

Holocene Climatic Change and Human Settlement Between the Central Sahara and the Nile Valley: Archaeological and Geomorphological Results

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Supraregional investigations of the Holocene occupational history of the eastern Sahara west of the Nile combined with the study of climatic, environmental, and geomorphological archives were carried out in contrasting desert regions from the Mediterranean coast strip to Wadi Howar in Sudan. The research areas are located far away from groundwater influence and are therefore capable of indicating environmental changes. Climatic development in accordance with nearly 500 ¹⁴C dates from archaeological sites indicates a Holocene optimum lasting from approximately 9500 B.P. till the beginning of the drying trend that set in about 6300 B.P. (9000–5300 cal. B.C.). Although the faunal and floral remains are arid types, they indicate slightly wetter conditions than today. Surface water was the key factor that influenced the adaptation strategies of the mobile hunter-gatherers (and in some parts, the pastoralists) in the desert regions. Large episodic camp sites agglomerated at favorable drainage systems and water pools, and settlement patterns strongly correlate with the paleohydrological factors examined with remote sensing cartography, geomorphological work, and the analysis of digital elevation models. © 2007 Wiley Periodicals, Inc.

INTRODUCTION

The Eastern Sahara is one of the most arid environments on earth, with precipitation less than 5 mm per year in the core area of the desert (New et al., 1999). Today the oases of the Western or Libyan Desert west of the Nile are the only localities which are inhabited because of the permanent groundwater charge of the Nubian Aquifer (Figure 1). During the so-called Holocene “wet phase” (or Holocene climatic optimum) the Eastern Sahara was occupied by hunter-gatherers, and in some parts the introduction of domesticated animals took place under favored ecological conditions. Since 1995, the interdisciplinary Arid Climate, Adaptation and Cultural Innovation in Africa (ACACIA) project of the University of Cologne (www.uni-koeln.de/sfb389) has been focused on the Holocene interaction of climatic and environmental change within the subprojects A1, A2, and E1 and the cultural development and adaptation in the

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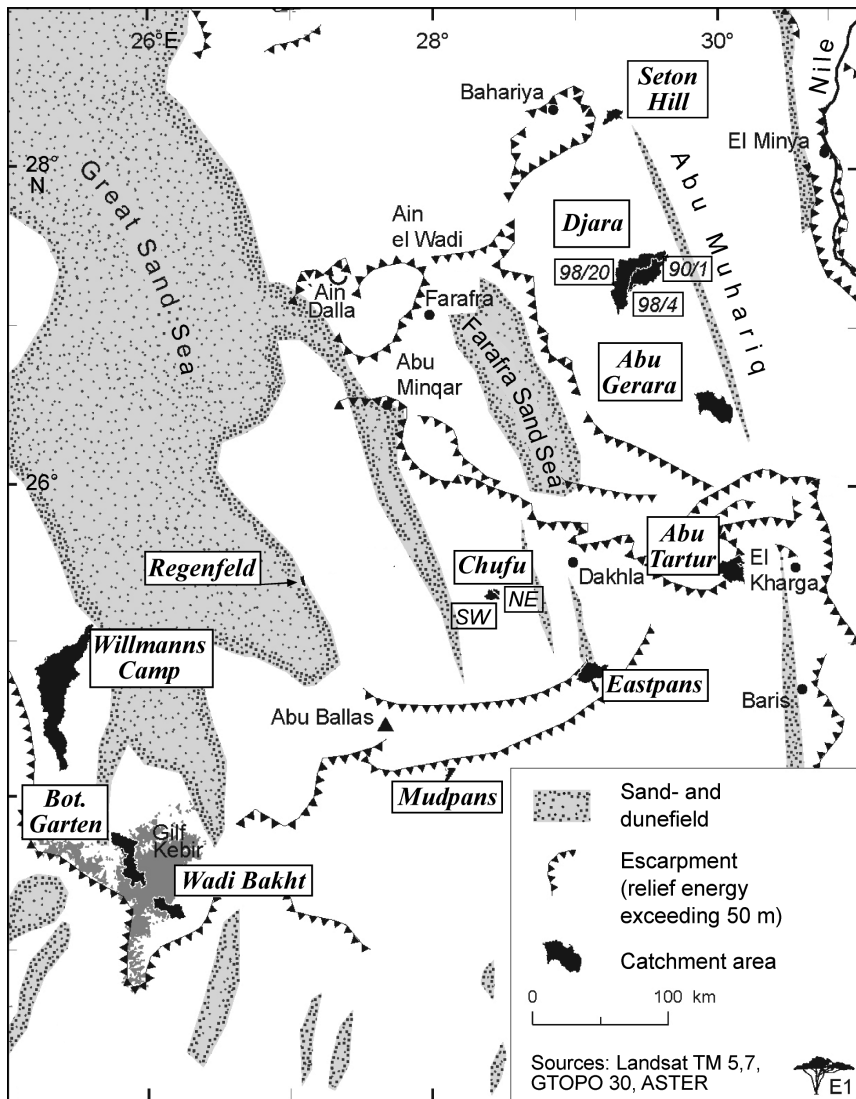


Figure 1. Geomorphological map of the southern part of the Western Desert (Egypt) with the ACACIA research regions and their catchment areas. The escarpments (relief energy exceeding 50 m) were calculated within ArcGIS with the use of GTOPO 30-data, the sand- and dunefields were mapped with the use of Landsat 5 and Landsat 7 data, and the catchment areas were calculated within the ArcGIS and Watershed modelling system (WMS).

