Quaternary Science Reviews xxx (2015) 1–14

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Human occupations and environmental changes in the Nile valley during the Holocene: The case of Kerma in Upper Nubia (northern Sudan)

Matthieu Honegger [a, *], Martin Williams [b]

[a] Université de Neuchâtel, Institut d'Archéologie, Espace Paul Vouga, CH-2068 Hauterive, Switzerland
[b] Earth Sciences, University of Adelaide, Adelaide, SA 5005, Australia

ARTICLE INFO

Article history:
Received 21 January 2015
Received in revised form
9 June 2015
Accepted 30 June 2015
Available online xxx

Keywords:
Nile valley
Holocene
14C chronology
Prehistory
Demography
Neolithic
African Humid Period
Aridity

ABSTRACT

Our article presents a detailed Holocene archaeological sequence from the Nile Valley at Kerma in Upper Nubia, northern Sudan. This sequence retraces the evolution of human populations thanks to the study of several sites, supported by 90 14C dates. Reconstruction of the environmental changes was supported by a study of dated stratigraphic sections located near the archaeological sites studied, and illustrates the effects on human occupation of changes in river flow and floods, which are in turn forced by climatic changes. The results shed new light on the evolutionary dynamics of the Holocene populations in Nile Valley, little known due to the numerous hiatuses in occupation. When compared with the situation in the Sahara and the rest of the Nile Valley, they confirm that the initial occupation took place ca. 10.5 kyr BP after the start of the African Humid Period, followed by a migration towards the banks of the Nile commencing 7.3 kyr BP. They also confirm the appearance of the Neolithic by ca. 8.0 kyr BP. The Kerma stratigraphic sequences show two prosperous periods (10–8 and 7-6 kyr BP) and two hiatuses in the occupation of the sites (7.5–7.1 and 6.0–5.4 kyr BP), resulting from increased aridity.

1. Introduction

During recent prehistory, North-East Africa was a particularly dynamic region in which certain major innovations appeared at an early date, such as sedentism, the adoption of an economy based on production (stock-breeding and agriculture), and the appearance of centralised states (Emberling, 2014; Honegger, 2014; Tassie, 2014). The environment, influenced by the arid Sahara and the Nile Valley, made it distinctive in that the climatic variations and the fluctuations of the River Nile played a fundamental role on patterns of human occupation. The Sahara was subject to important environmental changes with the return of the summer monsoon shortly before the start of the Holocene, which initiated the African Humid Period (12-5 kyr BP), also known as the time of the "Green Sahara" (deMenocal et al., 2000; Gasse, 2000a and b; Tierney and deMenocal, 2013; Costa et al., 2014; Otto-Bliesner et al., 2014). This period, which saw the reoccupation of the desert by groups of hunter-gatherers after 10.5 kyr BP, was followed by a progressive desertification during the Middle Holocene, which led to a progressive abandonment of the arid zones and withdrawal to the banks of the Nile (Kuper and Kröpelin, 2006).

This general situation, known for a long time, has become much more precisely known thanks to several research programmes undertaken in the Eastern Sahara, at Nabta Playa (Wendorf and Schild, 2001) in particular and in the western desert (Kuper, 2002). The increase in excavations, archaeological data and radiocarbon dates has permitted the drawing of an overall picture of human occupation of the arid environments, supported by a large number of calibrated radiocarbon ages. One of the best known reviews of archaeological sites in North-East Africa is based on more than 500 dates emanating from approximately 150 sites (Kuper and Kröpelin, 2006), whilst another more recent one, covering the entire Sahara, incorporates 3287 dates from 1011 sites (Manning and Timpson, 2014). Both of these highlight the same principal events, namely, an intensive occupation of the Sahara starting about 10.5 kyr BP, a first withdrawal to the Nile Valley about 7.3 kyr BP, followed by an abandonment of the principal desert regions commencing 5.5 kyr BP.

---

* Corresponding author.
E-mail address: matthieu.honegger@unine.ch (M. Honegger).

http://dx.doi.org/10.1016/j.quascirev.2015.06.031

Please cite this article in press as: Honegger, M., Williams, M., Human occupations and environmental changes in the Nile valley during the Holocene: The case of Kerma in Upper Nubia (northern Sudan), Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.06.031

Notwithstanding the abundance of data concerning the Sahara and the clarity of the tendencies observed, the situation in the Nile Valley remains poorly known, even if it was the central zone for the Holocene population. Since the first syntheses of the human occupations (Hassan, 1985, 1986), the number of excavations and ^{14}C dates has increased, but the same gaps remain. In the Egyptian valley, a hiatus occurs between the end of the Epipalaeolithic (8.5 kyr BP) and the Initial Neolithic of the Fayoum ca. 7.4 kyr BP (Midant-Reynes, 2006; Vermeersch, 2002). In Upper Egypt, the hiatus is spread over two millennia (8.5–6.5 kyr BP). In Lower Nubia, between the first and second Nile cataracts (Fig. 1), the archaeological sequence established during the 1960s is difficult to use due to its lack of precision (Wendorf, 1968). Further south, around the sixth cataract (Fig. 1), Central Sudan has been the subject of numerous excavations since 1970 (Usai, 2014), which have also established a sequence marked by gaps. The first occupations are by hunter-gatherers who manufactured pottery ca. 9.5–7.5 kyr BP (Khartoum Mesolithic). This is followed by a hiatus in occupation of half a millennium prior to the development of the Neolithic (7–5.5 kyr BP), which is itself followed by a hiatus of more than two millennia.

