Wadi Bakht Revisited: Holocene Climate Change and Prehistoric Occupation in the Gilf Kebir Region of the Eastern Sahara, SW Egypt

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Geoarchaeological and chronological evidence from the remote Gilf Kebir Plateau in southwest Egypt suggests a new model for the influence of early and mid-Holocene precipitation regimes on land-use strategies of prehistoric settlers in what is now the center of the largest hyperarid area on earth. We hypothesize that the quantitatively higher, daytime, monsoon summer rainfall characteristic of the early Holocene (9300–5400 ^{14}C yr B.P./8400–4300 yr B.C.) resulted in less grass growth on the plateau compared to the winter rains that presumably fell in the cool nights during the terminal phase of the Holocene pluvial (5400–4500 yr B.P./4300–3300 yr B.C.). The unparalleled climatic transition at 5400 yr B.P. (4300 yr B.C.) caused a fundamental environmental change that resulted in different patterns of human behavior, economy, and land use in the canyon-like valleys and on the plains surrounding the plateau. The model emphasizes the crucial impact of seasonal rainfall distribution on cultural landscapes in arid regions and the lower significance of annual precipitation rates, with implications for future numeric climate models. It also serves as an example of how past climate changes have affected human societies. © 2004 Wiley Periodicals, Inc.

INTRODUCTION

The Gilf Kebir Plateau is a huge, flat-topped sandstone plateau in the remote southwestern corner of Egypt (Figure 1). Crossed by the Tropic of Cancer, it represents the core of the Eastern Sahara–today the largest hyperarid region on earth, receiving less than 2 mm of average annual rainfall (Henning and Flohn, 1977). The Gilf Kebir ("big cliff" in Arabic) consists of two plateaus that are connected by a narrow bridge. The southeastern plateau has a surface of ca. 5800 km^2, which is about the size of the Mediterranean island of Corsica. The height of the plateau surface declines from 1050 m above sea level (m.a.s.l.) 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 almost vertical cliffs with an approximate total frontage of about 3000 km, the plateau rises more than 300 m above the surround-

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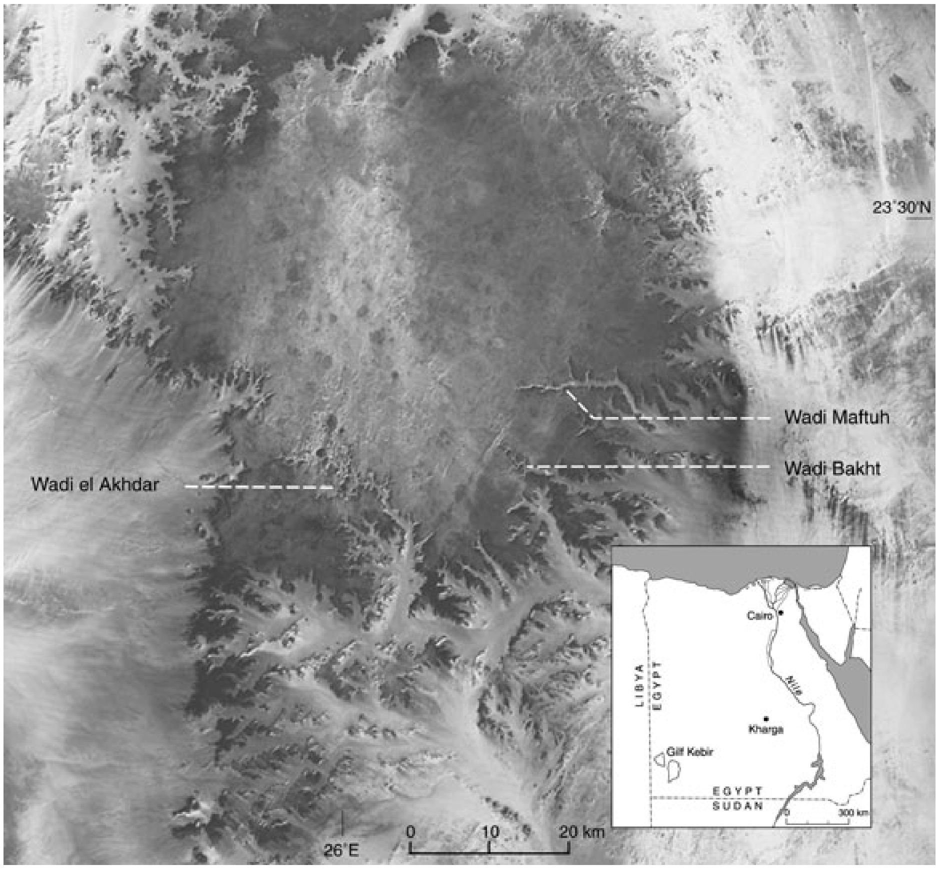

Figure 1. The southeastern part of the Gilf Kebir Plateau (NASA Advanced Space-borne Thermal Emission and Reflection Radiometer Data, processed by subproject E1, SFB 389/ACACIA).

ing desert plains. The eastern part of the plateau is irregularly dissected by canyon-like valleys up to 20 km long and 4 km wide, which trend predominantly west to east. The wadis are typically flat-floored, with remnants of drainage channels in their alluvial fill (Figure 2). Due to the almost complete lack of surface water and the extremely low groundwater level, the area under discussion has been totally uninhabited for several millennia.

The Gilf Kebir was named and approached for the first time by an expedition led by the Egyptian prince Kemal el Din and the geographer John Ball in 1926 (Kemal el Din, 1928). Since the first reconnaissance by the British explorer Ralph Bagnold in 1938 (Bagnold et al., 1939), the eastern valleys of the Gilf Kebir have received only short visits by geologists (Issawi, 1971; Klitzsch, 1979), archaeologists of the Combined Prehistoric Expedition (CPE) (Wendorf and Schild, 1980), and a joint expedition of the Geological Survey of Egypt and NASA (El-Baz and Maxwell, 1982) in the 1970s.

Figure 2. Wadi Bakht. Up-valley view of upper section with playa. Width of valley is 650 m, depth 100–130 m. Trucks for scale (arrow).

Since 1980, the Gilf Kebir and its neighboring regions have become the foci of extended stationary archaeological and palaeoecological field studies by the multidisciplinary research project B.O.S. (Besiedlungsgeschichte der Ost-Sahara, Settlement History of the Eastern Sahara; 1980–1992) and its follow-up project, ACACIA (Arid Climate, Adaptation and Cultural Innovation in Africa, Sonderforschungsbereich 389; since 1995), at the Collaborative Research Center of the University of Cologne.

RESEARCH OBJECTIVES

Reasons for the recent resumption of field work in the Gilf Kebir lay in its unique palaeoclimatic archives and rich archaeological heritage. In 1999 and 2000, two field seasons were dedicated to the study of Wadi Bakht and its surroundings to elucidate the relationship between environmental and cultural change. These questions are crucial within the general research agenda of ACACIA, which aims at a better understanding of the climatic and cultural evolution in northeastern Africa during the Holocene period. ACACIA also aims at a transcontinental comparison with the respective development in the southwestern part of the African continent, focusing on the complex interrelation between humans and changing environmental conditions, as well as human strategies of coping with arid habitats.

Even after two decades of extensive Quaternary field research in the region, the main geological section in Wadi Bakht (Wadi Bakht 82/13) may still be considered the most important key section for documenting the climatic evolution of the central Eastern Sahara during the past 12,000 years. It provides the thickest and most detailed sedimentary archive of Egypt's entire Western Desert (Kröpelin, 1993a), and has been singled out for its outstanding potential for reconstructing late prehistoric palaeoenvironments (McHugh, 1980). Such palaeoclimatic data from remote, highly continental areas are essential to developing a comprehensive understanding of the climate system, which make the evaluation and calibration of numeric climate models and reliable forecasting of future conditions possible.