Eastern Sahara based on geo-scientific, environmental, and archaeological studies of contrasting sample areas across the Libyan Desert. Following a supraregional approach, a transect of more than 1500 km from the Mediterranean coast in the north to the Wadi Howar in Sudan was investigated (Kuper, 1993; 2002). The data as currently derived from the ACACIA work and the former Cologne-based B.O.S. project

("Besiedlungsgeschichte der Ostsahara") are fundamental sources in reconstructing the climatic and cultural history of the last 12,000 years. The following paper presents an overview of archives, methods, and results of these activities.

THE HOLOCENE WET PHASE

Chronology

The occupational development of the desert areas outside the oases and the Nile Valley is closely linked to the changing climatic conditions (especially rainfall) and associated availability of surface water, vegetation, and animal life. It has been accepted that the number of ^{14}C dates from archaeological sites in arid environments may represent the intensity of human occupation (Vernet and Faure, 2000; Nicoll, 2001). The evidence derived from archaeological excavations and surveys coupled to nearly 500 ^{14}C dates (Figure 2) suggests that the Holocene wet phase lasted from approximately 9500–6000 B.P. (9000–5000 cal. B.C., calibration: dispersion calibration program, Cologne 2001, www.calpal.de). After the hyper-arid Pleistocene, the tropical summer rain front moved about 700–1000 km northward (e.g., Haynes, 1987; Neumann, 1989a; Pachur and Hoelzmann, 2000), which initiated more humid conditions in the Eastern Sahara. Initial playa and lacustrine deposits from Egypt and northern Sudan clearly show the onset of rains and fluvial activity in the Early Holocene between 9800 and 9500 B.P. (9000 cal. B.C.) (Kröpelin, 1993; Haynes, 2001; Hoelzmann, 2002), which is in good accordance with the earliest ^{14}C dates from archaeological sites in the Western Desert (Barich et al., 1991; Close, 1992; Nicoll, 2001; Wendorf et al., 2001; McDonald, 2001; Kuper, 2002; Gehlen et al., 2002). The terminal deterioration of the Eastern Sahara is marked by rapid depopulation effects ("exodus event" after Nicoll, 2001), which started in most desert areas in Egypt around 6000 B.P. (5000 cal. B.C.). The compilation of ^{14}C dates available for the eastern Sahara indicates a shifting of the depopulation trend of approximately 35 km per year toward the south (Figure 2) linked to the southward retreat of the monsoonal summer rain belt (Haynes, 1987; Kröpelin, 1993; Kuper, 2002, 2006).

Despite this general picture, in certain geographical areas slight variations of the occupational history become visible during the wet phase as a response to individual environmental potential (Figure 2). The desert core zone at its lowest carrying capacity, far away from the groundwater-discharge fed oases, is designated as the most sensitive to deterioration tendencies. Examples are the ACACIA study areas of Regenfeld and Mudpans in the southern Great Sand Sea, and Djara situated on the Egyptian Limestone Plateau between the Nile and the curve of the Egyptian oases (Figure 1). The drop off of the cumulative ^{14}C -histograms from these areas is a clear signal that the beginning of the drying trend set in as early as 6300 B.P. (5300 cal. B.C.), whereas ^{14}C curves from the oases and other more favored locations, such as Dakhla, Nabta/Kiseiba region, and Gilf Kebir, lasted longer (Schön, 1996; McDonald, 2001; Wendorf et al., 2001; Linstädter and Kröpelin, 2004).

Although the general pattern of the wet phase was that of a period of continuous human occupation lasting about 4000 years in the Egyptian part of the Eastern Sahara,