These disparities in the information between the different sectors of the valley have caused confusion as to the chronology regarding the evolution of human society. This is in particular the case for the least well-documented period (8.5–6.5 kyr BP), which corresponds to the beginning of the Neolithic. The transition to this new economic base is poorly understood, as are the cultural and economic relations, which the valley might have entertained at this time with the surrounding desert, for which the archaeological situation is far better documented. It would appear essential to be able to compare the different sectors of the valley one with another, and to compare these with the data from the desert, to understand the social evolutionary processes in North-East Africa (cf. Wengrow et al., 2014).

With a view to filling some of these gaps, systematic excavations have been ongoing these past 20 years east of the Nile in the region of Kerma in Upper Nubia (Sudan). On the basis of 130 identified sites located in or adjacent to the Holocene floodplain, some of which have been excavated, a chronological sequence has now been established that covers much of the Holocene and is based on 90 ^{14}C ages. This work has highlighted the evolution of the habitation structures, the mortuary practices, the material culture and the economic base (Honegger, 2014). Through study of the location of the settlements over time, and the evolution of their density, we will attempt to reconstruct the rhythm of occupation in the region, identifying those periods when the population was subjected to environmental pressures. In parallel, a geological survey has been undertaken on the basis of 21 stratigraphic sections exposed in the alluvial plain, some of which have yielded ^{14}C or OSL ages. One of our aims was to investigate the effects on human occupation of changes in river flow and floods, which are in turn forced by climatic changes. The confrontation of these data with those obtained from the archaeological excavations, followed by comparisons with the entire Nile Basin, allows us to propose a scenario for the

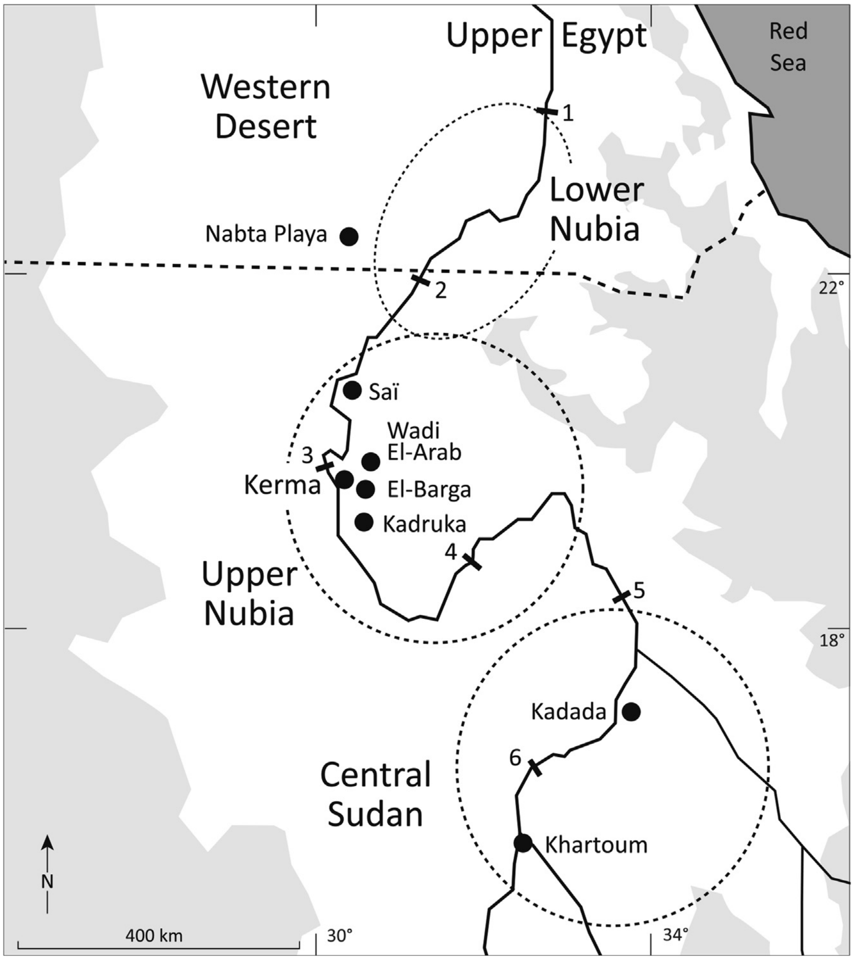

Fig. 1. Location of the Kerma area in the Nubian Nile valley with the other areas which deliver the main chronological sequence of the Holocene prehistory. Numbers are cataracts.

Please cite this article in press as: Honegger, M., Williams, M., Human occupations and environmental changes in the Nile valley during the Holocene: The case of Kerma in Upper Nubia (northern Sudan), Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.06.031