Due to the lack of appropriate charcoal samples and restraints in dating techniques on small quantities of carbon by conventional methods, the original chronology included long chronological gaps and high sigma values (Kröpelin, 1987, 1989), which called for additional dating. Another reason for resuming fieldwork in Wadi Bakht concerned its archaeological heritage. Since the excavations in the early 1980s, information has been obtained from laboratory analyses of the archaeological finds in the immediate surroundings of section 82/13. However, it became clear that reconstruction of the settlement system required the examination of more distant occupation sites and geomorphic units to collect data pertaining to the interaction of past human activities in the valleys, on the surrounding plains of the plateau surface, and in the eastern foreland of the Gilf Kebir.

To obtain a more integrated picture of the relationship between landscape change and prehistoric occupation in the region, fieldwork focused on:

- Detailed sampling of charcoal remains in the main geological section (Wadi Bakht 82/13), particularly in stratigraphically crucial and undated parts of the sequence, and their archaeobotanical analysis.
- Additional archaeological excavations in the adjacent areas of the plateau to supplement previous excavations at the bottom of the valleys of Wadi el Akhdar and Wadi Bakht, thereby considering the ensemble of the landscape as a former settlement chamber and cultural landscape. Prospecting also included previously unsurveyed sections of Wadi Bakht and the neighboring valley to the north, the so-called "Winkelwadi" (northern branch of Wadi Maftuh), and their alluvial fans in the eastern foreland of the Gilf Kebir to help determine whether these different geomorphic units were used by hunter-gatherers or pastoral nomads.
- Systematic survey of a 4-km-wide transect on the plateau between the three wadis in order to locate sites of raw material procurement and preform production. Emphasis in this context was placed on the size and the configuration of campsites, their respective distances, and their distance from sources of raw material, as well as the relationship between different types of occupation and specific geomorphic contexts.
- Mapping of all sites excavated and documented during the surveys and their integration into a Geographical Information System (GIS).

SECTION WADI BAKHT 82/13

As a consequence of the nearly constant trade winds, blowing roughly north–south, and an almost infinite source of sand from the Great Sand Sea of Egypt in the north, dune barriers have partly or completely blocked the upper courses of the west–east trending valleys during the arid phases of the Quaternary. This specific set of geomorphologic factors has permitted the accumulation and preservation of fine-grained, still-water sediments (so-called "playa" deposits) during the brief, intervening humid periods of the Pleistocene and, in particular, during the early and middle Holocene.

The most palaeoclimatologically significant playa deposits in the Gilf Kebir are exposed in an erosional breach in the upper section of Wadi Bakht. They are exposed over an area of at least 65,000 m^2 and have a maximum thickness of more than 8 m. The deposits are composed of thin alternating layers of siliceous mud and partly cemented sands that indicate water pools fed exclusively by local rainfall and runoff. These rain pools or playa lakes 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 extreme depth of the regional aquifer (Kröpelin, 1987, 1989). According to the topography of the valleys and information from the bore hole at "Eight Bells" some 40 km to the south (the only drill site in the Gilf Kebir region), the regional groundwater level is believed to lie several hundred meters below the playa surface.

Lacking any stratigraphic unconformities, the playa sequence in Wadi Bakht 82/13 appears to record every major rainfall event in the intake area during the entire early and mid-Holocene (i.e., over a period of 5500 calendar years) (Figure 3; Kröpelin, 1989). Microstratigrapical features, such as load casts and the thinness of the mud layers, indicate the event-controlled character of the layers, as well as their generally short sedimentation duration.

The base of the section consists of cross-bedded dune sands deposited during the terminal Pleistocene hyperarid phase and which, in their upper parts, constituted the dune barrier which hydrologically blocked the entire valley at this location (cf. Figure 2). The aeolian sands are thinly laminated and slightly consolidated by synsedimentary and post-depositional processes.

The playa strata conformably overlie the eolianites with an overall thickness of 8 m in the near-lake shore position of the section. These pelitic layers occur 89 times within the top 8 m of the section, and have an average thickness of only 14 mm, disregarding the singular top layer, which is over 1 m thick (Figure 4). It is clear that the earliest playa sediments must have been deposited in the deepest center part of the playa basin. Therefore, they are not exposed in the natural outcrop which is situated at the marginal, down-valley side several tens of meters from the presumed center. 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 9300 yr B.P./8400 yr B.C. (Kröpelin, 1993b; Haynes, 2001),

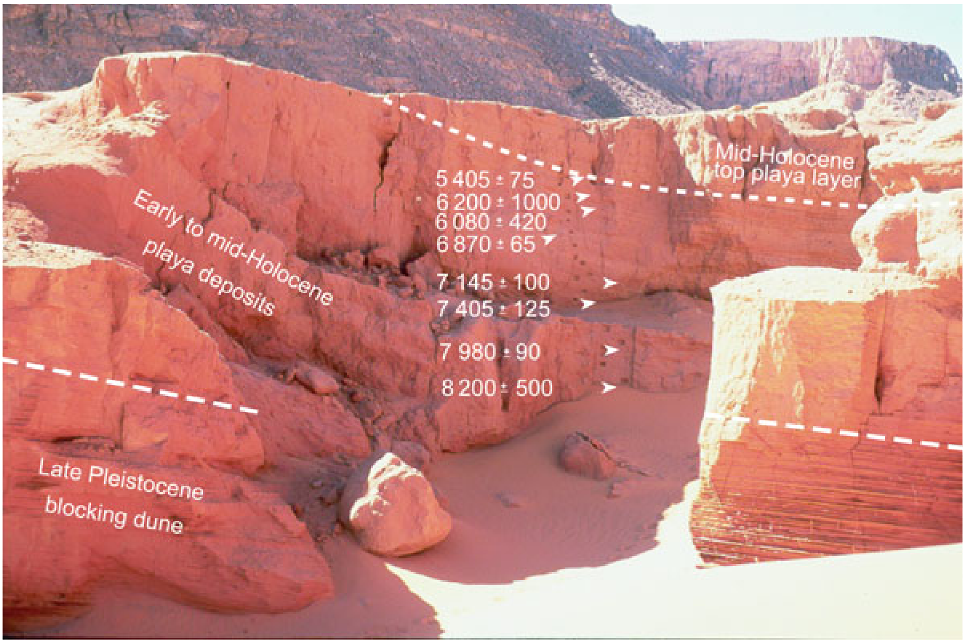

Figure 3. Wadi Bakht Section 82/13 with radiocarbon dates and main stratigraphic units. View to the south.

there are strong grounds to place the beginning of aquatic sedimentation in Wadi Bakht in the same phase. This inference is also consistent with the mapped extent of the playa surface, the average sedimentation rate, and the estimated thickness of hidden sediments in view of the swiftly decreasing dip of the strata towards the bottom of the playa basin (Kröpelin, 1989).

Both the mud deposits and the intercalated medium- to coarse-grained sand strata are noncalcareous and virtually biologically sterile, with the exception of rare, unspecific grass phytoliths. This is in contrast to the carbonatic, highly fossiliferous lake sediments that are typical for the Holocene in the more southerly regions of the Eastern Sahara (Kröpelin, 1993b, 1999; Hoelzmann et al., 2001).

Enhancement of Chronological Resolution

In order to improve the chronological resolution of section 82/13, 26 additional charcoal samples were collected in 1999. The largest pieces of charcoal originated from the already conventionally dated strata, and were, therefore, disregarded for new dating. They are from former human activities at the lake shore, or from windblown burned material resulting from natural or anthropogenic shrub or grass fires on the surrounding plateau or in the valley.

