Desert soils in Lower Wadi Howar (Northwest Sudan)
Evidence of climate change and human impact during the Holocene

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During the late Pleistocene and the Holocene the eastern Sahara was subject to dramatic climatic changes oscillating from very arid to humid and finally increasing arid conditions again (Pachur 1987; Kröpelin 1987; 1993; Kuper and Kröpelin 2006). Holocene pluvial conditions began about 9800 BP, at the end of the Younger Dryas cold interval. During the climate optimum the reconstructed annual precipitation was between 400 mm (Kröpelin 1993) and 600 mm (Vernet 1995). As a consequence, between 9500–3500 BP the southeastern Sahara was characterized by a raised groundwater table and numerous lakes (Kröpelin 1993). Analysis of about 320 charcoal samples from prehistoric sites in the eastern Sahara furnishes evidence for a fundamental change of vegetation during the Early and Middle Holocene. Around 7000 BP the Sahelian vegetation zones were 500–600 km north of their present range (Neumann 1989). A savanna-type vegetation existed that attracted Sudano-Sahelian fauna and therefore human groups to the region until about 5000 BP, when the current episode of hyperaridity ensued (Haynes 2001; Kuper and Kröpelin 2006).

There is evidence that the prehistoric inhabitants adapted their economic systems to the changing climatic conditions in the Wadi Howar region, one of the main research areas of the ACACIA-project of the University of Cologne (»Arid Climate Adaption and Cultural Innovation in Africa«). Here, within 3 000 years the prehistoric inhabitants developed from gatherers and hunters to pastoralists with intensive cattle herding. In response to increasingly arid conditions goats and sheep were finally added to the herds (Keding 1998; Keding and Vogelsang 2001; Jesse 2006a; 2006b). Today, the Wadi Howar region is very inhospitable and only a few nomads with their camels thrive there, but traces of the prehistoric occupants are visible in many places (e. g. Jesse 2005; 2006a; 2006b). Not only archaeological material such as pottery sherds, lithic artefacts and faunal remains can be found but also more subtle traces which can be detected for example by pedological analysis. The study of soils does not only give indications on climatic changes but can also show the effects of human impact on the landscape. In this paper, the results of pedological studies made during the 2006 archaeological field season of the ACACIA project in Lower Wadi Howar are presented.

Study area

The Wadi Howar is located in the north-west of the Sudan and traverses over a length of about 1 000 km the southern margin of the Sahara between Jebel Marra in the west and the Nile Valley in the East. Once it was a tributary of the river Nile and joined it north-west of Ed Debba (Pachur 1987; Pachur and Kröpelin 1987; see fig. 1). Today, the Wadi Howar region is located within the two 100 mm rainfall isohyets at 17° N and 31° N (Ritchie et al. 1985) and is part of the hyperarid core of the eastern Sahara desert with partly less than 25 mm annual rainfall and a potential evaporation of 5–6 m (Petit-Maire and Guo 1998). Vegetation in the eastern Sahara is very sparse and mainly confined to a few oases and to wadi channels, where single Tundub-bushes (*Capparis decidua*), acacia trees and transient communities of annuals and herbaceous perennials are present. The area of Wadi Howar is mainly characterized by sedimentary rocks (Nubian sandstone), aeolian sediments, fluvial and lacustrine deposits. Partly volcanic (basalt), plutonic (granite) and metamorphic (quartzite) rocks were found.

During the last years, research of the ACACIA project in the Wadi Howar region focused on the lower section of Wadi Howar which comprises the 400 km between Jebel Rahib in the west and the Nile Valley in the east. Intense occupation during the Neolithic period, especially the 4th and 3rd millennia BC, could be evidenced in the area of Abu Tabari and Conical Hill: more than a hundred sites were found and mapped. The sites are either located on slightly elevated former sandbanks or on top of up to 15 m high, artefact covered dunes of parabolic shape (Jesse 2003; in press; Lange 2005). Two sites in the area of Abu Tabari were selected for pedological studies: S02 / 52 and S02 / 28. Further investigations took place near the fortress Gala Abu Ahmed, situated about 100 km west of the Nile (fig. 1).

