 BC) conditions tended toward moderate aridity, in agreement with the occurrence of slightly more demanding tropical plant species (NEUMANN 1989) and the apparent main phase of Neolithic settlement in the Gilf Kebir (KUPER 1988. SCHÖN 1996).

In a palaeoclimatic interpretation of the thin discontinuous pelitic layers in the lower parts of the section 82/13 and the thick continuous pelitic layer in the top, it had been concluded that a regime of secular monsoonal-convective summer rains triggered by exceptional northward surges of the surface intertropical convergence zone prevailed from about 9,300 – 5,400 bp (8,400 – 4,300 BC). From 5,400 – 4,500 bp (4,300 – 3,300 BC), this phase was succeeded by a west-wind induced type of climate with occasional winter rainfall with steady rains. At about 4,800 bp (3,600 BC) the deposition of playa sediments stopped. This suggests that the dune blocking Wadi Bakht was breached at that time owing to exceptionally high water pressure or level pointing to a rainfall optimum, and/or a unique millennial rainfall event (KRÖPELIN 1987. 1989).

The new evidence of *Ziziphus*, *Maerua* and *Tamarix*, as already mentioned above, at around 6,870 ± 65 bp (5,750 ± 60 BC; Erl-2874) points to a slightly more humid episode and might correspond to isotopic data on increased rainfall at that period from Northwest Sudan (RODRIGUES et al. 2000).

Most crucial is the new AMS date of 5,405 ± 75 bp (4,210 ± 110 BC; Erl-2873) that signifies the time of the only major change in the climatic system to be deciphered from the stratigraphic record of Wadi Bakht. Exclusively at this time, there occurred a sharp change in the depositional system that is thought to mark the transition from an African monsoonal type of climate to a Mediterranean winter rainfall pattern with quantitatively lower amounts but more continuous rainfall during winter. A direct correlation of the 5,400 bp (4,500 BC) transition in the Gilf Kebir with the lowlands of Southwest Egypt is not viable because of the lack of comparable climate archives outside of the groundwater-supported oases that are not suitable for comparisons with the exclusively rainfed "dry playa" of Wadi Bakht (KUPER 1989. NICOLL 2001. SCHILD & WENDORF 2001. WENDORF & SCHILD 2001. GEHLEN et al. 2002). A general climatic instability around 6,000 bp (4,900 BC; i.e. over a period of ± 500 years), however, has also been stated for other regions of Africa and the Sahara (e.g. HOELZMANN et al. 1998. GUO et al. 2000).

Regarding the precipitation rates, stratigraphic and archaeobotanical analyses of the playa deposits lead to the conclusion that the climate in the central part of the Eastern Sahara has been relatively arid during the entire Holocene compared to the western and central Sahara at the same latitude. Even for the humid optimum of the early Holocene, the best-estimate maximum precipitation ranges between 100-150 mm per year (KRÖPELIN 1987. PETERS 1988. NEUMANN 1989). Nevertheless do these low figures of rainfall equate to more than 50 times the present rates of precipitation – a ratio which is in line with the one established for the entire Saharan belt along the Tropic of Cancer with a decreasing gradient from Mauritania to the Nile (PETIT-MAIRE & KRÖPELIN 1991). They also match with the well-established south-north gradient of decreasing precipitation that is supported by extensive evidence between the Wadi Howar at 17° N and the Gilf Kebir (HAYNES 1987. NEUMANN 1989. KRÖPELIN 1993b). In any case did the moderately more humid climatic conditions allow for settlement, gathering activities, nomadic cattle-keeping and far-reaching cultural contacts of prehistoric people, and for faunal migrations (HASSAN 1986. KUPER 1995. KUPER & KRÖPELIN in prep.).

The earlier notion of much more pronounced pluvials with annual rainfall of up to 600-800 mm in the Western Desert of Egypt adopted by some authors (McHUGH 1974. WENDORF et al. 1987) has therefore been an overstatement. Such maximum estimates which were solely based on the interpretation of faunal remains or rock art are not necessary to explain the known facts established for the late Quaternary wet phases in the region (KRÖPELIN & PACHUR 1991).