There is little doubt that many more, and bigger, charcoal samples could have been retrieved for high-resolution dating at subcentury, or even decadal scale, by

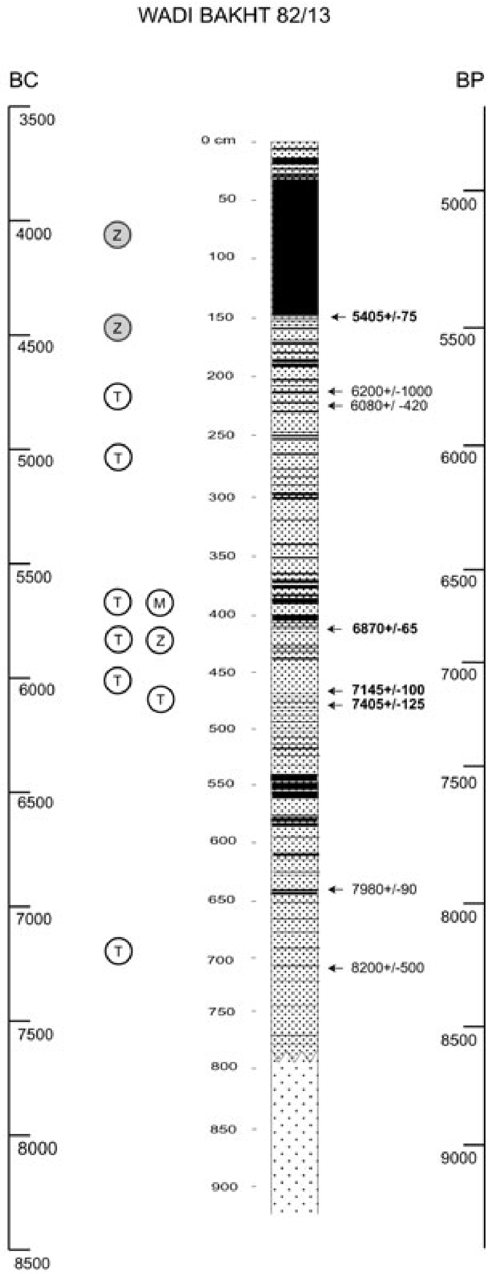

Figure 4. Stratigraphy of Wadi Bakht 82/13 with radiocarbon dates (new AMS dates in bold) and depths of identifiable charcoal remains (previously known finds shaded). Z: *Ziziphus* sp., T: *Tamarix* sp., M: *Maerua crassifolia* (based on Kröpelin, 1987).

gradually cutting back the exposed section with the aid of an available mechanical excavator. However, this would have resulted in the partial destruction of this outstanding locality, which is a candidate for nomination as a "Geological Monument" on UNESCO's Global Indicative List of Geologically Relevant Sites (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.

Accelerator Mass Spectrometry (AMS) dates on six microscopic charcoal fragments from the most interesting stratigraphical positions resulted in only four reliable ages. However, these substantially improved the temporal resolution in the middle part and, particularly, the top of the section, where the available conventional dates left gaps or had very high sigma values of up to 1000 years (Figure 4). The most ancient playa layers that are supposed to have been deposited between ca. 9300 yr B.P./8800 yr B.C. and 8200 yr B.P./7200 yr B.C. are not exposed in section Wadi Bakht 82/13.

The AMS date of 5405 ± 75 yr B.P./4210 ± 110 yr B.C. (Erl-2873) is of particular interest because it marks the onset of the compact, 120-cm-thick layer near the top that differs from the much thinner layers below because of its thickness and the lack of intercalated sand. This sharp stratigraphic boundary clearly indicates a major change in the precipitation regime (Kröpelin, 1987) that only now is reliably dated.

A sample from a pelitic layer 5 cm below the top would have provided a date for the last sedimentation event, but yielded no result due to lack of sufficient carbon. Therefore, the definite end of the accumulation phase must remain at about 4800 yr B.P./3300 yr B.C. This estimate is based on samples from the three most recent hearths on the playa surface, located very close to the section, that yielded dates of 4880 ± 390 yr B.P./3590 ± 480 yr B.C., 4820 ± 60 yr B.P./3590 ± 70 yr B.C., and 4770 ± 130 yr B.P./3530 ± 140 yr B.C. (KN-3182, KN-3098, KN-3184; Kuper, 1989; Kröpelin, 1989).

Artifacts and Archaeobotanical Identifications

Several stratified stone artifacts, mainly unmodified flakes, have also been retrieved near the base of the playa deposits at a depth of 8 m. This indicates the presence of humans around the playa throughout the millennia, which is in agreement with the settlement history in the neighboring Wadi el Akhdar, where the most ancient pottery has been dated to 7670 ± 75 yr B.P./6520 ± 70 yr B.C. and 7700 ± 60 yr B.P./6530 ± 70 yr B.C. (KN-2934, KN-2878 in Kuper, 1981; Pachur and Röper, 1984). The fresh edges of most of the artifacts indicate a short duration of subaerial exposure after production and rapid burial within the playa mud.

The 26 samples from section Wadi Bakht 82/13 yielded 61 single pieces of charcoal from nine different strata. Most, however, could not be identified to the species because of their very small size (< 1 mm), their strong silicification, or their crumbly structure. Fourteen pieces of charcoal, with a minimum edge length of 1 mm, could be identified. Most of these were determined to be *Tamarix* sp., but two pieces belong to the genus *Ziziphus* sp., and one stratum contained a piece of *Maerua crassifolia* (det. St. Nußbaum, Köln).

These species are generally consistent with earlier anthracological identifications, which were based on samples consisting of *Tamarix* sp. and *Ziziphus* sp. (Neumann, 1989). Remarkably, *Tamarix* is found throughout the section from a depth of 700 cm (ca. 8200 yr B.P./7200 yr B.C.) up to 160 cm below the top (ca. 5700 yr B.P./4600 yr B.C.; Figure 4). The previously undated lower occurrence of *Ziziphus* can now be placed at about 5500 yr B.P./4400 yr B.C. The new find dates back to ca. 6900 yr B.P./5750 yr B.C.

Tamarix is characteristic of saline positions on clayey soils and close to open water, where it usually inhabits the banks. *Tamarix articulata* can survive periods of drought, and is the most likely species for the locality. 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 between 50 and 150 mm per year in monsoonal summer rain and morphologically resembles the Gilf Kebir. It may, therefore, be considered a “living Gilf Kebir,” and serve as a best modern analog for the early to mid-Holocene climatic and environmental conditions in southwestern Eygpt (George and Kröpelin, 2000).

The joint occurrence of *Ziziphus*, *Maerua*, and *Tamarix* between depths of 380 and 430 cm indicates somewhat wetter conditions around 6870 ± 65 yr B.P./5750 ± 60 yr B.C. (Erl-2874). *Maerua crassifolia* probably populated the slopes in low density, as observed in comparable modern environments. The sandy down-valley positions were probably covered by savannah-like vegetation, the last relicts of which still occur in a few isolated locations in two valleys of the northwestern part of the Gilf Kebir Plateau (Wadi Hamra, Wadi Abd el Melik), where *Acacia tortilis* ssp. *raddiana* and *Acacia ehrenbergiana*, in association with a few occurrences of *Maerua crassifolia*, form the arboreal vegetation.

Palaeoclimatic Inferences

In combination with the previously reported conventional radiocarbon dates on charcoal, the stratigraphic and sedimentological evidence from the sections in Wadi Bakht and Wadi el Akhdar has been used to develop the following climatic model (Kröpelin, 1987, 1989). Until about 9300 yr B.P., 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 9300 yr B.P./8400 yr B.C. and approximately 6000 yr B.P./4900 yr B.C. 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 6000 and 5000 yr B.P. (4900–3800 yr B.C.), conditions tended toward moderate aridity, in agreement with the occurrence of slightly more demanding tropical plant species (Neumann, 1987) and the apparent main phase of Neolithic settlement (Kuper, 1988, 1993).

In a palaeometeorological interpretation of the thin discontinuous pelitic layers in the lower parts of the section and the thick continuous pelitic layer at 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 9500–6000 yr B.P. (8500–4900 yr B.C.). From 6000–5000 yr B.P. (4900–3800 yr B.C.), this phase was succeeded by a west wind–induced climatic type with occasional, yet steady winter rainfall. At about 4800 yr B.P./3600 yr B.C., the deposition of playa sediments stopped. This suggests that the dune blocking Wadi Bakht was breached at that time due to exceptionally high water pressure or level suggestive of a rainfall optimum, and/or a unique millennial rainfall event (Kröpelin, 1987, 1989).