Material and Methods

Sampling

At each study location an assessment of topographic units and potential interesting soil profiles was performed by an intense survey. Soil profiles were described

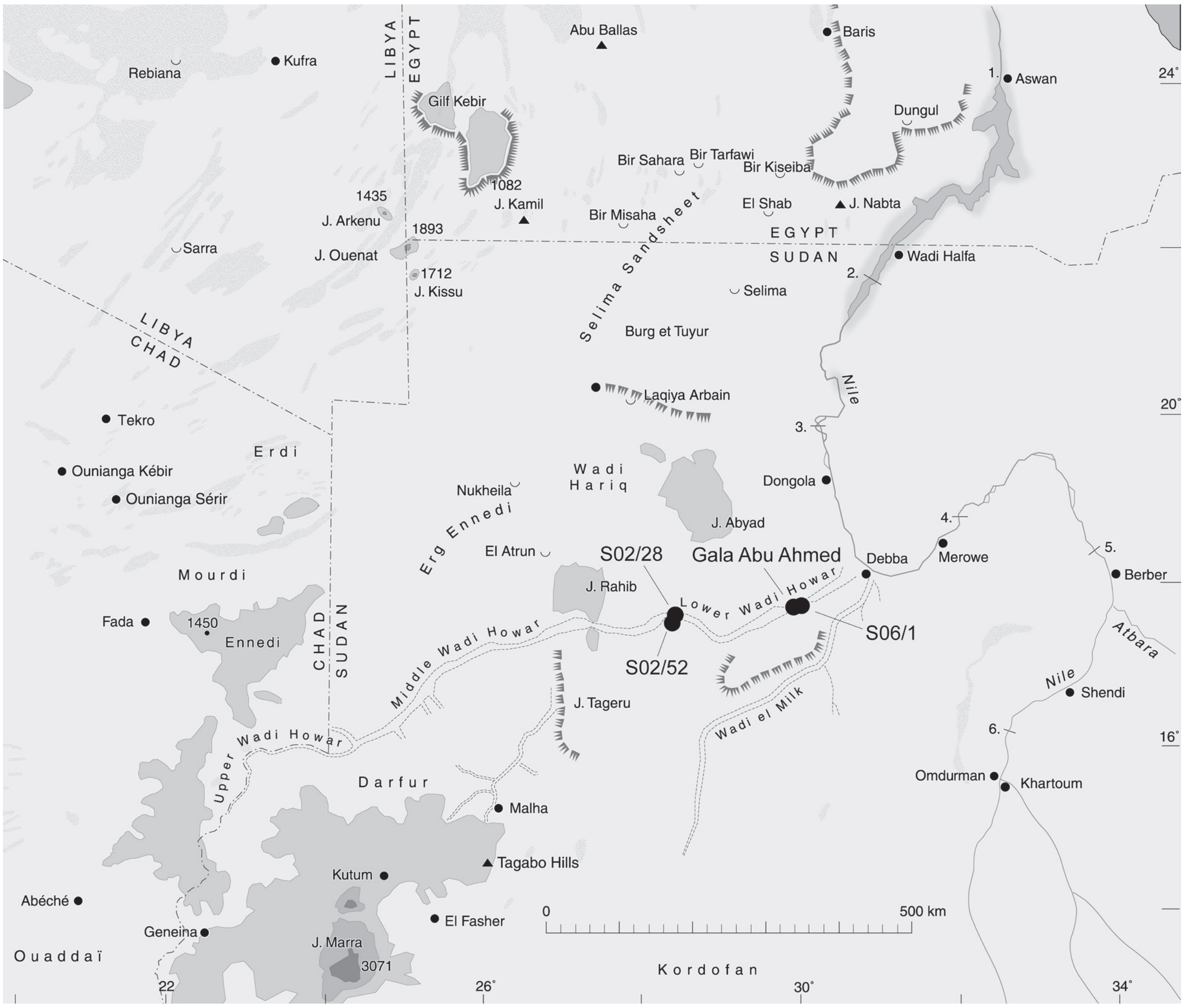

Fig. 1: Study area eastern Sahara with selected sites.

according to the US Soil Taxonomy (Soil Survey Staff 1999). Disturbed as well as partly undisturbed soil samples were taken from each horizon. The description and sampling in the field was completed by laboratory analysis of the soil samples.

Carbon quantification

Bulk density was determined according to Schlichting et al. (1995) by sampling two replicates of undisturbed soil material from each horizon in 850 cm^3 stainless steel cylinders. The soil was air-dried and weighed with a precision balance (Sartorius, Göttingen).