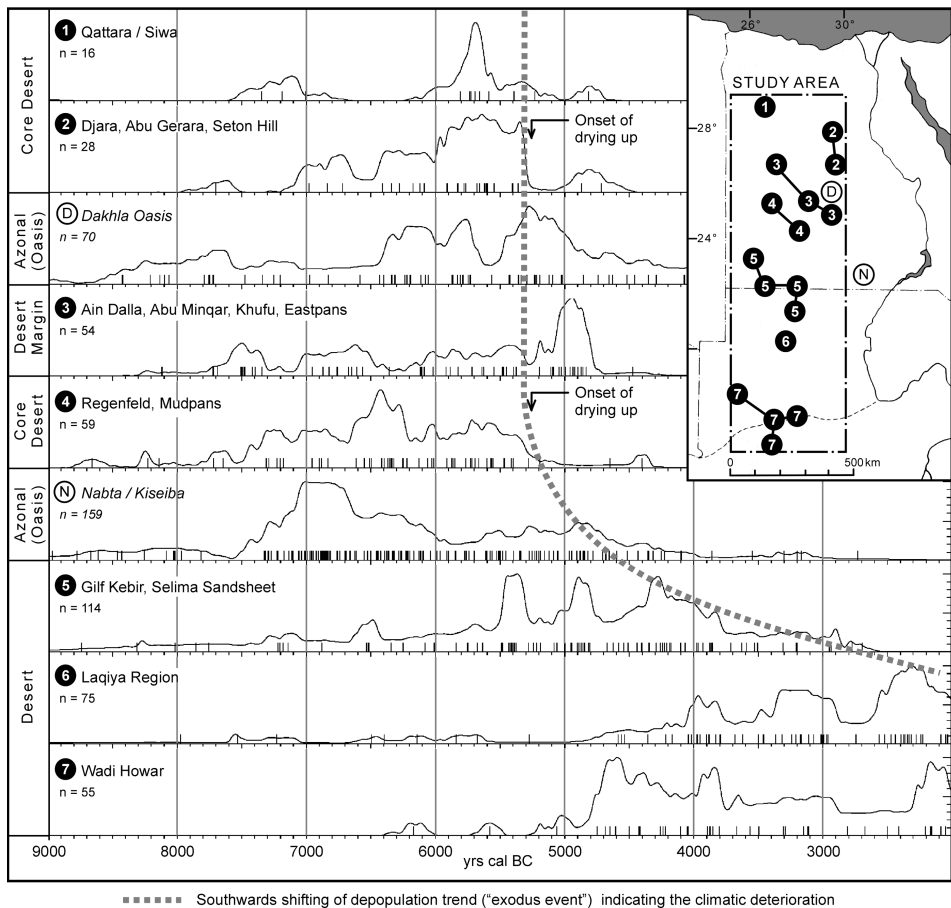


Figure 2. Calibrated ^{14}C chronology (cal. B.C.) showing the occupational history and the beginning of the drying up in the Eastern Sahara (southward shifting of depopulation trend after Kuper, 2006). The ticks on the time scale represent the calibrated ^{14}C mean values of the individual ^{14}C dates. The curves are cumulative histograms, calculated by fitting Gaussian curves in B.P. (uncalibrated) to the calibrated distribution on the y-scale. The dates are calculated and plotted by the Cologne Radiocarbon Calibration and Palaeoclimate Research Package (<http://www.calpal.de>) by B. Weninger. Source: 401 Dates from areas 1–7 by ACACIA/B.O.S.; 70 dates from Dakhla after McDonald, 2001; 159 dates from Nabta/Kiseiba after Wendorf et al., 2001.

the individual ^{14}C curves of the different areas under study form a picture of climatic oscillations and frequent dry inter-phases. However, a striking parallelism across the many individual sequences as a result of general climatic trends within the humid phase is rarely visible. Whereas the Early Holocene is characterized by only a small amount of ^{14}C dates, the accumulation of dates between 8500 and 6300/6000 B.P. (7500–5300/5000 cal. B.C.) is a relatively synchronous phenomenon across the Libyan Desert and is in good concordance with ^{14}C curves (Nicoll, 2001; Wendorf et al., 2001) and sedimentological sequences elsewhere (Brookes, 1993; Kleindienst et al., 1999;

Donner et al., 1999; Hassan et al., 2001; Wendorf et al., 2001). Particularly in the northern regions, such as the Djara area, ¹⁴C dates and additional archaeological data suggest that occupation did not start before 8500 B.P. (7500 cal. B.C.) and rapidly increased from 7500 B.P. (6300 cal. B.C.) onward. Winter rains resulting from a southward shift of the Mediterranean regime might have influenced the northern areas of Egypt during the mid-Holocene (e.g., Vermeersch, 1978; Arz et al., 2003) forming an additional stimulus for occupational events during the cooler winter season with less water loss due to evaporation. Although evidence of an overlap of the rain belts is still rare, archaeobotanical identifications of the Jericho rose (*Anastatica hierochuntica*) in Djara suggest predominant winter rains. This species is currently found on the coastal plain of Egypt and the Negev of Israel. In addition, the presence of domesticated sheep in Djara, which can go without water for several days in the low-temperature winter season, suggests occupation events, which predominantly took place during the winter season (Kindermann et al., 2006).

Environmental Conditions

The environmental conditions during the wet phase are reconstructed throughout a number of studies by the B.O.S. and ACACIA projects as well as by other investigations in the Libyan Desert. However, the latter are mostly concentrated on azonal oases and more favored refuge areas, such as the study of the Dakhleh Oasis Project in Dakhla (McDonald, 1999; Churcher, 1999) or the impressive work done by the Combined Prehistoric Expedition in Nabta Playa and Bir Kiseiba (Wendorf et al., 2001). The rains during the humid phase provided increased surface runoff which created ephemeral lakes across the eastern Saharan deserts. The remnants of mud or playa deposits outside the oases are characterized by a significant absence of any aquatic bioactivity such as the remains of mollusks or plants which could be linked to permanent or regular seasonal inundation (Kröpelin, 1987; Neumann, 1989b; Embabi, 1999; Bubenzer and Hilgers, 2003). This fact and the low-grade salinity of playa sediments indicate generally arid conditions with only episodic and highly variable rain events. As a result, the prehistoric occupation of the deserts required highly mobile and flexible strategies.

The ecological interpretation is underlined by the analysis of bones and charcoals from numerous archaeological sites across the Western Desert. The most important sites for which paleo-fauna and flora have been analyzed during the B.O.S. mission are Mudpans (Abu Ballas scarpland) and those of the Gilf Kebir valleys, while ACACIA has yielded new data from Regenfeld (Great Sand Sea), Eastpans (Abu Ballas scarpland), and Djara (Limestone Plateau). The common fauna documented on most sites is that of a desert environment featuring small gazelles (*Gazella dorcas* and *G. leptoceros*), hare (*Lepus capensis*), and fennek (*Fennecus cerda*), whereas intrusions of semiarid fauna are less frequent (Van Neer and Uerpman, 1989; Berke 2001). Among the charcoals extracted from campfires, *Acacia* and *Tamarix* are the common wood flora. On the basis of the archaeobotanical records, Neumann (1989a, 1989b) estimated the annual precipitation to be a maximum of 50 mm in the Early Holocene, and 100 mm in the Mid-Holocene.

METHODS AND RESULTS

During the Holocene wet phase, long-lasting nonperennial surface freshwater pools were the key factors for episodic human occupation in the desert areas. Hence, the examination of favorable relief positions relating to the paleohydrological systems are of special interest. The results of the geomorphologic field investigations in the areas under study, combined with remote sensing interpretation, form the basis of a systematic catalogue of possible geomorphological settings in concordance with the occupational intensity and settlement patterns.