Modern weather sequences in desert regions may help to explain the climatic conditions in the central Eastern Sahara at the end of the postglacial humid period (GEB 2000). Even if many of the waves and cyclones are weak or not even developed compared to the mid-Holocene conditions because of insufficient humidity at the ground and in the lower troposphere, the dynamics of present-day weather sequences are apparently similar to those of the middle Holocene. They are controlled by

(a) a temporary northward extension of monsoonal rain,
(b) inter-seasonal rain period at the Red Sea, and
(c) an advance of winter rains as far south as latitude 20° N.

Such a combination of tropical and non-tropical weather mechanisms may have resulted in a partial overlapping of areas with both summer and winter rain (GEB 2000). Winter precipitation at that time was presumably of greater extent, abundance and duration, due to increased interior moisture sources. In-situ evaporated moisture was partially recycled to the ground and not completely blown out to the Atlantic as today. Such sources of moisture, advection of water vapour from the south, and advection and production of upper waves or vorticity are major factors.

There is general agreement that arid to hyperarid conditions in the Western Desert of Egypt began around 4,500 bp (3,300 BC – RITCHIE et al. 1985. PACHUR & KRÖPELIN 1989. KUPER 2002). This desiccation of Southwest Egypt, the highly continental centre of the Eastern Sahara, has been an irreversible process. It was the beginning of the continuous southward shift of the desert boundary which roughly corresponds to the 100 mm isohyets, progressing with an average rate of about 35 km per 100 years or 1° latitude per 300 years (HAYNES 1987. KRÖPELIN 1993b).

There was no ecologically significant revival of the rains over the Egyptian desert after the end of the "Neolithic" wet phase. The Nile valley was settled during the Predynastic of Egypt, an interval between c. 4,000 and 3,000 BC, by refugees from the Eastern Sahara fleeing from mid-Holocene droughts; this was the very time when the identity of Egyptian society was forged (HASSAN 1988. KUPER 2002). The coincidence of the desert lands becoming uninhabitable, and the forming of the Pharaonic Nile culture, now confirmed by geo-archaeological field evidence, has been a much-discussed historical and philosophical issue (BUTZER 1959).

7. Geoarchaeological implications

From a geoarchaeological perspective, some of the major questions concern the hydrologic and environmental conditions for prehistoric settlement during different occupation phases and possible climatic explanations for changes in land-use and humanactivities. Even if there is indication of absolute high-stands with a maximum water depth of 7 m in the deepest part of the dune-blocked basin and water volumes of several 100,000 m^3, the large majority of the playa lakes has been much shallower and less voluminous. Considering the potential evaporation rates in the range of several metres per year, the playa lakes must have dried out within several weeks or months after the rainy season or single rainfall events as it is the case today in the rain-fed pools of Northern Kordofan in Sudan or the Ennedi region of Northeast-Chad that receive comparable amounts of precipitation. Therefore, the water resources in Wadi Bakht have never been sufficient for permanent settlement in the connotation of years or decades or even generations with a few possible exceptions that may have occurred during the mid-Holocene playa phase when some open water may have persisted until the onset of the rains in the following year.

Nevertheless, it cannot be totally excluded that there were some small rock pools or gueltas in the Gilf Kebir at the shady steep-sided heads of secondary canyons that provided limited quantities of water all over some of the rainier years. Such potential localities have been observed in one or two amphitheatre-like settings in the northern branch of Wadi Maftuh (Winkelwadi). However, no such sites have been located in the Wadi Bakht or its tributary valleys. As a conclusion, it is most likely that settlement during the entire early and mid-Holocene, or what has been called the "Neolithic wet phase", was possible only temporarily during summer and autumn in the early Holocene, and during the winter months during the middle Holocene.

Because of the geological and hydrological preconditions which prevented water storage in subsurface layers of the playa or on the plateau, there were also little chances to bridge the seasonal or episodic occupation from one year to the other by the use of wells. Accordingly, no signs of well constructions have been observed over the entire Wadi Bakht area.