Total carbon (TC) of air-dried soil samples (< 2 mm), milled to < 63 µm, was determined with a CHN-Analyser (Vario EL III, Elementar, Hanau). To determine inorganic carbon (TIC) the samples were heated to 550° C for 6 h to destroy organic carbon before measurement. Organic carbon (TOC) was determined as the difference of TC and TIC:

$$TOC = TC - TIC \qquad (1)$$

The size of the soil organic carbon stocks on a spatial basis was determined based on the carbon contents of the different horizons:

$$\sum C_i = \sum c_i \times l_i \times d_i \times 10 \qquad (2)$$

where C_i is the TOC content of a soil layer in kg m^{-2}; c_i is the TOC concentration in g $100g^{-1}$soil (< 2mm); l_i is the depth of the layer in cm; and d_i is the bulk density in g cm^{-3}.

To determine total P concentrations, 10 ml of concentrated HNO_3 (13 M) were added to 0.5 g soil and heated to 185° C for 20 min in a closed PTFE container. P concentrations were measured photometrically by a continuous flow analyzer (Skalar, Erkelenz) with a detection limit of 0.55 µM P, according to Murphy and Riley (1962).

Conductivity

10 g of soil was mixed with 25 ml of de-ionized water and stirred for 30 min by hand. The conductivity was determined at 20° C with a Cond.315 (WTW instruments, Weilheim).

	Feldspars	Quartz
Radiation	Sr / Y-90 beta source 0.1426 Gy / s	Sr / Y-90 beta source 0.1085 Gy/s
Stimulation	IR-diodes (880 ± 80 nm) 300 s @ 50° C	Blue diodes (470 ± 30 nm) 50 s @ 125° C
Detection filter	Schott BG39 Schott GG400 Corning 7–59	U-340-filter (7.5 mm, transmission at 290–370 nm)
Pre-heating	230° C, after test dose 250° C	240° C, after test dose 200° C

Tab. 1: Parameters for OSL-dating of quartz and feldspars.

OSL-Dating

The sample for *Optically Stimulated Luminescence* dating (OSL) was collected from the centre-part of an undisturbed soil layer during night and sealed in light-safe black plastic bags. Sample preparation involved drying and sieving, followed by the removal of acid soluble carbonates and organic material in dilute hydrochloric acid (10 %) and hydrogen peroxide (10 %) and Na-oxalate (0.01 %) according to Aitken (1998). Sodium polytungstate at 2.58 g cm^{-3} specific gravity for potassium-feldspars and 2.68 g cm^{-3} specific gravity for quartz grains was used to enrich the quartz- and feldspar-fraction. The quartz-fraction was etched in hydrofluoric acid (40 %) for 40 min to remove any residual feldspars and the outer 10 µm of quartz grains. Following another treatment with hydrochloric acid to remove soluble fluorides and final dry sieving a monolayer of grains was mounted with silicon on 1 mm diameter steel discs for analysis.

Optically stimulated luminescence was determined by SAR-BLSL (*Single Aliquot Regenerative Dose Blue Light Stimulated Luminescence*, according to Murray and Wintle 2000) for quartz and SAR-IRSL (*Single Aliquot Regenerative Dose Infrared Stimulated Luminescence*, according to Wallinga et al. 2000 and Preusser 2003); for details see table 1.

Results and discussion

Paleo-environmental conditions and soil formation at Neolithic settlements in the region of Abu Tabari

The **site S02 / 52** was located on a former sandbank. The sandbank was elevated up to 2 m above the plain ground of the Wadi Howar and covered an area of about 100 m by 400 m. The surface was covered by a dense layer of artefacts, comprising pottery sherds, lithic objects and animal bones. Via the pottery an attribution of the site to the 4th or the first half of the 3rd millennium BC can be supposed (Lange 2005). The ground of the wadi was covered by fluviatile sediments and pebbles. To get an idea of the former environmental conditions, soil profiles, lined up from the centre and top of the site to the lower margin were studied. The results of the two profiles in the extreme upper and lower position (# 8 and # 10) are as follows (tab. 2a and 2b).

Profile 8 on the hilltop showed a weakly developed soil with a small accumulation of organic carbon between 2 and 65 cm below the surface (fig. 2). The sediment was well rooted and showed large phosphorus contents, which decreased with depth. The soil was characterized as a Typic Torripsamment, according to US soil taxonomy.