Supporting evidence for an extreme rainfall event are the uppermost remains of pelitic layers that are preserved at surprisingly elevated positions above the playa surface on the southern slopes. They suggest an absolute high-stand, with a maximum water depth up to 7 m in the deepest part of the former basin. Such a pool must have contained a water volume of several 100,000 m^2.

Regarding 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 along the Tropic of Cancer. Even during the humid optimum of the early and mid-Holocene, the best estimate of maximum precipitation ranges between 100 and 150 mm per year (Kröpelin, 1987, 1989; Neumann, 1987, 1989; Peters, 1988). Therefore, the earlier notion of a much more pronounced Holocene pluvial with rainfall of up to 600–800 mm in the Western Desert of Egypt adopted by some authors (e.g., McHugh, 1974) has been an overstatement. "Maximalist" estimates of rainfall in the range of 200–600 mm, or even more, are not necessary to explain all of the known facts established for the late Quaternary wet phases thus far (Kröpelin and Pachur, 1991).

Nevertheless, even these low figures of palaeo-rainfall during the first half of the Holocene are more than 50 times the current rates of precipitation in the hyperarid core of the Eastern Sahara ($<$ 2 mm of estimated mean annual rainfall). This estimate 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 and Kröpelin, 1991). It also matches the northward decrease of precipitation in northern Sudan that is supported by extensive evidence (e.g., Haynes, 1987; Neumann, 1989; Kröpelin, 1993b). These more favorable climatic conditions were of crucial importance for faunal migrations, nomadic cattle-keeping, gathering activities, and the origins of Egyptian agriculture (Hassan, 1986; Kuper, 1995), and allowed for cultural contacts between prehistoric people from east to west and north to south.

REINTERPRETATION OF THE PALAEOCLIMATOLOGICAL EVIDENCE

The new AMS dates improve the chronological resolution of the stratigraphic record in Wadi Bakht section 82/13 for the first half of the Holocene (about 9500–6000 yr B.P. or 8500–4900 B.C.). This period was interpreted as having a monsoon-controlled climate, with short but violent summer rains (Kröpelin, 1987, 1989). The new evidence of stocks of *Ziziphus*, *Maerua*, and *Tamarix* at around 6870 ± 65 yr B.P./5750 ± 60 yr B.C. suggests a slightly more humid episode, and might correspond to isotopic evidence for increased rainfall during that period in Northwest Sudan (Rodrigues et al., 2000).

Most crucial is the new date of 5405 ± 75 yr B.P./4210 ± 110 yr B.C. (Erl-2873) that marks the onset of the only major climate change to be deciphered from the stratigraphical sequence. At this time, a sharp change occurred in the depositional system that is thought to reflect the transition from an African monsoonal type of climate to a Mediterranean climate with quantitatively lower amounts, but more continuous winter rainfall. A direct correlation between this 5400 yr B.P. transition in the Gilf Kebir with the lowlands of Southwest Egypt is not viable because most of the contemporary climate data from this region originate from groundwater-supported oases, which are not suitable for comparisons with the exclusively rain-fed "dry playa" of Wadi Bakht (cf. Kuper, 1989; Nicoll, 2001; Schild and Wendorf, 2001; Wendorf and Schild, 2001). However, general climatic instability around 6000 yr B.P./4900 yr B.C. (i.e., ±500 years), has also been proposed for other regions of Africa and the Sahara (Hoelzmann et al., 1998; Gasse, 2000; Guo et al., 2000).

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—compared to the mid-Holocene conditions—many of the waves and cyclones are weak or even undeveloped because of insufficient humidity at ground level and in the lower troposphere, the dynamics of present-day weather patterns are apparently similar to those of 6000 years ago. They are controlled by (a) a temporary northward extension of monsoonal rain, (b) an interseasonal rain period at the Red Sea, and (c) an advance of winter rains as far south as 20°N latitude. Such a combination of tropical and nontropical weather mechanisms may have resulted in a partial overlap of areas with both summer and winter rain (Geb, 2000). Winter precipitation at that time was presumably of greater intensity, 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. *In situ* moisture sources, advection of water vapor from the south, and advection and production of upper waves or vorticity are major factors. It is beyond the scope of this paper to speculate more on the climate mechanisms that may have driven the 5400 yr B.P. shift in the precipitation pattern over the Gilf Kebir.

It is also worth noting the abrupt increase in aeolian dust supply centered at 4780 yr B.P./3540 ± 190 yr B.C. in Ocean Drilling Project (ODP) site 658C off Cap Blanc, Mauritania (DeMenocal et al., 2000). The well-dated terrigenous record indicates the abrupt termination of the African humid period at this time, which is attributed to a weakening of the African monsoon system. The climatic transition is thought to have been completed in less than four centuries.

Coupled atmosphere–ocean–vegetation climate models also show an abrupt mid-Holocene shift in subtropical African climate (CLIMBER2; Claussen et al., 1999). The abrupt nature of the modeled climate transition was attributed to the sensitivity of vegetation to changing precipitation patterns associated with the gradually decreasing insolation forcing of the monsoon. The gradually decreasing monsoonal precipitation leads to decreases in vegetation cover. In turn, this raises the surface albedo, as desert sands become increasingly prevalent, thereby reducing the efficiency of the initial radiation forcing of the monsoon (Claussen et al., 1999). The timing and nature of this modeled transition seems consistent with the mid-Holocene stratigraphical evidence from Wadi Bakht and the abrupt increase in aeolian dust supply.

It is now generally agreed that arid to hyperarid conditions in the Western Desert of Egypt began about 4500 yr B.P./3500 yr B.C. (Ritchie et al., 1985; Pachur and Kröpelin, 1989; Kuper, 2002). This desiccation of southwestern Egypt, the high continental center of the eastern Sahara, has been an irreversible process. The desiccation of the southeastern Sahara occurred as a continuous southward shift of the desert boundary (roughly corresponding to the 100 mm isohyet), progressing at an average rate of about 35 km/100 yr or 1° latitude/300 yr (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 (between ca. 4000 and 3000 yr B.C.) 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 development of the Pharaonic Nile culture, now confirmed by geoarchaeological field evidence, has been a much-discussed historical and philosophical issue (e.g., Butzer, 1959).

EXCAVATIONS AND SURVEYS

Archaeological excavations since 1980 concentrated on two major valleys in the southeastern part of the Gilf Kebir: Wadi el Akhdar and Wadi Bakht. In these valleys, numerous sites were excavated by the B.O.S. project from 1980 to 1983 (Kuper, 1981; Hallier, 1996; Schön, 1996; Linstädter, 1999). Figure 5 integrates the major results of this work into a chronological framework, and shows the close relationship between climatic development and settlement history. Archaeological data are combined with the results of sedimentological and archaeozoological data, which reflect the climatic and environmental evolution during the first half of the Holocene.

A remarkable fact of the prehistoric occupation of the Gilf Kebir is the existence of a Late Neolithic (*sensu* CPE; Wendorf et al., 1984) in the 4th and 5th millennium B.C. During that period, which was already marked by increased aridity, human settlements in the vast plains of the Egyptian part of the Eastern Sahara had already moved to the oasis depressions of Kharga, Dakhla, Farafra, and Bahariya (now called the "New Valley"), to the Nile, or to northern Sudan (Kuper, 1988). In the Gilf Kebir, however, the upper reaches of Wadi el Akhdar and Wadi Bakht still supplied adequate water reservoirs as a result of increased seasonal or episodic rainfall that accumulated behind the dunes, which hydrologically blocked both valleys.

The occurrence of numerous, artifact-rich archaeological sites close to these blocking dunes formed the basis of a model of settlement activities in which the upper reaches of the Wadi Bakht and Wadi el Akhdar were considered as mere retreat areas. Questions regarding the extent of the economic area used by the prehistoric population remained unanswered, although it was obvious that the area inside the wadis and close to the dwelling sites could not have been sufficient for the needs of hunter-gatherers nor of nomadic pastoralists.