Remote Sensing and Digital Elevation Models

For the eastern Sahara, various publications focus on the paleohydrological conditions (e.g., Sonntag et al., 1980; McCauley et al., 1982; Pachur and Röttiger, 1997; Hoelzmann et al., 2001; Gasse, 2001; Hill, 2001; Nicoll, 2001; Robinson, 2002). However, due to the lack of close meshed area-wide topographical data, an affordable civil analysis of digital elevation data was only possible on the macroscale (<1:500.000, e.g., with the use of the GTOPO30-data; <http://edcdaac.usgs.gov/topo30/README.asp>). With the availability of new elevation data, for example from the Shuttle Radar Topography Mission (<http://edc.usgs.gov/srtm/>) or the Aster-Sensor (Terra-Satellite, Abrams, 2000; <http://asterweb.jpl.nasa.gov/>), it is possible to calculate and to analyze digital elevation models up to a scale of 1:50.000. The investigation of the paleodrainage system, in particular, facilitates information on former land use potentials (Bubenzer and Bolten 2003, Bolten et al., 2006). Taking into account the current geological conditions, especially the water permeability of regional bedrock, it is possible to deduce favorable environmental factors of archaeological sites as a base for regionalization and modeling. Especially the ASTER-data allow both an optical geomorphological mapping as well as a stereoscopic analysis (e.g., with the software OrthoEngine, PCI Geomatics). Therefore, the generation of digital elevation models, a subsequent analysis within a Geographical Information System (e.g., ArcGIS, ESRI) or hydro-modeling software (e.g., Watershed Modeling System, WMS, Boss International), and a calculation of catchment parameters are possible. The geomorphological and geological characteristics of the catchment areas investigated are listed in Table I. A schematic interpretation and subsumption of the data for each region is given in Table II.

Favorable Geomorphological Positions and Geological Factors for Human Occupation in the Desert

With the exception of areas with significant Holocene sand accumulation or aeolian deflation, it is assumed that the recent major geomorphological settings have existed at least since the late Pleistocene in the archaeological regions investigated (Figure 1) (e.g., Brookes, 1993; Besler, 2002; Bubenzer and Besler, 2005). Hence the deduced catchment parameters may also be accepted for the Holocene wet phase. Nevertheless, the values of the catchment areas are hypothetical maxima, considering

Table 1. Geomorphological and geological characteristics of the catchment areas (calculation: ASTER-DGM, Hydro-Modelling software WMS, ArcGIS).

Name of the research area	Max. altitude in the catchment [masl]	Min. altitude in the catchment [masl]	Max. altitudinal range [m]	Catchment area [km ²]	Geological and geomorphological conditions
Seton Hill	210	138	72	93	Tei-FM with W-E-faults at the southern fringe of Temh-outliers, in a wadi-system that drain off from W to E and ends at a longitudinal dune barrier.
Djara 98/20	360	174	186	563	Singular shallow basins of karstic origin in the upper layers of the
Djara 98/4	332	170	162	287	Tetrn-FM, located at the end of a
Djara 90/1	203	187	16	1	distinct dendritic wadi-system from SW. No playa-deposits at Djara 90/1 (cave).
Abu Gerara 98/6	396	277	119	388	Basal layers of the Tetrd-FM, water-surplus from S and SW from a distinct wadi-system.
Regenfeld	555 (corridor)	422	133	23	Mega-dune corridor in Kuq-FM in transition to Kuw-FM. Drainage direction from S to N.
Chufu NE	345	229	116	16	Upper layers of the Kuq-FM, close to the Kuw-FM, distinct wind
Chufu SW	345	239	106	54	streak relief (grooved terrain). Drainage direction from northeast to southwest.
Abu Tartur	602	141	461	282	Depression in the Kum-FM, located in the foreland of the Kurkur-escarpment (Tpk-FM). Water-surplus from the Abu Tartur-Plateau and from its southern foreland (Kls-FM).
Eastpans	415	257	158	227	Sand sheet (Qs) and playa in a shallow basin within the Kls-FM. Close to a fault with WSW-ENE-direction.

(continued)

Table I. (continued)

Name of the research area	Max. altitude in the catchment [masl]	Min. altitude in the catchment [masl]	Max. altitudinal range [m]	Catchment area [km ²]	Geological and geomorphological conditions
Wilmanns Camp	856	309	547	1600	In Kut-FM, Wadi inflow from the northern part of the Abu Ras-Plateau.
Mudpans	406	297	109	56	Klb-FM, in the S of Kls-FM-escarpment. In the S terminated from a west-east fault.
Bot. Garten	1080	783	297	421	Klg-FM, at the mouth of 2 wadis from S and E, partly blocked by a dune barrier.
Wadi Bakht	1064	822	242	200	In Klg-FM, distinct dune barrier within Wadi Bakht.

Lithology of the named geological Formations (FM), see Geol. Map of Egypt 1:500.000, Klitzsch, et al. 1987)

Quaternary:

Qs: Sand sheet

Tertiary (Paleocene (p), Eocene (e)):

Temh: Silty neritic limestone with thin shale intercalations.

Tei: Well-bedded grey alveolimid lagoonal limestone.

Ten: Fossiliferous platform limestone with minor shale intercalations in the upper part.

Tetd: Dense, thickly bedded platform limestone, locally reefal or lagoonal, with characteristic concretions and local flint bands.

Tpk: Succession of ochreous marl, marly limestone and dolomite.

Cretaceous (lower (l), upper (u)):

Kuw: Phosphate beds alternating with black shale and glauconitic sandstone.

Kuq: Varicolored shale, siltstone, and flaggy sandstone.

Kut: Fluvialite and locally aeolian sandstone, fine to medium grained with interbedded channel and soil deposits.

Kum: Coastal mud-plain deposits and channel sandstone to deltaic and marginal marine sand- and mudstone.

Kls: Medium- to coarse-grained, flood-plain sandstone with interbedded channel deposits and soil horizons.

Klb: Marine claystone and mudstone in lower parts, grading into siltstone or shoreline sandstone in upper parts.