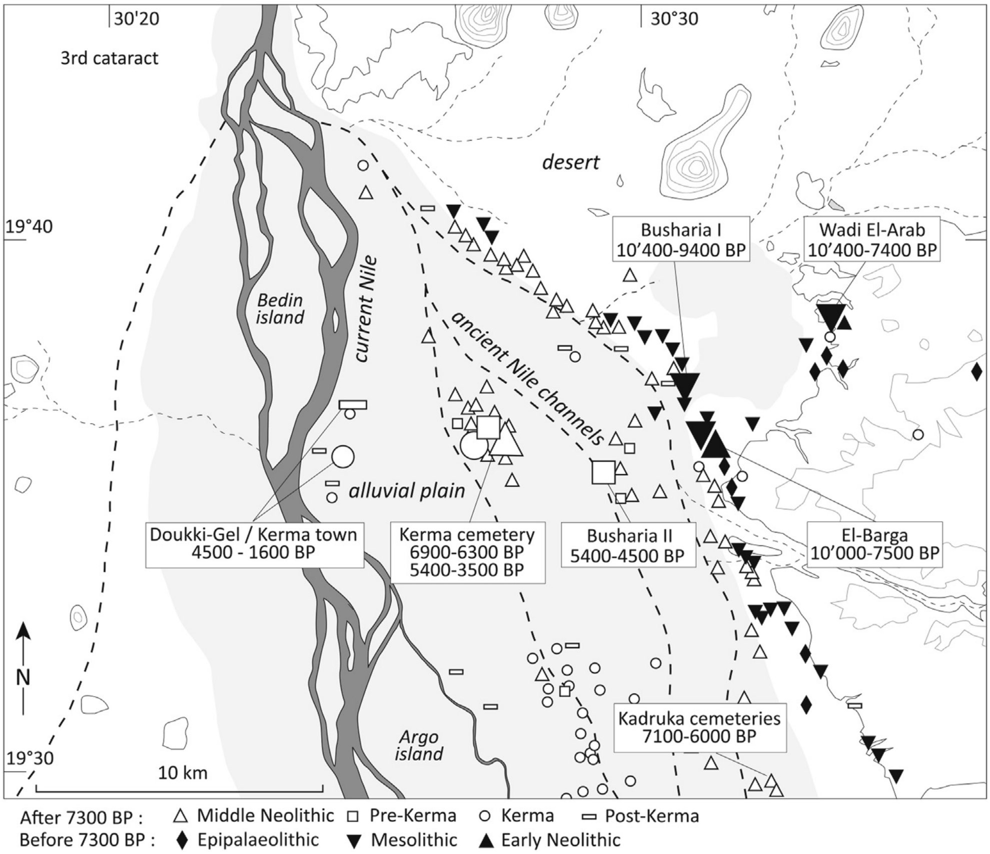

Fig. 2. The area of Kerma, south of the Third Nile Cataract (Sudan), with the location of the Holocene archaeological sites including the sites discussed in the text. The excavated sites are indicated with larger symbols.

dynamics of the occupation of the valley, which takes into account the environmental constraints and supplies new insights into the origins and development of the Neolithic.

2. Study area

2.1. Location

Kerma is located on the right bank of the Nile, several kilometres south of the third cataract in Northern Sudan (Fig. 1). This small township has given its name to the first kingdom of sub-Saharan Africa, which flourished between 4.5 and 2.5 kyr BP (2500–1500 BC) (Bonnet, 1992). The capital of the kingdom and its vast necropolis are within the study area. The right bank of the river is occupied by an alluvial plain 10–15 km wide, which extends south for more than 100 km. This is the most extensive alluvial plain in Nubia, and was crossed by several arms of the river during the wettest periods of the Holocene (Macklin et al., 2013). This plain and its close surroundings have long attracted human groups. For millennia the area has been densely populated, giving rise to a wealth of archaeological remains, whose number and interest have already been noted during the surveys undertaken to the south of the region of Kerma (Reinold, 1993; Welsby, 2001). The study area corresponds to a rough square, whose sides are ca.15 km long, which covers the alluvial plain and its desert margin, where most of the archaeological sites are located.

2.2. Geology and geomorphology

The study area consists of two main geological units: the Mesozoic Nubian Sandstone plateau lying at least 13 km east of the present-day Nile channel, and the late Quaternary Nile alluvial plain situated between plateau and Nile. The plateau rises a few tens of metres above the alluvial plain and has a crenulated and dissected western margin (Plate 1) from which emerge a series of ephemeral stream channels. On leaving the plateau the channels radiate out westwards as shallow distributary channels on gently sloping alluvial fans and vanish on reaching the eastern edge of the Nile alluvial plain. The stepped margin of the plateau has been eroded to form two main pediment surfaces (Williams, 2012a). The dissected upper pediment surface consists of isolated tabular sandstone remnants rising 2–3 m above the lower pediment surface and covered by a nearly continuous desert pavement cover. The lower pediment surface is better preserved and is a mantled pediment (Plate 2), with a weathered to fresh sandstone substrate overlain by a highly vesicular fossil soil which is in turn capped by one or more hardpan units with a protective cover of desert pavement at the surface (Williams, 2012a).

3. Results

3.1. Archaeological sequences

The 130 sites identified in the study area are often highly eroded and have yielded fragmentary material, which was generally sufficient to propose reasonably precise dates by means of typological comparisons of the pottery collected, based on previous classifications (Gatto, 2013; Honegger, 2004a, 2014; Privati, 1999). In most instances, the sites represent the remains of habitations, campsites or villages. A limited number of cemeteries were also found. The survey was conducted systematically during many seasons on foot and sometimes by car in order to identify all the remains from the

Please cite this article in press as: Honegger, M., Williams, M., Human occupations and environmental changes in the Nile valley during the Holocene: The case of Kerma in Upper Nubia (northern Sudan), Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.06.031