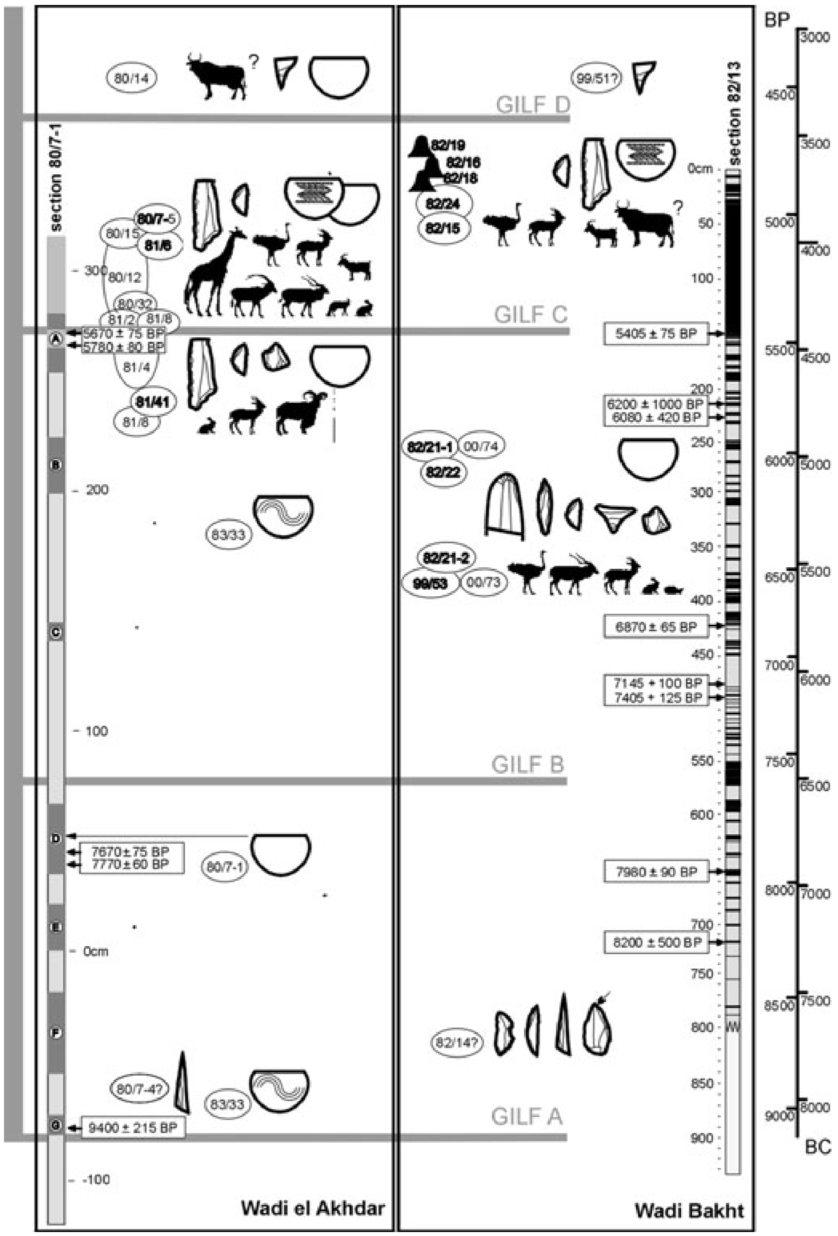

Figure 5. Phases of Holocene settlement in the southeastern Gilf Kebir and their climatic background. Time scales are calibrated (B.C.) and uncalibrated (B.P.) and show charcoal-based ^{14}C dates from the two main sections in Wadi el Akhdar and Wadi Bakht, including new AMS ages from the latter. The left column reflects different phases of (palaeo)soil formation in the sandy lacustrine deposits of Wadi el Akhdar site 80/7-1. The right column shows the interlayering of sandy (grey) and pelitic (black) layers in the key section Wadi Bakht 82/13 in Wadi Bakht. Only radiocarbon-dated sites are displayed. Drawings of artifacts and symbols are not to scale.

Another unresolved problem was the source of raw materials for the production of lithic tools. In the sections of the valley surveyed by the B.O.S. project, no outcrops of quartzite or chalcedony varieties had been found. There were also only a few observations of other archaeological evidence, such as funeral sites or clues regarding material or cultural exchange with other investigated occupation areas in the Eastern Sahara.

Typological Chronology

Since a correlation of the Gilf Kebir artifactual materials with that of other regions in North Africa is still difficult, and because it is beyond the scope of this paper to discuss new concepts or classification systems, such as "Neolithic" vs. "Ceramic" (cf. Kuper, 1995), a local and neutral four-phase system is used here to fit the findings into observable temporal categories: "Gilf A," "Gilf B," "Gilf C," and "Gilf D." Gilf A, which starts at 8100 yr B.C., corresponds to the Epipalaeolithic *sensu* B.O.S. (Gehlen et al., 2002) or Early Neolithic *sensu* CPE (Wendorf et al., 1984). Gilf B (6500–4350 yr B.C.) represents the Middle Neolithic. Gilf C (4350–3500 yr B.C.) corresponds to the CPE-Late Neolithic, which, according to the available data, marks the final phase of human settlement in Wadi Bakht. The last phase, Gilf D, corresponds to the Younger Late Neolithic period ("Jüngeres Spätneolithikum"), defined by the material from the Wadi el Akhdar site 80/14 (Cziesla, 1996; Schön, 1996).

Very little evidence is available from the Gilf A and Gilf D phases. For the Gilf A phase, two radiocarbon dates are available from Wadi el Akhdar (Wadi el Akhdar 80/7-1 and 83/33), while in Wadi Bakht, Epipalaeolithic tools, such as elongated triangles or backed points, could only be extracted from mixed assemblages on the basis of typological features (Gehlen et al., 2002). Only one stone-circle site, excavated on the plateau south of the middle section of Wadi Bakht in 2000 (Wadi Bakht Plateau 99/51), may be assigned to the Gilf D phase. Here, asymmetrical arrow heads comparable to those from Wadi el Akhdar 80/14 were recovered that clearly differ from microlithic forms of other occupation phases of Wadi Bakht. Nevertheless, records for this phase remain extraordinarily rare.

The Gilf B and Gilf C phases are well represented, and were, therefore, the focus of the recent investigations. In total, 151 sites are known in Wadi Bakht and its surroundings. Out of these, 17 sites were described and excavated in the early 1980s. In the course of the resumption of excavations and, in particular, extensive foot surveys in 1999 and 2000, another 134 sites have been added. Among these, 10 sites did not receive further examination, since they consisted of single finds or stone hearths ("Steinplätze," Gabriel, 1987) without any other archaeological material. The remaining 124 sites can be attributed to the following categories:

- Quartzite outcrops: minor bedrock hills with diameters between 10 and 60 m, which, in almost all cases, show evidence of extensive exploitation by humans.
- Camp sites: sites suggesting more extended stays because of evidence for stone hearths or stone circles, or material such as grinding stones, pottery, bones, and ostrich egg shells.

- Isolated workshops: debris indicating short-term stays for supply of stone tools or blanks.

The Lower Reaches of Wadi Bakht and the Foreland

The extensive lower reaches of Wadi Bakht and the other valleys, as well as the entire eastern foreland of the Gilf Kebir, may be considered areas that were used for hunting and herding (Figure 6). The presence of campsites or workshops supports this assumption. The assemblages point to short- and medium-term stays of groups or individuals, as opposed to the long-term or repeated stays in the upper parts of the valleys or on the plateau surface. The artifact inventories reflect a few specialized activities, such as the production of stone tools.