Klg: Fluvialite sandstone with intercalations of burrowed silt- and sandstone.

Table II. Schematic depiction of geological factors in the archaeological research regions which led to a surplus of surface water in the Western Desert of Egypt.

Arch. region	Favorable geomorphological positions				Favorable geological factors	
	A	B	C	D	E	F
	Escarpment foreland	Paleo-drainage system with intermediate or terminal pan	Paleo-drainage system with dune barriers	Megadune-corridor	Petrography (low permeability)	Tectonic fault
Seton Hill	X		X			X
Djara		X			X	
Abu Gerara		X			X (?)	
Regenfeld		(X)		X	X	
Chufu		X			X	
Abu Tartur	X	X			X	X (?)
Eastpans	X	X				X
Willmanns Camp		X		X		
Mudpans	X				X	X
Gilf Kebir, Bot. Garten			X		X (?)	
Gilf Kebir, Wadi Bakht			X		X (?)	

that the whole catchment areas were probably not covered by precipitation events during the wet phase. Additionally, it is likely that surface runoff was generated only locally, with the result that the depressions in the catchment areas were not affected by each rainfall.

Although the synopsis of all parameters shows distinct differences with respect to the altitudinal range and the area sizes, the field research, satellite images, digital elevation data, and geological map illustrate that each archaeological region must have profited from a water surplus. The favorable relief positions with water pools and playa deposits as a result of this surface water accumulation can be listed as follows (Table II):

1. Depressions in the foreland of escarpments, often in combination with tectonic faults (F). Both supply a water surplus, in particular for endorheic depressions.
2. Pans within or at the end of paleodrainage systems. Depending on the permeability of the bedrock (type E, compare Table II), we find partly distinct dendritic paleodrainage systems, even on the mostly karstic Limestone Plateau between the Egyptian oases and the Nile Valley. Most of the distinct wadis were generated during the late Tertiary or the Pleistocene. Therefore, the lower discharge during the Holocene wet phase had not reached the terminal pans but filled several intermediate shallow basins.

3. In three cases the water accumulation resulted from a dune barrier within a Wadi, as for instance at the Wadi Bakht with its playa deposits (Kröpelin, 1987).
4. Finally, it can be deduced that the Pleistocene megadunes (e.g., in the Great Sand Sea of Egypt) must have stored enough water to supply episodic or periodic shallow ponds in their corridors during the Holocene wet phase (Bubenzler and Besler, 2005).

Setting of Archaeological Sites

From the research areas studied, two examples illustrate the manifold relations between prehistoric site location and the geomorphological position mentioned. The Regenfeld area is situated in the southern Great Sand Sea with its longitudinal paleodunes, and the area of Djara belongs to the Egyptian Limestone Plateau between the oases and the Nile Valley (Figure 1). They represent contrasting habitats due to their individual relief configuration and to their Early and Mid-Holocene climatic conditions (cf. above, summer versus winter rain). However, a striking parallelism can be observed in the response of settlement patterns to geo-factors, among which relief positions that collected surface water during the Holocene wet phase play the most important role (Figure 3).

Djara is characterized by a system of partly interacting shallow depressions stretching over an area of 6×4 km at the end of a paleodrainage system (type B in Table II) with relatively large catchment areas. The depressions were incised 15–20 m deep in the surrounding Hamada gravel plains that form the characteristic feature of the Limestone Plateau landscape. At Regenfeld, a 600 m long terminal pan about 8 m in depth forms the basis of water collection within a dune corridor some 2–3 km in width. However, the catchment area is rather small, and additional surplus water probably came from the fossil dune storage (type D in Table II).

The methodology employed during the field study was that of systematic surveys combined with detailed excavations of sample sites. Sites are generally defined as places of human activity or, in archaeological terms, as loci where significant remains of cultural material can be found (cf. Banning 2002, 81). As a distinct spatial unit, a surface site has to be enclosed within a boundary, and specific criteria are needed that define the extent of the site. To avoid arbitrary criteria, which can be helpful in registering complex site structures, sites are defined as distinct clusters of artifacts and features that contrast in density with the surrounding area.

In the case of Djara, a total of nearly 70 km² has been systematically surveyed through fieldwalking in a grid and a survey by car between 1996 and 2002 (Kindermann, 2004). Moreover, several linear transects covering the surroundings of this area have been surveyed. In Regenfeld, random sample transects within an area of approximately 1600 km² has been surveyed in 1996, 1997, and 2000 (Riemer, in review). The strategy of these long-distance surveys implies that not only were the proposed favorable locations the subject of field observations, but the entire landscape. A survey form was used to provide comparable data about a site, including information about the geomorphological setting, site dimension, artifact number and density, type variability, and site function, among others. In both study areas, the