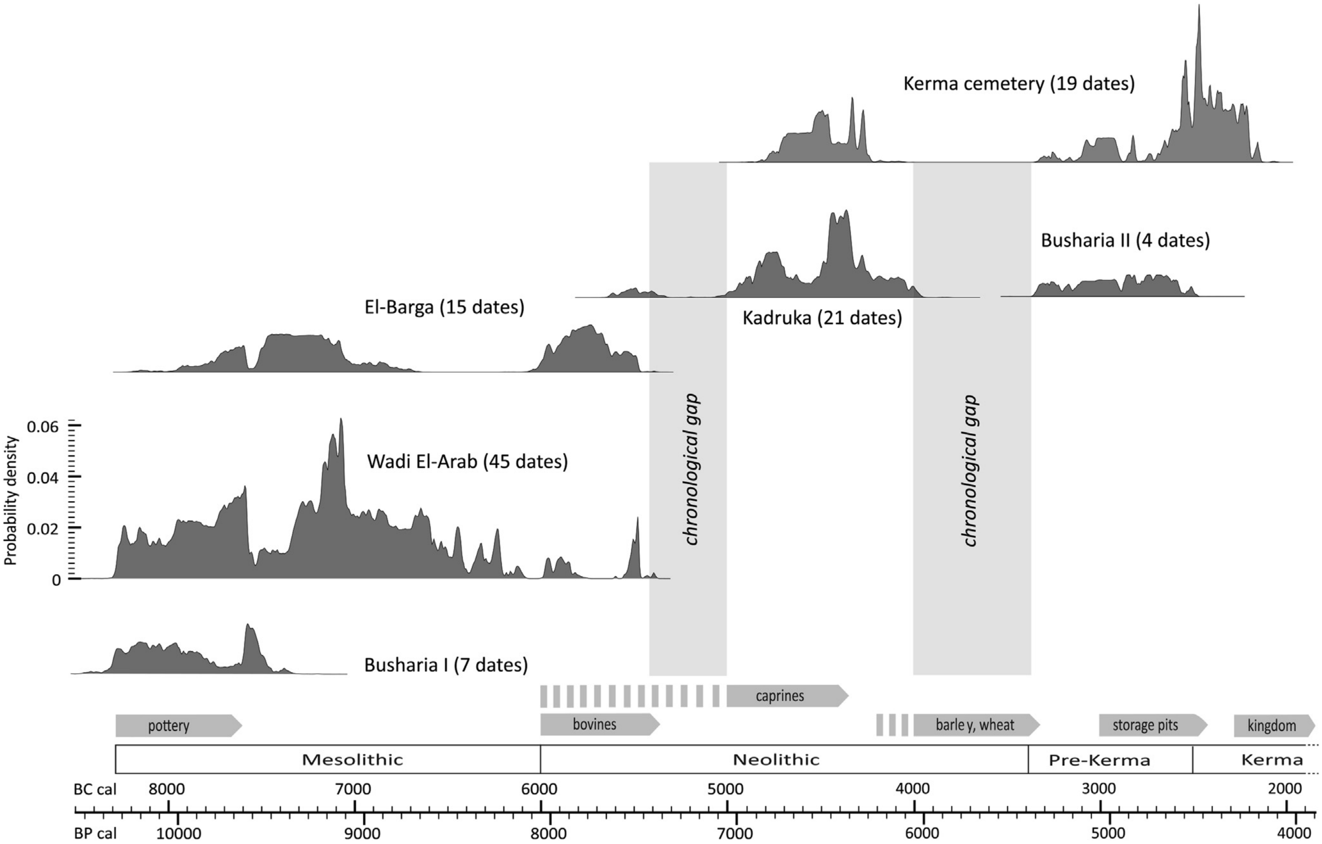

Fig. 3. ^{14}C chronology of the human occupation in the Kerma area with the main cultural complexes and the innovations which characterized this evolution (calibration based on Reimer et al., 2013). For each sites, the sum of the calibrated dates (2σ) is represented by a density curve (OxCal v4.2.4; Bronk Ramsey, 2009).

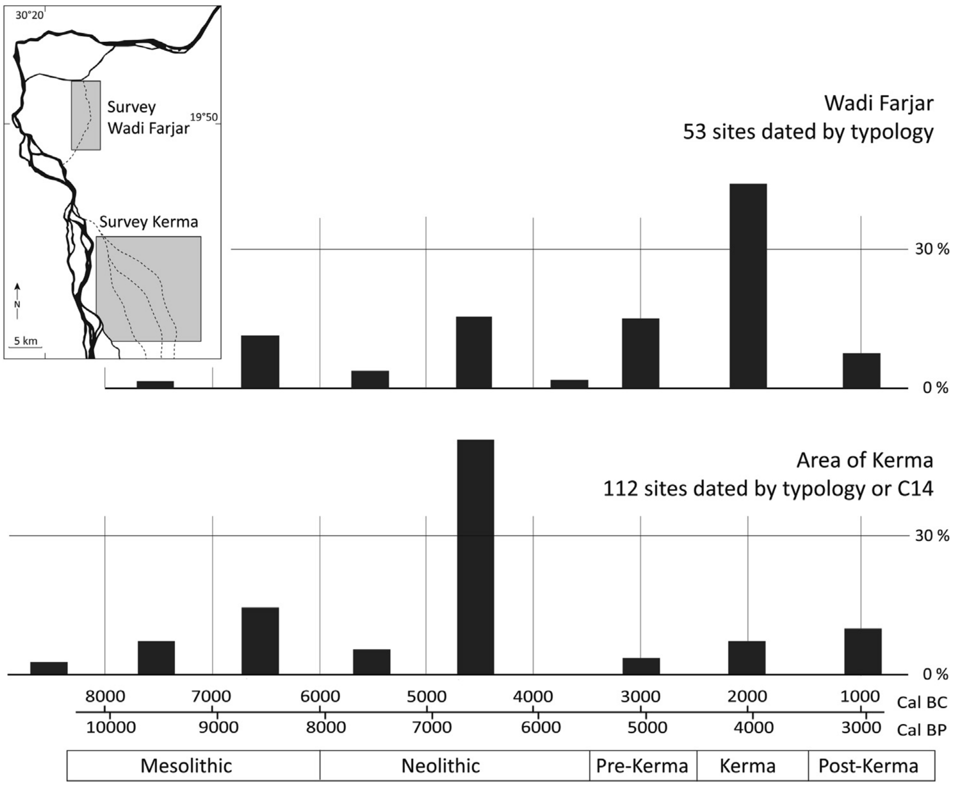

Fig. 4. Comparison of the proportion of Holocene archaeological sites by period and millennium between the Kerma area and Wadi Farjar.