Out of the 30 sites in the lower reaches of Wadi Bakht and Wadi Maftuh and their eastern forelands, 14 are classified as campsites, 12 as workshops, and 4 as outcrops. The small number of outcrops confirms that the area was not primarily used for obtaining lithic raw materials. Including the workshops and campsites, about 88% of the sites point to short- or medium-term stays. In terms of spatial context and artifact density, these sites do not match those studied in the middle section of

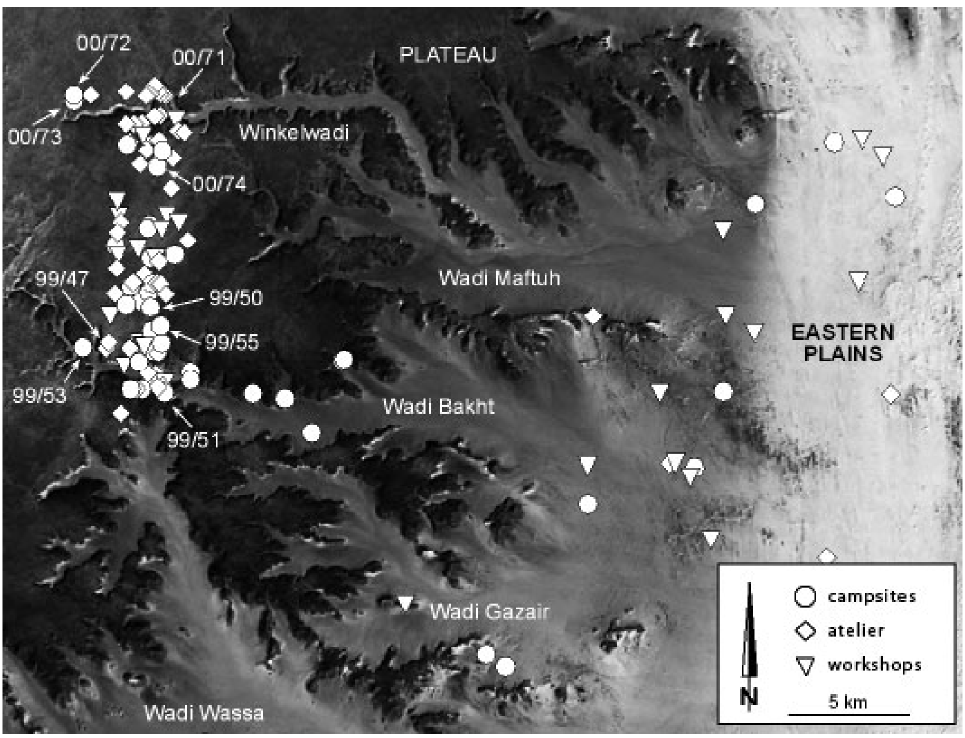

Figure 6. Prehistoric sites in the southeastern Gilf Kebir. The sites were discovered by a vehicle (plains) and a foot survey (plateau) in 1999 and 2000.

Wadi Bakht or in the upper part of Wadi el Akhdar. No processing remains of ostrich egg shells or animal bones were found. Apart from some edge-retouched blades and flakes, the differentiated tool inventories of the sites close to the barrier dune are missing. Ceramics only occurred at one site in the lower reaches of Wadi Bakht and at two sites in the exit of Wadi Maftuh. The undecorated ceramics of these three sites suggest a link to Gilf B. The dating of the other sites is difficult, since typologically indicative tools are absent.

The Plateau

The study area on the surface of the Gilf Kebir Plateau is not accessible by vehicles because of the lack of ascent routes up the valley cliffs. The survey of the 4 × 12 km area was, therefore, undertaken by foot (Figure 6). According to the aforementioned hypothesis, outcrops of different quarzite varieties should be found on the plateau. In fact, out of the 95 discovered sites, more than 50% are outcrops with traces of raw-material exploitation. Some of them are directly connected to a camp site. In addition, 27% other campsites and 19% workshops were also mapped (Figure 7). They show a completely different composition of site types, characterized by rich deposits of raw material. Outcrops and workshops, which mostly occur close to the deposits, form up to 73% of the sites at which the different phases of stone tool production (from acquisition to blank production) were conducted. This seems to

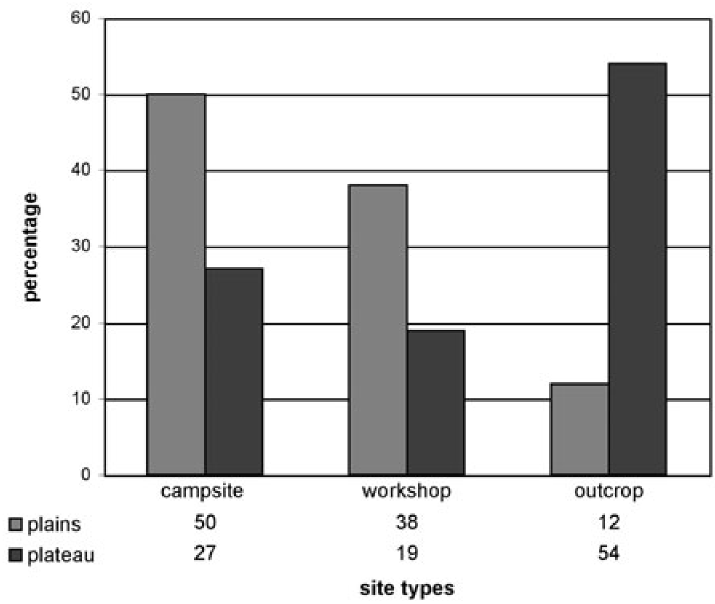

Figure 7. Site types in the plains and on the plateau. On the plateau, more than half of the sites are outcrops with traces of raw-material exploitation. The site-type distribution in the plains is characterized by a dominance of sites with remains reflecting short- to medium-term stay (camps and workshops).

demonstrate that a part of the settlement area on the plateau was primarily used as a source of raw material. The inventories of the remaining sites include isolated and outcrop-attached campsites, and show that the use of the area was not limited to the mentioned activities.

While the production processes near the outcrops have been described elsewhere (Linstädter, 2003), the campsites shall be discussed in more detail. Although the plateau is relatively flat, fluvial drainage patterns are ubiquitous. Water from occasional runoff accumulates in shallow depressions, resulting in fine-grained, playa-type sediments or curled clay flakes. Archaeological inventories at such locations cannot be compared to the inventories of the sites in the Wadi Bakht because of their smaller size. While most of the campsites are located in the positions described above, some are found on small hills of mostly volcanic origin. Stone structures also occur at these hills. Various types of constructions were detected, including partially notched slabs, probably used as tent weights (Wadi Maftuh Plateau 00/74), simple windscreens, stone circles (Wadi Bakht Plateau 99/55), and complex structures (Wadi Bakht Plateau 99/51; Figure 8).

Since the conditions for preservation on the plateau are better than in the foreland, six sites were excavated that yielded datable specimens of ceramics and stone artifacts. This material provides information on the chronological position of individual sites. Out of the seven inventories that include ceramics, Gilf B sherds (Figure 9.5–9.6, corresponding to the middle Neolithic ceramics in Linstädter, 1999) were found only at two sites at the upper end of the northern branch of Wadi

Figure 8. Site Wadi Bakht Plateau 99/51 seen from southeast. In the right background, the steep northern bank of Wadi Bakht is visible.