The thickness of the upper soil horizon with a mean organic carbon content of 0.12 % and a bulk density of 1.63 g cm^{-3} was 0.6 m. It covered an area of approximately 4 000 m^2. So, the site contained an estimated amount of 4.7 t of organic carbon or 9.4 t organic material.

Fig. 2: Weakly developed soil at the Neolithic site S02/52, Lower Wadi Howar, profile 8.

Location: Lower Wadi Howar **Parent material: Aeolian sediments covered by artefacts (rock tools, bones, etc.)**						
Horiz.	*Depth [cm]*	*Text.*	C_{inorg} *[%]*	C_{org} *[%]*	P_t *[mg kg⁻¹]*	*other*
	0–2	sand	–	–	–	50 vol. % rock fragm. > 2 mm (artefacts) 7.5YR7/6 single grain no roots
A	2–23	loam. sand	0.05	0.12	353	< 5 vol. % rock fragm. > 2 mm 10YR4/3 coherent single grain 6–20 roots 10 cm^{-2} conductivity 99 $\mu S\ cm^{-1}$ bulk density 1.63 g cm^{-3}
AC	23–65	sand	0.03	0.12	208	< 5 vol. % rock fragm. > 2 mm 10YR6/4 6–20 roots 10 cm^{-2} single grain conductivity 490 $\mu S\ cm^{-1}$
C	> 65	sand	–	–	–	< 5 vol. % rock fragm. > 2 mm 10YR7/6 no roots single grain

Tab. 2a: Typic Torripsamment (profile 8) on the top of the settlement site S02/52, Lower Wadi Howar; Munsel colour was determined with moist soil.

Location: Lower Wadi Howar **Parent material: Lacustrine sediments (»Playa«)**							
Horiz.	*Depth [cm]*	*Text.*	C_{inorg} *[%]*	C_{org} *[%]*	P_t *[mg kg⁻¹]*	*Conduct. [µS cm⁻¹]*	*other*
	0–1	sand	–	–	–	–	50 vol. % rock fragm. > 2 mm single grain no roots
Ccm	1–20	silty sand	1.28	0.17	–	142	2.5Y6/3 massive (petrocalc.hor.) no roots
	20–> 42		1.57	0.17	153	608	

Tab. 2b: Calcareous sediments (profile 10) at the margin of the settlement site S02/52, Lower Wadi Howar; Munsel colour was determined with moist sediment.

Profile 10 at the wadi ground showed cemented, lacustrine sediments (»Playa sediment«) with high contents of inorganic carbon and also distinct contents of organic carbon. The phosphorus content was distinctly smaller than in the centre of the site. These Playa sediments covered an area of about 0.5 km^2. The sediments contained relicts of a land mollusc, most probably *Subulina isseli* (Jickeli 1874; pers. comm. N. Pöllath).

In both soil profiles we found large concentrations of salt in 20–40 cm depth, which is typical for arid and semi-arid soils due to an upward groundwater movement. With up to 500 $\mu S\ cm^{-1}$ the conductivity was within the normal range of arid soils, as reported by Gabriel (1986).

Site S02/28 was also located on a relatively flat former sandbank with a maximum height of about 1 m above ground level. The site consists of a large scatter of archaeological finds stretching over an area of about 500 m x 450 m. Radiocarbon dates point to an occupation of the site around 3000 BC (Jesse in press). A geomagnetic survey in 2006 showed anomalies near the western edge of the sandbank.[1] In the test trenches distinct redoximorphic features and concentrations of iron nodules in 30–80 cm depth were found (fig. 3, table 3). The boundary between the upper, oxygen rich and well aerated zone and the groundwater zone with reducing soil conditions followed the relief of the slope (fig. 4).