Please cite this article in press as: Honegger, M., Williams, M., Human occupations and environmental changes in the Nile valley during the Holocene: The case of Kerma in Upper Nubia (northern Sudan), Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.06.031

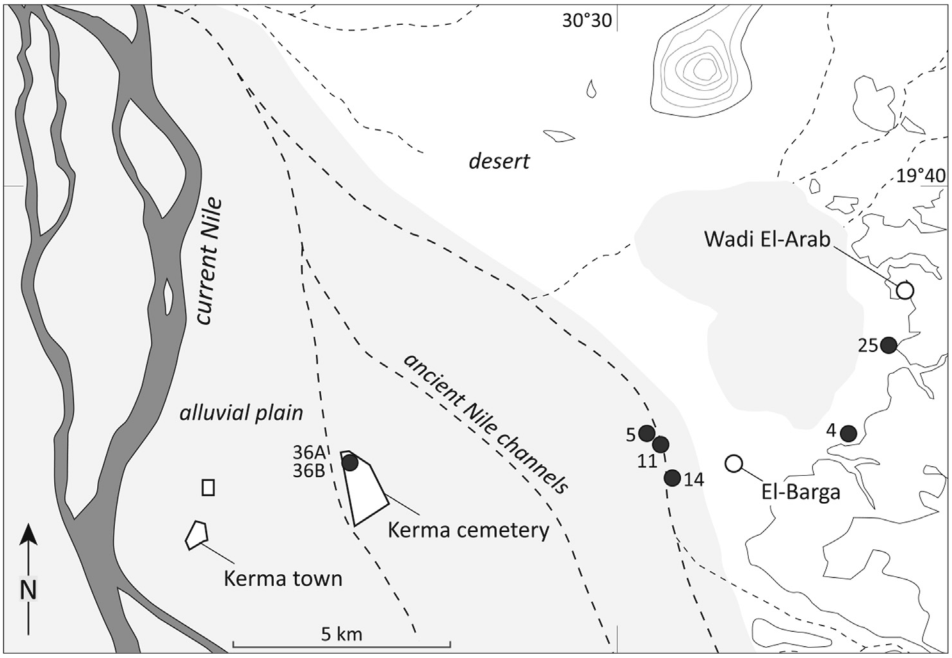

Fig. 5. Location of dated geological sections examined on the alluvial plain and Nubian Sandstone piedmont, Kerma area, northern Sudan.

surface and to collect the more significant material, especially pottery. Some local informants helped us in the identification of some sites, even in the cultivated area where the ploughing can reveal ancient occupations. From the ensemble of discovered sites, those best preserved have been the subject of excavations, or are currently under investigation (Fig. 2). Occasionally, as at Wadi El-Arab, a deposit 80 cm thick with several archaeological levels was preserved, but in most instances the wind had eroded most of the stratigraphy, unless it was high Nile floods which carried away most of the artefacts. For this reason, most of the excavations concentrated on the structures dug into the soil: pits, post-holes, semi-subterranean habitations and burials. It is only with the emergence of the Kingdom of Kerma and the introduction of sun-baked bricks, around 4 kyr BP (2000 BC) (Bonnet, 2000), that the habitations, which are also more densely spaced, tend to be better preserved. For the sites more ancient than Kerma Kingdom and the use of bricks, the surface remains are mainly stone tools, pottery sherds and sporadic faunal remains. The organic material is often not preserved. The only structures present at the surface are eroded hearths forming small mounds, caused by the hardening of silt by fire. It is difficult to estimate precisely the influence of preservation biases on the representation of the archaeological sites of different periods. For this reason, we compare two different areas surveyed

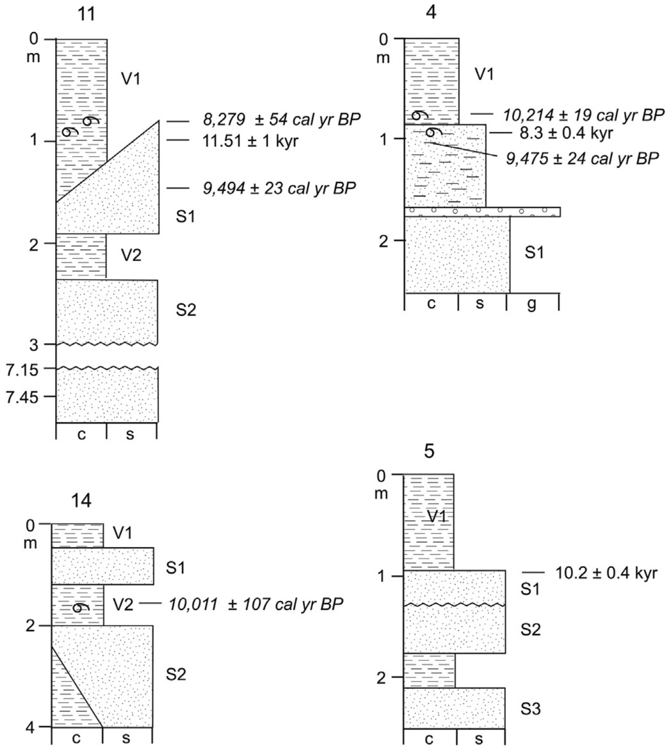

Fig. 6. Stratigraphic logs of four dated geological sites on the Holocene alluvial plain, Kerma area, northern Sudan. The 14C ages are shown in italics. All depths are given in Table 2. S1, S2 and S3 are sand units and V1 and V2 are cracking clay (vertisol) units. All are numbered from the top down.