ARCHAEOLOGICAL AND GEOMORPHOLOGICAL RESULTS

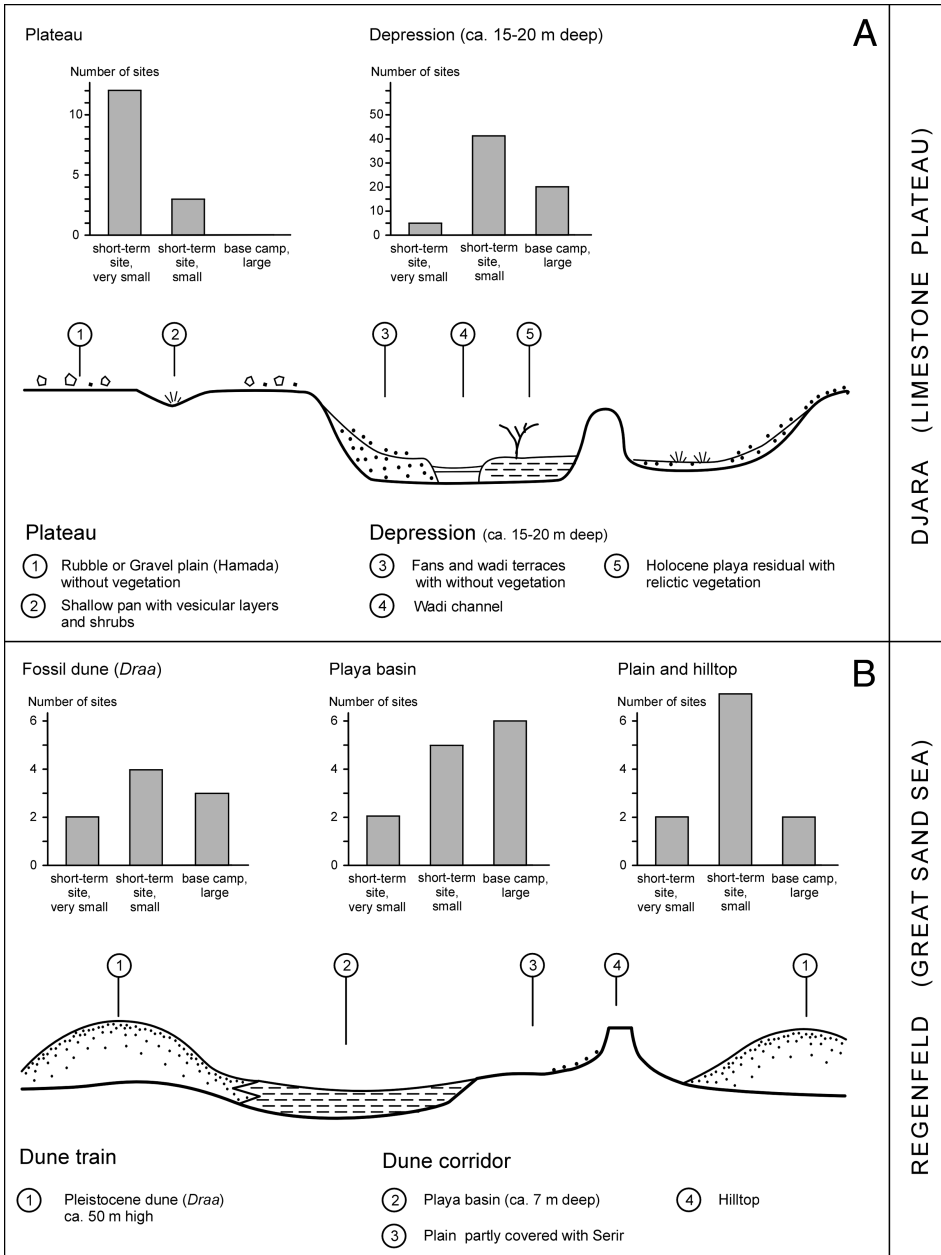


Figure 3. Sites in their setting: geomorphological units and settlement patterns in two contrasting study regions (schematic profiles). A. Djara, Limestone Plateau (study area ca. 70 km²), B. Regenfeld, southern Great Sand Sea (sampling within a study area of ca. 1600 km²).

examination of archaeological sites and their geomorphological settings yielded concentrations of sites in the favorable basins. The classification of sites by size, artifact density, and artifact types points to diversified settlement patterns connected to the geomorphological units (compare Bolten et al., 2006). Large multi-occupied camp sites, featuring a longer stay and a varied activity spectrum, such as preparation of gathered wild seeds, butchering of wild game, jewelry manufacture, and all stages of tool production, were exclusively or predominantly found at the water pools. Although small sites of a specific function such as hunting stands and atelier sites were positioned on hilltops or outcrops, most small short-term sites lacking artifacts of a distinct function are scattered throughout the entire landscape, representing a short-term stay or overnight stop during episodic rounds through the desert.

CONCLUSIONS

Although most parts of the Eastern Sahara outside of the Nile Valley and the oases were uninhabitable, some places were favorable enough for occupation by hunter-gatherers during the Holocene humid wet phase. These sites profited mainly from a surplus of surface water. Consequently the pre-Holocene landscape evolution was also essential for the habitability of the Eastern Sahara during the Early and Mid-Holocene.

In addition to classical archaeological and geomorphological methods, remote sensing and the analysis of digital elevation models are important techniques for an area-wide specification and quantification of favorable relief locations. In general, the introduced results from the different research areas not only mirror the regional conditions but also serve as a basis for supraregional comparisons and modeling. Finally, the cooperation of archaeology and geomorphology allows better understanding of the complex interrelation of human societies and their environments and gives an idea of the former land use potential in North-East Africa.

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REFERENCES

- Abrams, M. (2000). The Advance Spaceborne Thermal Emission and Reflection Radiometer (ASTER): Data products for the high spatial resolution imager on NASA's Terra platform. *International Journal of Remote Sensing*, 21, 847–859.
- Arz, H.W., Lamy, F., Pätzold, J., Müller, P.J., & Prins, M. (2003). Mediterranean moisture source for an early-Holocene humid period in the northern Red Sea. *Science*, 300, 118–121.
- Banning, E.B. (2002). *Archaeological survey. Manuals in Archaeological Method, Theory, and Technique*. New York: Kluwer Academic/Plenum Publishers.
- Barich, E.B., Hassan, F.A., & Abdel-Moneim, A.M. (1991). From settlement to site: Formation and transformation of archaeological sites. *Scienze dell'Antichita*, 5, 33–62.
- Berke, H. (2001). Gunsträume und Grenzbereiche. Archäozoologische Beobachtungen in der Libyschen Wüste, Sudan und Ägypten. In B. Gehlen, M. Heinen, & A. Tillmann (Eds.), *Zeit-Räume. Archäologische Berichte* 14. (pp. 257–282). Bonn: DGUF.
- Besler, H. (2002). The great sand (Egypt) during the late Pleistocene and the Holocene. *Zeitschrift für Geomorphologie, Supplement-Band*, 127, 1–19.