The lacustrine sediments and the redoximorphic features prove, that during the Holocene humid phase this landscape was most probably at least temporarily covered by the shallow waters of an extended lake with several flat islands such as the sandbanks of the sites S02/52 and S02/28. So, most probably both settlements were ori-

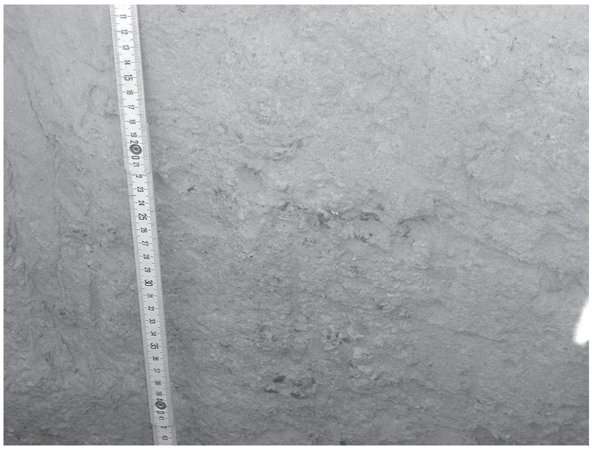

Fig. 3: Nodules of iron-oxide at the western edge of the Neolithic settlement S02/28, Lower Wadi Howar, profile 17.

Location: Lower Wadi Howar
Parent material: Aeolian-fluviatile sediments, covered by artefacts (stone tools etc.)

Horiz.	*Depth [cm]*	*Text.*	*other*
	0–1	sand	35 vol. % rock fragments > 2 mm 7.5YR6/6 single grain no roots
Ak	1–20	weak silty sand	< 2 vol. % rock fragments > 2 mm 2.5YR5/3 coherent single grain 6–10 roots
B	20–40	weak silty sand	< 2 vol. % rock fragments > 2 mm 2.5YR5/3 coherent single grain 6–10 roots 10 cm^{-2} 10 % redoximorphic features, single ironoxide nodules
Bc	40–50	weak silty sand	2–5 vol. % rock fragments > 2 mm 10YR6/4 coherent single grain 10–20 roots 10 cm^{-2} 50 % redoximorphic features, 15 % ironoxide nodules
BC	50–> 100	weak silty sand	< 2 vol. % rock fragments > 2 mm 2.5YR5/3 coherent single grain 6–10 roots 10 cm^{-2} 10 % redoximorphic features, single ironoxide nodules

Tab. 3: Typic Torripsamment with distinct relictic redoximorphic features (profile17) at the margin of the settlement site S02/28, Lower Wadi Howar; Munsel colour was determined with moist soil.

1 The geophysical survey was done by Carsten Mischka of the Institute for Prehistoric Archaeology at the University of Cologne.

Location: South slope (20°) of Lower Wadi Howar; Parent material: rocky debris under recent aeolian sand cover					
Horiz.	*Depth [cm]*	*Text.*	*C_{inorg} [%]*	*C_{org} [%]*	*other*
	0–20	sand	0.02	0.03	< 2 vol. % rock fragments > 2 mm 7.5YR8 / 8 single grain no roots
Ab	20–34	silty sand	< 0.02	0.05	60–80 vol. % rock fragments > 2 mm 7.5YR4 / 4 coherent single grain 3–10 roots 10 cm^{-2}
Bb	34–66	silty sand	0.04	0.05	> 90 vol. % rock fragments > 2 mm 7.5YR5 / 6 coherent single grain 1–5 roots 10 cm^{-2}
BCb	66–82	silty sand	0.03	0.04	> 90 vol. % rock fragments > 2 mm 7.5YR6 / 8 coherent single grain 1–5 roots 10cm^{-2}

Tab. 4: Paleosoil (Typic Torriorthent, profile 1) at the basis of the tumulus S06 / 1 near the fortress Gala Abu Ahmed, Lower Wadi Howar; Munsel colour was determined with moist soil.

sample	*paleodose (Gy)*	*error (Gy)*	*dose rate (Gy / ka)*	*error (Gy / ka)*	*depth (cm)*	*water content (%)*	*age (ka)*	*Error (ka)*
S106 Q	1,09	0,11	0,777	0,031	25 ± 5	2	1,40	0,15
S106 KF	1,18	0,09	1,402	0,214	25 ± 5	2	0,84	0,14

Tab. 5: OSL-ages of the covering sand layer of profile 1, site S06 / 1, Lower Wadi Howar. Fractions: – Q quartz; – KF potassium-feldspar; – D_e paleodose; – D_o dose rate. Rel. SD: 43 % for quartz and 38 % for potassiumfeldspar.