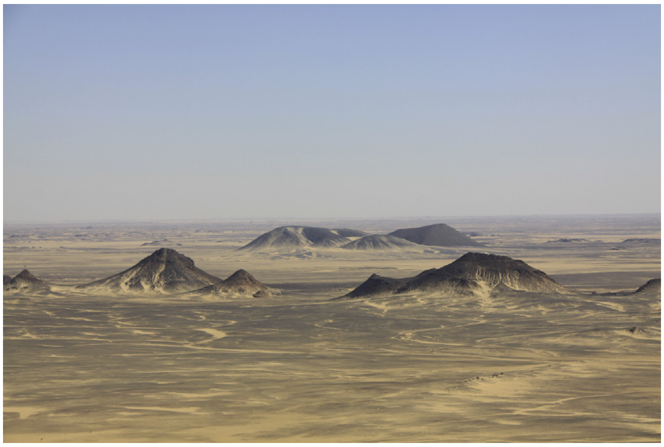

Plate 1. Nubian Sandstone erosional remnants flanked by pediment surface, east of Kerma, north Sudan.

Please cite this article in press as: Honegger, M., Williams, M., Human occupations and environmental changes in the Nile valley during the Holocene: The case of Kerma in Upper Nubia (northern Sudan), Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.06.031

Plate 2. Mantled pediment. Weathered Nubian Sandstone overlain by fossil soil, Kerma area, north Sudan.

with the same method to check if our observations are indeed representative (see below, Section 4.2).

The sites excavated have provided numerous ^{14}C ages on which to establish their chronologies (Table 1). These ages have been obtained on charcoal, ostrich eggshell or shellfish from the Nile (*Unio* sp.), and the results obtained have been consistent, irrespective of the material used for dating purposes. Ostrich eggshell samples were the most numerous, followed by charcoal and Nile mussel shells. Such shells could give older ages due to the hard water effect if old carbonates are present in the catchment area. At Kerma, the ^{14}C results on these samples do not reveal any difference with those obtained on other material.

3.2. Localisation of the prehistoric settlements and principal sites excavated

Only the Holocene sites are discussed in this paper. We have therefore ignored the few sites dating to the Early Stone Age (ESA) found close to the present-day course of the Nile (Chaix et al., 2000) and the sites from the Middle Stone Age (MSA), all of which are located in the desert. No Late Stone Age (LSA) site was found, which is normal for Upper Nubia. Generally speaking, the LSA is poorly represented in North-East Africa, except for in Upper Egypt where it is better documented (Vermeersch, 2006).

In the region of Kerma, the first Holocene occupations date from 10.3 kyr BP. They concern hunter-gatherer populations having adopted pottery, which are known as Mesolithic in Sudan, by reference to the terminology proposed by Arkell (1949) during his excavations at Khartoum. It is possible that a number of the sites are earlier, as suggested by the microlithic industry without the presence of pottery, which we have classified as Epipalaeolithic, without supplying any precise chronology, given the absence of ^{14}C dates. The latest sites shown by our surveys have been labelled post-Kerma. Not numerous, these sites essentially comprise settlements dating from the New Empire (about 1550–1070 BC) or the Kingdoms of Napata (about 750–315 BC) or Meroe (about 300 BC-350 AD), which bring us to the beginning of our Era.

The distribution of the sites shows a clear contrast in regard to their location (Fig. 2). The sites dating from prior to 7.3 kyr BP are established beyond the alluvial plain, generally on small outcrops of Nubian Sandstone, or else at the foot of sandstone erosional remnants. Some of these sites are located round the perimeter of a depression with a diameter of about 5 km, seasonally flooded from either the Nile or local runoff or from a rise in the local water table, as occurs todays at the southern end of the Seleim Basin. The alluvial plain was probably hard of access at that time, since several arms of the Nile were active, transforming the zone into a swampy plain. Neither technical progress nor cultural preference appear adequate to explain why people avoided the floodplain at this time. The alluvial plain was rich in Nile resources and human groups most probably went there regularly to fish or collect shells, but they did not construct villages or campsites in this area.

After 7.3 kyr BP, virtually all the sites listed are located on the alluvial plain, whose margins are then totally deserted, having probably become less appealing due to a more arid climate, as occurred also in the western desert (see below). On the alluvial plain, rare stratigraphic observations were made in the Kerma cemetery. Our trial trenches show a succession of Neolithic occupation levels between 6.9 and 6.3 kyr BP separated by silt from the Nile. The area was thus occupied at regular intervals, but was not sheltered from occasional extreme floods. The later sites, starting in the 6th and 5th millennia BP, were not covered by silt from the Nile and are often severely affected by eolian erosion.

We will note the date of 10.3 kyr BP, which corresponds to the first Holocene occupation and that of 7.3 kyr BP, which marks the abandonment of the plateau edge in favour of the alluvial plain which had until then been unoccupied. These two dates correspond with the most important events observed in the western desert and in the Sahara as a whole (Kuper and Kröpelin, 2006; Manning and Timpson, 2014). They demonstrate that the region of Kerma was subject to the same environmental influences, notably, a reoccupation of the desert regions after the onset of the African Humid Period, followed by a return to the valley when an arid climatic phase set in.