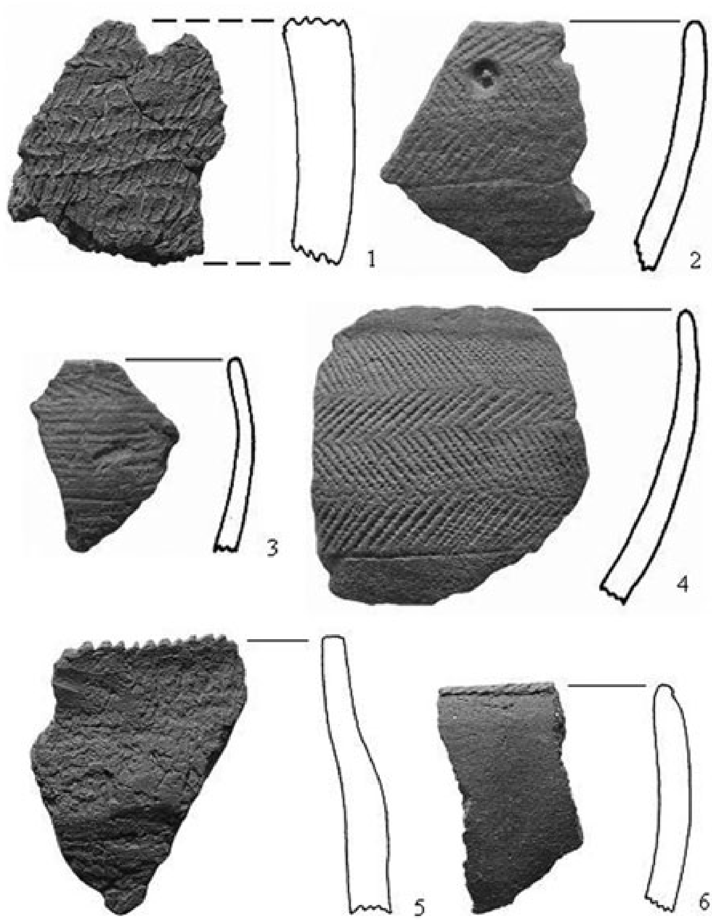

Figure 9. Pottery from sites Wadi Bakht Plateau 99/51 (1), Wadi Bakht Plateau 99/50 (2–4), and Wadi Bakht 82/21 (5–6).

Maftuh (Winkelwadi; Wadi Maftuh Plateau 00/72, Wadi Maftuh Plateau 00/73). Gilf C ceramics (comparable to late Neolithic ceramics in Schön, 1996; Hallier, 1996) were found at six sites distributed over the whole survey area (Figure 9.2–9.4). Evidence of the typical Gilf B microlith forms (Linstädter, 1999), frequently occurring in the middle reaches of the Wadi Bakht, were only found on the plateau site Wadi Maftuh Plateau 00/73 close to the head of Wadi Maftuh, which is dated to 6600 ± 50 yr B.P./5550 ± 50 yr B.C. (KN-5463).

Two sites which supplied interesting material are mentioned here. During the excavation at the Wadi Bakht Plateau site 99/51 (Figure 10a), which features complex stone structures, unusual asymmetrical microliths (Figure 10d) were discovered

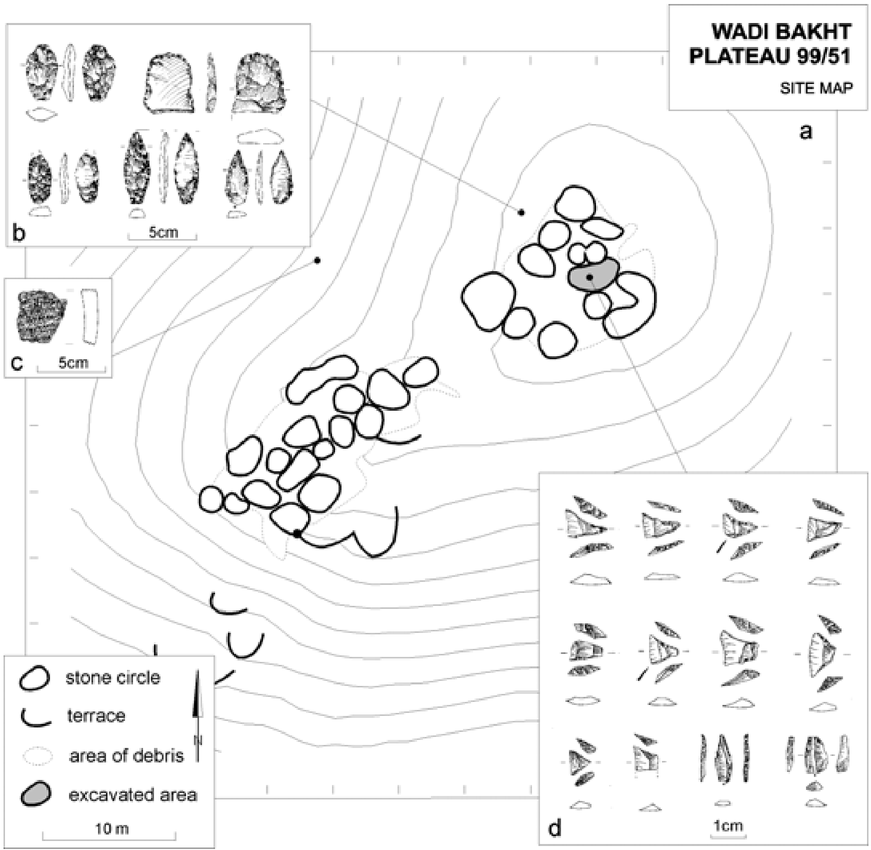

Figure 10. Site map of Wadi Bakht Plateau 99/51. The hill is topped by two flat stone structures (a). Close to the stone structures, bifacially retouched stone tools (b), and a roulette-decorated potsherd (c) were discovered. The excavation of one of the stone circles in the upper (right) structure yielded an inventory with *some transversal arrow heads (d).

that were previously found only on the Wadi el Akhdar site 80/14 (Cziesla, 1996). This site is radiocarbon-dated to the first half of the 3rd millennium B.C. Since no other sites are known from this time in the Gilf Kebir region, these data were considered with reservation. The new finds from Wadi Bakht Plateau 99/51 provide further data concerning the end of the settlement in the Gilf Kebir. Outside the stone structures of Wadi Bakht Plateau 99/51, facially retouched stone artifacts were found (Figure 10b). This artifact type has not yet been recorded in the Gilf Kebir for the Neolithic period. Until now, the Abu Ballas scarp lands southeast of the Dakhla oases were considered to be the southernmost limit of their distribution (Gehlen et al., 2002). In addition "roulette"-decorated pottery was found, which has also not yet been recorded here (Figures 9.1 and 10c).

Based on the distribution, density, and homogeneity of the artifacts, the site Wadi Maftuh Plateau 00/74 appears to be the result of a short- to medium-term stay (Figure 10). The site is located on fluvial deposits at the edge of a depression. Large blocks were brought here from the surrounding outcrops and partially notched. In connection with other groups of artifacts, such as grinding stones or workshops, they may be interpreted as tent constructions. Decorated ceramics were observed in the southeastern part of the site and undecorated ceramics in the southwestern and central sectors (Figure 11). The site is dated by ostrich eggshell to 5850 ± 50 yr B.P./4700 ± 70 yr B.C. (KN-5461).

LAND-USE STRATEGIES

The evidence from the plateau and eastern forelands indicates a cultural landscape in which special land-use systems developed as a function of raw-material availability and geomorphologic factors. The wadis were not independent settlement areas, even if the available data cannot be used to assign every single site to a definite phase. In any case, the new pottery finds encourage a further examination of past typologies. The use of most raw-material sources appears too complex to be completely understood. Nevertheless, on the basis of all now available

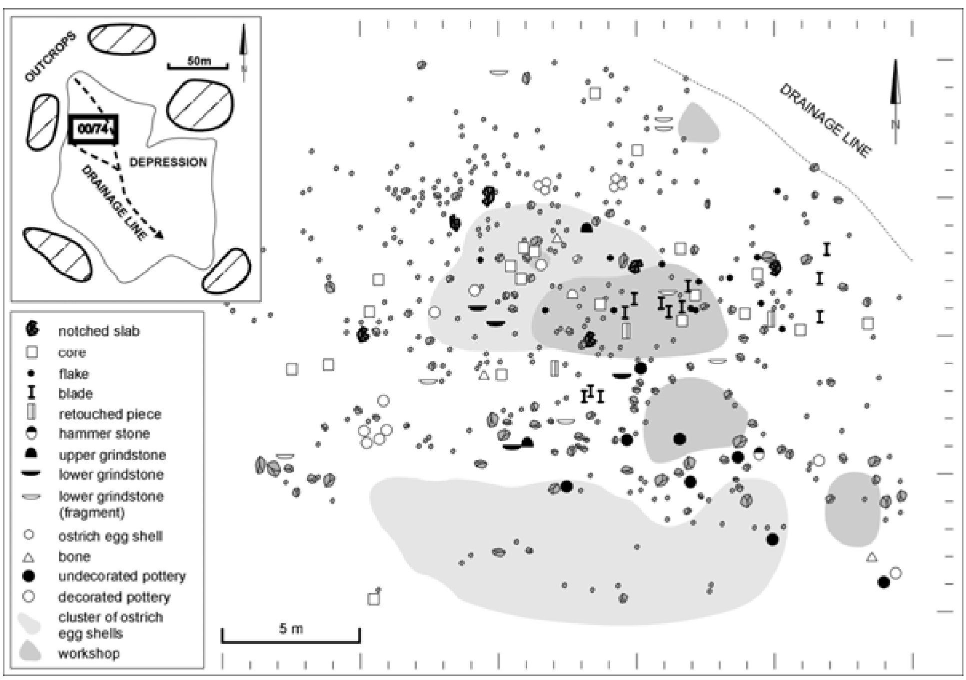

Figure 11. Site map of Wadi Maftuh Plateau 00/74. The site is located at the border of a shallow depression between two drainage lines. The depression is surrounded by some quarzite outcrops.

evidence, the different systems of land use in the Gilf B and Gilf C phases can be distinguished (Figure 12).