The unsuitable hydrological conditions for long-term stationary stays in Wadi Bakht also apply to the other valleys of the southeast Gilf Kebir. They differ from the permanent availability of water in the neighbouring Jebel Ouenat some 80 km to the south. There, two permanent springs exist to the present day due to the inselberg's almost 1000 m higher elevation which attracts more rainfall and a hydrogeologically supportive plutonic structure which prevents infiltration, accelerates run-off and provides for pools deeply hidden below giant granite boulders that significantly reduce the evaporation. It may therefore be assumed that the seasonal, periodic or episodic inhabitants of the Gilf Kebir were based at Jebel Ouenat (22° N – 25° E) with its permanent water points and lush valleys. Especially Karkur Talh in its northeast part which drains towards the 80 km distant southern tip of the Gilf Kebir must have provided optimal conditions for permanent settlement all over the early and mid-Holocene, as is well documented by the abundant rock art there (WINKLER 1939. RHOTERT 1952).

A remarkable fact of the prehistoric occupation of the Gilf Kebir is the existence of a Late Neolithic in the 4th and 5th millennium BC. During that period, which was already marked by increased aridity, human settlement elsewhere in the Egyptian part of the Eastern Sahara had already moved to the oasis depressions of Kharga, Dakhla, Farafra and Bahariya, or to the Nile or northern Sudan (KUPER 1988. KUPER & KRÖPELIN in prep.). In the southeast Gilf Kebir, however, the upper reaches of Wadi Bakht and neighbouring Wadi el Akhdar were still used by prehistoric man, apparently even more intensely than during the generally more favourable early Holocene (SCHÖN 1996).

Despite their poor preservation, the faunal inventories of Wadi Bakht show a clear difference between these phases (PETERS 1988. VAN NEER & UERPMANN 1989). While the faunal remains from the earlier phase are restricted to wild game such as antelope and gazelle, the later phase also includes sheep or goat and cattle. This fact, in connection with archaeological indications, led to the inference that the first inhabitants were hunter-gatherers, and that the later ones were pastoral groups, for the needs of which the altered conditions on the plateau provided a suitable habitat (LINSTÄDTER & KRÖPELIN 2004).

An expansion of the settlement to the plateau during a phase of general climatic deterioration in the Eastern Sahara due to the retreating monsoonal rains (HAYNES 1987. KRÖPELIN 1987. PACHUR & KRÖPELIN 1989) seems surprising at first glance but may be explained by a model of climatic control that is supported by new chronological and archaeological evidence (LINSTÄDTER & KRÖPELIN 2004). Apparently, the quantitatively more significant monsoonal summer rains that were characteristic for the early Holocene (9,300 – 5,500 bp / 8,400 – 4,400 BC) typically fell during the day-time and resulted in lower amounts of grass growth on the plateau than the presumed winter rains characteristic for the terminal phase of the Holocene pluvial (5,500 – 4,800 bp / 4,400 – 3,500 BC).

The two precipitation regimes – the short but more violent downpours of monsoon-driven summer rains, and the rather continuous winter-rains – certainly had a different effect upon surface run-off, evaporation and soil infiltration of the water. The winter precipitation, which typically fell at night because of the nocturnal temperature reduction, was subjected to clearly lower evaporation rates than the monsoonal summer rains and resulted in a better moisture penetration of the soil. The steady winter rains also had substantially lower surface run-off rates. The combination of these factors seems to have had a decisive impact on the amount of water available for the plants and especially on the growth of grass. Accordingly, the total annual precipitation seems to have been less important than its temporal distribution, particularly for the exploitable grasslands on the extended plateau surfaces of the Gilf Kebir. Concerning the growth of grass, the orthic solonchaks on the level ground of the plateau (ALAILY 1993) apparently responded more favourably to the winter rains than the cambic arenosols or takyric yermosols on the valley floor that were derived from fluvial sands and debris, or from the pelitic playa deposits.

As a conclusion, the role of seasonal rainfall distribution on cultural landscapes in arid regions seems to have been more significant than the sum of annual precipitation. This assumption involves an aspect neglected in existing numeric models of subtropical palaeoclimates. The unique climatic transition at about 5,500 bp (4,400 BC) appears to have induced a fundamental environmental change that resulted in different patterns of human behaviour, economy and land-use in the canyon-like valleys and on the surrounding plains on the plateau.

Despite a marked trend towards increasing aridity in the region, the mid-Holocene winter rainfall pattern has apparently produced more favourable conditions than the monsoonal short summer precipitation did during the preceding millennia. It facilitated the use of the plateau for groups with pastoral nomadic economies, until even these last retreat areas had to be given up owing to the final desiccation of the Eastern Sahara around 4,500 bp (3,300 BC).

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