3.3. Settlement chronology

The sites that still contain archaeological stratigraphies or structures have been the subject of excavations as well as being ^{14}C dated. Fig. 3 summarises the situation for each site, indicating the period of occupation as well as the principal innovations. The calibrated ^{14}C results are presented by density curves obtained with the software OxCal v4.2.4 (Bronk Ramsey, 2009). The distinction by site of the density curves highlights the fact that the chronological sequences differ if the site is located outside or inside the floodplain.

The two main chronological gaps observed in the overall archaeological sequence and discussed below, were confirmed by the typological comparisons with the other sites discovered in the survey, which are not ^{14}C dated. If the radiocarbon calibration curve (Intcal 13; Reimer et al., 2013) has an influence on the shape of the ^{14}C density curves because of the fluctuations in atmospheric ^{14}C (Chiverrell et al., 2011), it has no influence on the validity of the two chronological gaps. More elaborate methods are now available to interpret ^{14}C density curves (Jones et al., 2015).

The three most ancient sites are located beyond the alluvial plain. The regular presence of habitation structures and the development of cemeteries allow us to hypothesise that the occupants were sedentarised, or at least that they organised their activities around a principal habitation site. Busharia I is an eroded site which contained a few remains of hearths and its primary interest resides in having produced numerous sherds, which are the most ancient in the Sudan, dated ca. 8.3 kyr BP. Wadi El-Arab is a much richer site which extends over more than three hectares and contains stratified occupation levels, preserved from erosion under a surface hardpan. The site was occupied during almost three millennia, produced the bases of semi-subterranean habitations, hearths and some ten tombs disseminated within the habitations. The best-preserved occupations are dated between 10 and 8.5 kyr

Please cite this article in press as: Honegger, M., Williams, M., Human occupations and environmental changes in the Nile valley during the Holocene: The case of Kerma in Upper Nubia (northern Sudan), Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.06.031

Table 1
Radiocarbon ages of archaeological sites studied in the Kerma region, northern Sudan. Calibration based on Reimer et al. (2013).