- Bolten, A., Bubenzer, O., & Darius, F. (2006). A digital elevation model as a base for the reconstruction of Holocene land use potential in arid regions. *Geoarchaeology*, 21, 751–762.
- Brookes, I.A. (1993). Geomorphology and Quaternary geology of the Dakhla Oasis region, Egypt. *Quaternary Science Reviews*, 12, 529–552.
- Bubenzer, O., & Besler, H. (2005). Human occupation of sand seas during the early and mid-Holocene. Examples from Egypt. *Zeitschrift für Geomorphologie, Supplement-Band*, 138, 153–165.
- Bubenzer, O., & Bolten, A. (2003). Detecting areas with different land use potential. In Egypt, Sudan, and Namibia, GIS helps compare human strategies of coping with arid habitats. *ArcNews*, 25, 34.
- Bubenzer, O., & Hilgers, A. (2003). Luminescence dating of Holocene playa deposits of the Egyptian Plateau, Western Desert, Egypt. *Quaternary Science Reviews*, 22, 1077–1084.
- Churcher, C.S. (1999). Holocene faunas of the Dakhleh Oasis. In C.S. Churcher & A.J. Mills (Eds.), *Reports from the Survey of the Dakhleh Oasis, Western Desert of Egypt, 1977–1987. Dakhleh Oasis Project Monograph*, 2. (pp. 109–115). Oxford: Oxbow.
- Close, A.E. (1992). Holocene Occupation of the eastern Sahara. In F. Klees & R. Kuper (Eds.), *New light on the northeast African past. Africa Praehistorica*, 5. (pp. 155–183). Köln: Heinrich-Barth-Institut.
- Donner, J.J., Ashour, M.M., Embabi, N.S., & Siiriäinen, A. (1999). The Quaternary geology of a playa in Farafra, Western Desert of Egypt. In J. Donner (Ed.), *Studies of playas in the Western Desert of Egypt. Annales Academiae Scientiarum Fennicae*, 160. (pp. 49–94). Helsinki: Academia Scientiarum Fennica.
- Embabi, N.S. (1999). Playas of the Western Desert, Egypt. In J. Donner (Ed.), *Studies of playas in the Western Desert of Egypt. Academia Scientiarum Fennicae*, 160. (pp. 5–47). Helsinki: Academia Scientiarum Fennica.
- Gasse, F. (2001). Hydrological changes in Africa. *Science*, 292, 2259–2260.
- Gehlen, B., Kindermann, K., Linstädter, J., & Riemer, H. (2002). The Holocene occupation of the Eastern Sahara: Regional chronologies and supra-regional developments in four areas of the absolute desert. In Jennerstrasse 8 (Eds.), *Tides of the desert—Gezeiten der Wüste. Contributions to the archaeology and environmental history of Africa in honour of Rudolph Kuper. Africa Praehistorica*, 14. (pp. 85–116). Köln: Heinrich-Barth-Institut.
- Hassan, F.A., Barich, B., Mahmoud, M., & Hemdan, M.A. (2001). Holocene playa deposits of Farafra Oasis, Egypt, and their palaeoclimatic and geoarchaeological significance. *Geoarchaeology*, 16, 29–44.
- Haynes, C.V., Jr. (1987). Holocene migration rates of the Sudano-Sahelian wetting front, Arba'in Desert, Eastern Sahara. In A.E. Close (Ed.), *Prehistory of arid north Africa*. (pp. 69–84). Dallas, TX: Southern Methodist University Press.
- Haynes, C.V., Jr. (2001). Geochronology and climate change of the Pleistocene—Holocene transition in the Darb el Arba'in Desert, Eastern Sahara. *Geoarchaeology*, 16, 119–141.
- Hill, C.L. (2001). Geologic contexts of the Acheulian (Middle Pleistocene) in the Eastern Sahara. *Geoarchaeology*, 16, 65–94.
- Hoelzmann, P., Keding, B., Berke, H., Kröpelin, S., & Kruse, H.-J. (2001). Environmental change and archaeology: Lake evolution and human occupation in the Eastern Sahara during the Holocene. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 169, 193–217.
- Hoelzmann, P. (2002). Lacustrine sediments as indicators of climate change during the Late Quaternary in western Nubia (eastern Sahara). In Jennerstr. 8 (Eds.), *Tides of the desert—Gezeiten der Wüste. Contributions to the archaeology and environmental history of Africa in honour of Rudolph Kuper. Africa Praehistorica*, 14. (pp. 375–388). Köln: Heinrich-Barth-Institut.
- Kindermann, K. (2004). Djara: Excavations and surveys of the 1998–2002 seasons. *Archéo-Nil*, 14, 31–50.
- Kindermann, K., Bubenzer, O., Nussbaum, S., Riemer, H., Darius, F., Pöllath, N., & Smettan, U. (2006). Palaeoenvironment and Holocene land use of Djara, Western Desert of Egypt, *Quaternary Science Reviews*, 25, 1619–1637.
- Kleindienst, M.R., Churcher, C.S., McDonald, M.M.A., & Schwarcz, H.P. (1999). Geography, geology, geochronology and geoarchaeology of the Dakhleh Oasis region: An interim report. In C.S. Churcher & A.J. Mills (Eds.), *Reports from the survey of the Dakhleh Oasis 1977–1987* (pp. 1–54). Dakhleh Oasis Project, Monograph 2. Oxford: Oxbow.
- Klitzsch, E., List, F.K., & G. Pöhlmann (Eds.) (1987). Geological map of Egypt, 1:500,000, sheets NH 35 SE, NG 35 NE, NG 35 SE, NG 35 SW, NG 36 SW. Cairo: The Egyptian General Petroleum Cooperation.
- Kröpelin, S. (1987). Palaeoclimatic evidence from early to mid-Holocene playas in the Gilf Kebir (Southwest Egypt). *Palaeoecology of Africa*, 18, 189–208.