Gilf B, at least in the Wadi Bakht, is characterized by large sites of up to 10,000 m^2, with extremely high artifact densities of up to 2000 artifacts per square meter, in particular, on the blocking dune. All material groups and differentiated stone tool inventories are present. Different activities, for instance, the production of ostrich egg shell beads, suggest medium- to long-term stays which go beyond basic food acquisition. While some finds also indicate settlement in the eastern foreland, the use of the plateau during this phase seems to have been less important. Its use is only supported by outcrop sites on the edges of the plateau and by three campsites with ceramics and typical microliths. The evidence remains scarce and is restricted to a distance of 1 km from the plateau edges. Therefore, the Gilf B settlement system was centered in the valley, from where the adjacent parts of the plateau, the lower section of the valley, and the foreland were utilized.

In the Gilf C phase (corresponding to the Late Neolithic *sensu* CPE), the land-use system seems to have changed fundamentally. Sites in the Wadi Bakht only extend over 80–100 m^2, and predominantly occur on the playa surface. The artifact density is extremely low. Nevertheless, sites with material from this phase are located within the examined area of the plateau. It is assumed that the outcrops

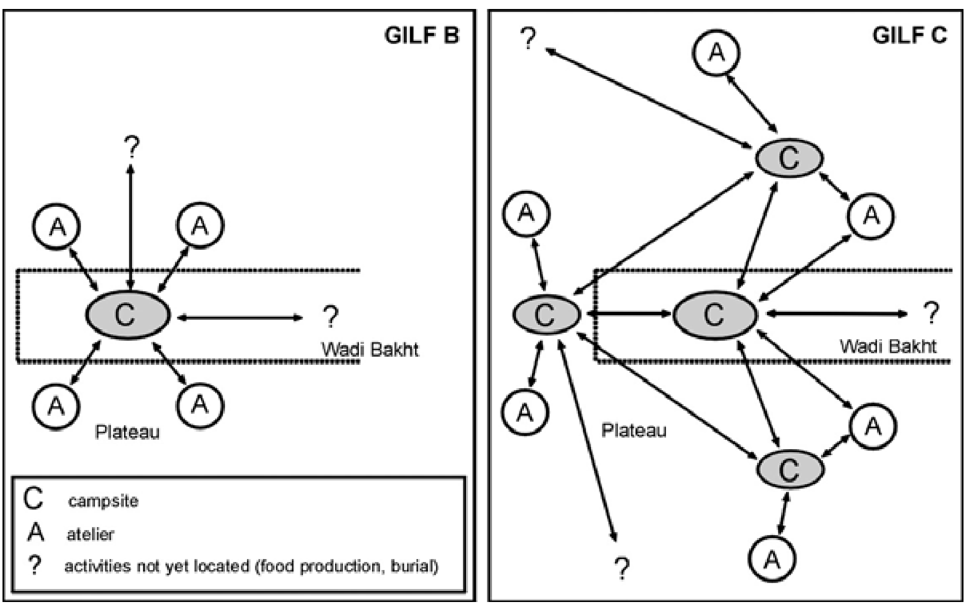

Figure 12. Model of land-use systems in the phases Gilf B and Gilf C in the surroundings of the Wadi Bakht. The Gilf B system is characterized by central campsites in the wadis and an exploitation of the raw-material outcrops at plateau rims. The Gilf C system shows a more net-like distribution of campsites in the wadis, as well as on the plateau. Based on these sites, raw-material outcrops on the whole surveyed plateau were used.

close to the wadis were used in both phases. This observation leads to the conclusion that the main habitat of this phase was the plateau. This inference is supported by observations in the upper reaches of Wadi Maftuh ("Winkelwadi"). Although the valley is also blocked here, in this case by remnants of a Pleistocene terrace (Kröpelin, 1989), there is no evidence of prehistoric settlement on the wadi floor. In the vicinity on the plateau, however, there is the same evidence of extensive use like on the plateau above Wadi Bakht.

CONCLUSIONS

From a geoarchaeological perspective, the major question concerns the reasons for the different use of residential areas during the Gilf B and C phases. Despite their poor preservation, the faunal inventories of Wadi el Akhdar and Wadi Bakht (Peters, 1988; Van Neer and Uerpmann, 1989) show a clear difference between these phases (Figure 5). While the faunal remains from Gilf B are restricted to wild game, such as antelope and gazelle, Gilf C also includes sheep or goat and cattle. This fact, in connection with other indications, such as the abundance of arrowheads in the Gilf B assemblages, leads to the inference that the first settlers were hunter-gatherers. Later settlers were pastoral groups, and the altered conditions on the plateau provided a suitable habitat for this activity.

An expansion of the settlement to the plateau during a phase of general climatic deterioration in the Eastern Sahara due to retreating monsoonal rains (Haynes, 1987; Kröpelin, 1987; Pachur and Kröpelin, 1989) may seem surprising at first glance. Here, we offer a model of climatic control that is supported by the new chronological and archaeological evidence. We propose that the quantitatively more significant monsoonal summer rains that were characteristic of the early Holocene (9300-5500 yr B.P./8400–4400 yr B.C.) typically fell during the daytime, and resulted in less grass growth on the plateau than the presumed winter rains that characterized the terminal phase of the Holocene pluvial period (5500–4800 yr B.P./4400–3500 yr B.C.).

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 runoff, evaporation, and soil infiltration of the water. The winter precipitation, which typically fell at night because of the nocturnal temperature reduction, was clearly subjected to lower evaporation rates than the monsoonal summer rains, and resulted in better moisture penetration into the soil. The steady winter rains also had substantially lower surface runoff rates. The combination of these factors seems to have had a decisive impact on the amount of water available for 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 favorably 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.

Consequently, the unparalleled climatic transition at about 5500 yr B.P./4400 yr B.C. appears to have induced a fundamental environmental change that resulted in different patterns of human behavior, economy, and land use in the canyon-like valleys and on the plains surrounding the plateau. This model emphasizes the crucial impact of seasonal rainfall distribution on cultural landscapes in arid regions and the lower significance of annual precipitation rates. It also implies new aspects for future numeric models of subtropical palaeoclimates.

Despite a marked trend towards increasing aridity in the region, the mid-Holocene winter rainfall pattern apparently produced more favorable conditions than the short summer monsoonal precipitation did during the preceding millennia. It facilitated the use of the plateau for groups with nomadic pastoral economies, until even these last retreat areas had to be abandoned due to the final desiccation of the Eastern Sahara around 4500 yr B.P. (3300 yr B.C.).

While the described phenomena may be relevant to other elevated palaeoenvironments in semiarid regions, it is important to recognize that, in the Eastern Sahara, they have been restricted to the Gilf Kebir Plateau because of its specific altitudinal, geomorphological, and climatic boundary conditions. Ongoing field studies in the corridors of the Great Sand Sea of Egypt will help to evaluate whether there is comparable evidence for the adjacent lowlands.

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