Location: Ground of Wadi Howar; Parent material: lacustrine sediments under a thin aeolian sand cover					
Horiz.	*Depth [cm]*	*Text.*	*C_{inorg} [%]*	*C_{org} [%]*	*other*
	0–5	sand	–	–	< 5 vol. % rock fragments > 2 mm 7.5YR7 / 6 single grain no roots
ACb	5–45	silty loam	0.13	0.13	10YR4 / 3 blocky 6–10 roots 10 cm^{-2} conductivity 99 µS cm^{-1}
–	45–83				no samples
C	83–134	Silty loam	0.09	0.15	10YR5 / 4 blocky no roots conductivity 490 µS cm^{-1}
Cg	> 134	Silty loam	–	–	7.5YR5 / 2 blocky

Tab. 6: Typic Torriorthent (profile 7) on the wadi ground near the fortress Gala Abu Ahmed, Lower Wadi Howar; Munsel colour was determined with moist soil.

ginally located adjacent to open water surfaces. Similar lacustrine sediments were found in the Oyo Depression in NW Sudan (19° N, 26° E) and were dated by ^{14}C to 6500–2500 BC (Ritchie et al. 1985). Considerable sand contents were lacking. This indicates carbonate deposition in a stratified lake with stagnant bottom waters, according to Ritchie et al. (1985). A comparison with actual sedimentation cycles allows the reconstruction of a humid tropical climate with annual monsoonal rainfall of at least 400 mm (ibid.). This humid period with formation of lacustrine sediments ended between 4500 BP (Nicoll 2001) and 3700 BP (Petit-Maire and Guo 1998).

The study of the faunal remains of site S02/52 indicates a subsistence strategy of the Neolithic dwellers based on cattle herding and especially fishing. It seems that site S02/52 was used as a preferred and specialized fishing place (N. Pöllath, pers. comm.). The exposed position within a shallow lake offered the best conditions for such a specialized, maybe seasonal use. Fish bone finds from early to middle Holocene sites in the Middle Wadi Howar showed a rich ichthyofaunal spectrum, which allows to reconstruct the main freshwater biotopes that once characterized the Wadi Howar area (Pöllath and Peters 2003). The input of organic residues resulted in an enrichment of phosphorus and carbon in the upper soil layers as could be evidenced at site S02/52. The large amounts of phosphorus prove an intense and long term use of the site. This anthropogenic input of organic residues favoured and initiated the formation of raw soils. Such enrichment was exclusively found at settlement sites (for example also at the nearby site S02/01). This could be explained by the special conservation conditions for soils under the dense artefact cover of the settlements and an erosion of the upper soil layer elsewhere. But it is also plausible that soil formation took place exclusively at former settlements, and was triggered and initiated by the human input of organic residues. That would mean that not only the environment determined human behaviour and living conditions but also that man influenced his environment.

Archaeological sites as climate archives
About 1.5 km east of the fortress Gala Abu Ahmed a number of tumuli were found along the southern shoreline of Wadi Howar (see Kröpelin 1993; Jesse and Kuper 2004). One tumulus was excavated, site S06/1. It was located in the middle of the slope. Instead of the expected burial we found distinctly weathered soil material at the base of the tumulus in 0.2 m depth (profile 1; fig. 5; tab. 4). Organic carbon contents were very low, even if there was a weak enrichment in 0.2 to 0.66 m depth. The upper soil layer (horizon Ab) was well rooted and the minerals were distinctly weathered. The soil was classified as Typic Torriorthent. The OSL-age of the covering sand layer was 0.8 to 1.36 ka (tab. 5).

Even for an arid soil the organic carbon contents were very low compared to mean organic carbon contents of other extra arid desert soils, which are normally between 0.2–1.5 kg C m^{-2} (Lioubimtseva 1997). In contrast to the low carbon contents the red-yellowish colours indicate a distinct weathering of soil minerals, which requires humid climate conditions. Due to the protection by the tumulus this soil was preserved from erosion. Remnants of well developed fossil soils were also found under the dense artefact cover of the Neolithic settlements near Abu Tabari (see above) and also reported from other sites in the Sahara, e. g. in Egypt (Blume et al. 1984), Niger (Vogg 1986; Völkel 1987; 1988), and Wadi Shaw in north-western Sudan (Gabriel 1986). These paleo-soils verify more humid climate conditions during the middle Holocene (6000–5000 BC). The covering sand layer of profile 1 at site S06/1 developed later as the result of erosion processes of the southern slope of Wadi Howar. The resultant OSL-age can therefore only be used as a *terminus ante quem* for the soil formation and the tumulus.