- Kröpelin, S. (1993). Geomorphology, landscape evolution and paleoclimates of southwest Egypt. *Catena Supplement*, 26, 31–65.
- Kuper, R. (1993). Prehistoric research in the southern Libyan desert. A brief account and some conclusions of the B.O.S. project. *Cahier de Recherches de l'Institut de Papyrologie et d'Égyptologie de Lille*, 17, 123–140.
- Kuper, R. (2002). Routes and roots in Egypt's western Desert: The early Holocene resettlement of the eastern Sahara. In R. Friedman (Ed.), *Egypt and Nubia. Gifts of the desert*. (pp. 1–12). London: British Museum Press.
- Kuper, R. (2006). After 5000 BC: The Libyan desert in transition. *Comptes Rendus Palevol* 5, 409–419.
- Linstädter, J., & Kröpelin, S. (2004). Wadi Bakht revisited: Holocene climate change and prehistoric occupation in the Gilf Kebir region of the eastern Sahara, SW Egypt. *Geoarchaeology*, 19, 753–778.
- McCauley, J.F., Schaber, G.G., Breed, C.S., Grolier, M.J., Haynes, C.V., Issawi, B., Elachi, C., & Blom, R. (1982). Subsurface valleys and geoarchaeology of the Eastern Sahara revealed by shuttle radar. *Science*, 218, 1004–1020.
- McDonald, M.M.A. (1999). Neolithic cultural units and adaptations in the Dakhleh Oasis. In C.S. Churcher & A.J. Mills (Eds.), *Reports from the survey of the Dakhleh Oasis 1977–1987. Dakhleh Oasis Project: Monograph 2. Oxbow Monograph 97*. (pp. 117–132). Oxford: Oxbow.
- McDonald, M.M.A. (2001). The late prehistoric radiocarbon chronology for Dakhleh Oasis within the wider environmental and cultural setting of the Egyptian western desert. In M. Marlow (Ed.), *The oasis papers 1: Proceedings of the first international symposium of the Dakhleh Oasis Project. Dakhleh Oasis Project: Monograph 6. Oxbow Monograph 97*. (pp. 26–42). Oxford: Oxbow.
- Neumann, K. (1989a). Zur Vegetationsgeschichte der Ostsahara im Holozän. In R. Kuper (Ed.), *Forschungen zur Umweltgeschichte der Ostsahara. Africa Praehistorica 2*. (pp. 13–181). Köln: Heinrich-Barth-Institut.
- Neumann, K. (1989b). Holocene vegetation of the Eastern Sahara: Charcoals from prehistoric sites. *African Archaeological Review*, 7, 97–116.
- New, M., Hulme, M., & Jones, P. (1999). Representing twentieth-century space-time climate variability. Part I: Development of a 1961–90 mean monthly terrestrial climatology. *Journal of climate*, 12, 829–856.
- Nicoll, K. (2001). Radiocarbon chronologies for prehistoric human occupation and hydroclimatic change in Egypt and northern Sudan. *Geoarchaeology*, 16(1), 47–64.
- Pachur, H.J., & Röttiger, F. (1997). Evidence for a large extended palaeolake in the eastern Sahara as revealed by Spaceborne Radar Lab images. *Remote Sensing of Environment*, 61, 437–440.
- Pachur, H.-J., & Hoelzmann, P. (2000). Late Quaternary palaeoecology and palaeoclimates of the eastern Sahara. *Journal of African Earth Sciences*, 30, 929–939.
- Riemer, H. (in review). Risks and resources in an arid landscape. An archaeological case study from the Great Sand Sea, Egypt. In M. Bollig & O. Bubenzler (Eds.), *African Landscapes: Theory, methods and cases from interdisciplinary research* (in review).
- Robinson, C.A. (2002). Application of satellite radar data suggest that the Kharga Depression in south-western Egypt is a fracture rock aquifer. *International Journal of Remote Sensing*, 23, 4101–4113.
- Schön, W. (1996). *Ausgrabungen im Wadi el Akhdar, Gilf Kebir. Africa Praehistorica, 8*. Köln: Heinrich-Barth-Institut.
- Sonntag, C., Thorweih, U., Rudolph, J., Löhnert, E.P., Junghans, C., Münnich, K.O., Klitzsch, E., Shazly, E.M., & Swailem, F.M. (1980). Isotopic identification of Saharian groundwaters. Groundwater formation in the past. *Palaeoecology of Africa*, 12, 159–171.
- Van Neer, W., & Uerpman, H.-P. (1989). Palaeoecological significance of the Holocene faunal remains of the B.O.S.-missions. In R. Kuper (Ed.), *Forschungen zur Umweltgeschichte der Ostsahara. Africa Praehistorica 2*. (pp. 307–341). Köln: Heinrich-Barth-Institut.
- Vermeersch, P.M. (1978). *El Kab II. L'Elkabien, épipaléolithique de la vallée du Nil égyptien*. Leuven: University Press.
- Vernet, R., & Faure, H. (2000). Isotopic chronology of the Sahara and the Sahel during the late Pleistocene and the early and mid-Holocene (15,000–6,000 B.P.). *Quaternary International*, 68–71, 385–387.
- Wendorf, F., Schild, A., & Associates (2001). *The Archaeology of Nabta Playa*. New York: Kluwer Academic/Plenum.

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