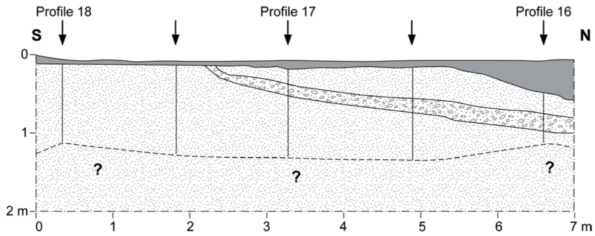

Fig. 4: Stratigraphic situation at the margin of the Neolithic settlement S02/28, Lower Wadi Howar, soil profiles 16–18. The horizon Bc with high concentration of iron nodules marks the former shore line.

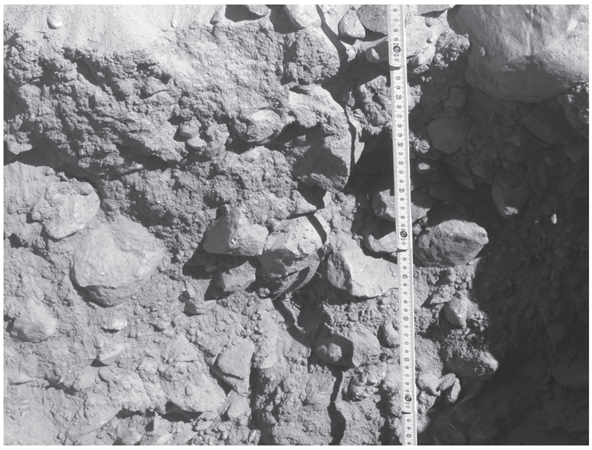

Fig. 5: Distinctly weathered soil material at the basis of the tumulus S06/1, Lower Wadi Howar, profile 1.

A well in the Wadi Howar
Near the fortress Gala Abu Ahmed a circular embankment with a diameter of 5 m was found on the wadi ground, which is typical for former wells (Kröpelin 1993). The sediments were studied by drilling up to a maxi-

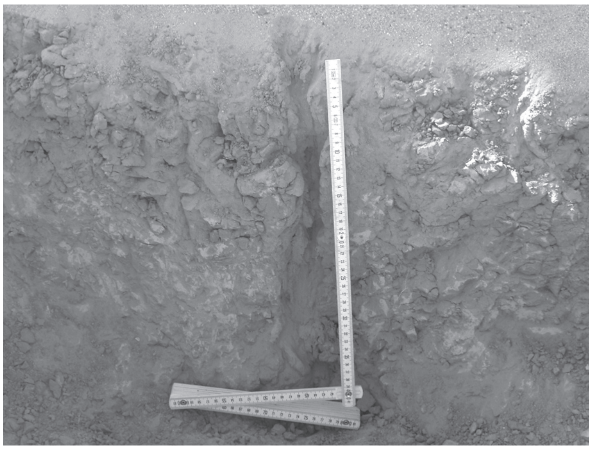

Fig. 6: Calcarous sediment of the former well near the Fortress Gala Abu Ahmed, profile 7.

mum depth of 134 cm below surface (profile 7; fig. 6; tab. 6). Below the aeolian sand cover, we found silty-loamy sediments with high contents of organic carbon and a distinct enrichment of salt in 83–134 cm depth. The soil was characterized as a Typic Torriorthent. The sediments prove the existence of a small lake at the deepest point of the wadi for a longer period. After the drying up of the lake, the existing groundwater reservoir on this spot was obviously still used for water supply. The age of the well is unclear. But it is conceivable that it was used by the habitants of the fortress, which is dated by several finds and ^{14}C-ages to the first half of the first millennium BC (Napata-time; Jesse and Kuper 2004). Maybe, the water supply even was the reason for the maintenance of a large fortress more than 100 km west of the River Nile. Finds of pottery prove that already in former times the Wadi Howar was used as an important trading route from the Nile to the west. Controlling the few water supplies with punctual checkpoints would have meant controlling the whole border line.

Conclusions

The analysis of desert soils near archaeological sites allowed new insights in the environmental and living conditions of the early inhabitants of the Wadi Howar and their interactions with their environment. It also provided us with more information about the soil genesis in arid regions. Further studies should concentrate on dating the described indicators of a more humid climate in the eastern Sahara during the Holocene.

Acknowledgements

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