	Lab	BP uncalibrated	BP calibrated 2σ	BC calibrated 2σ	Context	Period	Material
Cemetery of Kerma							
1	ETH-40519	3810 ± 35	4400–4090	2450–2140	grave 321	Early Kerma I	Ostrich eggshell
2	ETH-40520	3830 ± 35	4410–4100	2460–2150	grave 339	Early Kerma I	Ostrich eggshell
3	ETH-47156	3836 ± 30	4410–4140	2460–2190	grave 477	Early Kerma I	Blades of grass
4	ETH-47157	3920 ± 31	4440–4240	2490–2290	grave 442	Recent Pre-Kerma	Blades of grass
5	ETH-47155	3936 ± 30	4520–4250	2570–2300	grave 449	Recent Pre-Kerma	Blades of grass
6	ETH-47153	3957 ± 30	4520–4290	2570–2340	grave 491	Early Kerma I	Ostrich eggshell
7	ETH-43724	3970 ± 35	4530–4290	2580–2340	grave 383	Early Kerma I	Ostrich eggshell
8	ETH-47151	3976 ± 30	4530–4350	2580–2400	grave 407	Early Kerma I	Ostrich eggshell
9	ETH-20153	3885 ± 50	4430–4160	2480–2210	chapel	Early Kerma I	Charcoal
10	ETH-27203	4050 ± 55	4810–4420	2860–2470	chapel	Early Kerma I	Charcoal
11	ETH-47154	4079 ± 31	4810–4440	2860–2490	grave 463	Recent Pre-Kerma	Blades of grass
12	ETH-18829	4365 ± 55	5270–4840	3320–2890	settlement	Middle Pre-Kerma	Charcoal
13	ETH-18828	4400 ± 55	5280–4850	3330–2900	settlement	Middle Pre-Kerma	Charcoal
14	ETH-51603	5458 ± 30	6300–6210	4350–4260	settlement	Middle Neolithic	Charcoal
15	LY-13649	5520 ± 85	6490–6030	4540–4080	settlement	Middle Neolithic	Charcoal
16	B-6626	5670 ± 30	6530–6400	4580–4450	settlement	Middle Neolithic	Charcoal
17	CRG-770	5670 ± 75	6640–6310	4690–4360	settlement	Middle Neolithic	Charcoal
18	ETH-14925	5770 ± 65	6720–6410	4770–4460	settlement	Middle Neolithic	Charcoal
19	ETH-18827	5815 ± 60	6770–6470	4820–4520	settlement	Middle Neolithic	Charcoal
Busharia II							
20	ETH-20839	4085 ± 50	4820–4440	2870–2490	settlement	Recent Pre-Kerma	Charcoal
21	ETH-40951	4150 ± 35	4830–4570	2880–2620	settlement	Recent Pre-Kerma	Charcoal
22	LY-11146	4345 ± 65	5280–4830	3330–2880	settlement	Recent Pre-Kerma	Charcoal
23	LY-1662-(OXA)	4470 ± 45	5300–4900	3350–2950	settlement	Middle Pre-Kerma	Charcoal
El-Barga							
24	ETH-28405	6605 ± 60	7580–7430	5630–5480	grave 70	Early Neolithic	Ostrich eggshell
25	ETH-28406	6785 ± 60	7740–7560	5790–5610	grave 47b	Early Neolithic	Nile shell
26	ETH-30041	6865 ± 65	7840–7590	5890–5640	grave 111	Early Neolithic	Ostrich eggshell
27	ETH-30342	6900 ± 65	7920–7610	5970–5660	grave 112	Early Neolithic	Ostrich eggshell
28	ETH-27207	6960 ± 65	7930–7680	5980–5730	grave 22	Early Neolithic	Nile shell
29	ETH-27208	7045 ± 70	8000–7720	6050–5770	grave 16	Early Neolithic	Ostrich eggshell
30	ETH-27206	8020 ± 65	9080–8640	7130–6690	grave 33	Mesolithic III	Nile shell
31	ETH-31779	8180 ± 65	9400–9000	7450–7050	settlement	Mesolithic II	Ostrich eggshell
32	ETH-27204	8190 ± 70	9400–9000	7450–7050	settlement	Mesolithic II	Charcoal
33	ETH-35678	8205 ± 50	9370–9020	7420–7070	settlement	Mesolithic II	Ostrich eggshell
34	ETH-31780	8310 ± 65	9480–9120	7530–7170	settlement	Mesolithic II	Ostrich eggshell
35	ETH-25503	8340 ± 65	9490–9140	7540–7190	settlement	Mesolithic II	Charcoal
36	ETH-27610	8360 ± 60	9520–9140	7570–7190	settlement	Mesolithic II	Charcoal
37	ETH-35677	8640 ± 55	9740–9520	7790–7570	grave 137	Mesolithic II	Ostrich eggshell
38	ETH-27205	8730 ± 70	10,20–9540	8170–7590	settlement	Mesolithic II	Ostrich eggshell
Wadi El-Arab							
39	ETH-47148	6526 ± 33	7510–7330	5560–5380	settlement	Neolithic I	Ostrich eggshell
40	ETH-51609	7006 ± 36	7940–7750	5990–5800	settlement	Neolithic I	Ostrich eggshell
41	ETH-51610	7365 ± 35	8310–8050	6360–6100	settlement	Mesolithic IV	Ostrich eggshell
42	ETH-40526	7400 ± 40	8340–8070	6390–6120	settlement	Mesolithic IV	Ostrich eggshell
43	ETH-40524	7590 ± 40	8450–8340	6500–6390	settlement	Mesolithic III	Ostrich eggshell
44	ETH-35681	7750 ± 50	8610–8420	6660–6470	settlement	Mesolithic III	Charcoal
45	ETH-36468	7755 ± 55	8630–8420	6680–6470	settlement	Mesolithic III	Ostrich eggshell
46	ETH-40945	7820 ± 40	8720–8480	6770–6530	settlement	Mesolithic III	Ostrich eggshell
47	ETH-31785	7845 ± 65	8980–8460	7030–6510	settlement	Mesolithic III	Ostrich eggshell
48	ETH-40943	7875 ± 40	8970–8560	7020–6610	settlement	Mesolithic III	Ostrich eggshell
49	ETH-35680	7955 ± 50	8990–8650	7040–6700	settlement	Mesolithic III	Ostrich eggshell
50	ETH-40937	7965 ± 40	8990–8650	7040–6700	settlement	Mesolithic III	Ostrich eggshell
51	ETH-30460	7965 ± 65	9010–8630	7060–6680	settlement	Mesolithic III	Nile shell
52	ETH-43719	7975 ± 35	9000–8660	7050–6710	settlement	Mesolithic III	Nile shell
53	ETH-30343	7985 ± 70	9020–8630	7070–6680	settlement	Mesolithic III	Ostrich eggshell
54	ETH-40525	7995 ± 45	9010–8660	7060–6710	settlement	Mesolithic III	Ostrich eggshell
55	ETH-43722	8025 ± 35	9020–8770	7070–6820	settlement	Mesolithic III	Nile shell
56	ETH-47149	8101 ± 36	9130–8820	7180–6870	settlement	Mesolithic III	Ostrich eggshell
57	ETH-40527	8110 ± 40	9240–8980	7290–7030	settlement	Mesolithic III	Ostrich eggshell
58	ETH-31786	8125 ± 60	9280–8790	7330–6840	settlement	Mesolithic III	Ostrich eggshell
59	ETH-43721	8135 ± 35	9240–9000	7290–7050	settlement	Mesolithic III	Nile shell
60	ETH-40946	8135 ± 40	9250–9000	7300–7050	settlement	Mesolithic III	Ostrich eggshell
61	ETH-31787	8140 ± 65	9300–8790	7350–6840	settlement	Mesolithic II	Ostrich eggshell
62	ETH-47150	8163 ± 36	9250–9010	7300–7060	settlement	Mesolithic II	Ostrich eggshell
63	ETH-43723	8190 ± 35	9260–9030	7310–7080	settlement	Mesolithic II	Nile shell
64	ETH-51611	8231 ± 38	9400–9030	7450–7080	settlement	Mesolithic II	Ostrich eggshell
65	ETH-43720	8240 ± 35	9400–9040	7450–7090	settlement	Mesolithic II	Nile shell
66	ETH-40947	8265 ± 40	9420–9130	7470–7180	settlement	Mesolithic II	Ostrich eggshell
67	ETH-27209	8290 ± 70	9470–9040	7520–7090	settlement	Mesolithic II	Ostrich eggshell
68	ETH-40948	8390 ± 40	9490–9300	7540–7350	settlement	Mesolithic II	Ostrich eggshell
69	ETH-40944	8560 ± 40	9580–9480	7630–7530	settlement	Mesolithic II	Ostrich eggshell

(*continued on next page*)

Please cite this article in press as: Honegger, M., Williams, M., Human occupations and environmental changes in the Nile valley during the Holocene: The case of Kerma in Upper Nubia (northern Sudan), Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.06.031

Table 1 (*continued*)

	Lab	BP uncalibrated	BP calibrated 2σ	BC calibrated 2σ	Context	Period	Material
70	ETH-40940	8640 ± 40	9680–9540	7730–7590	settlement	Mesolithic II	Ostrich eggshell
71	ETH-36469	8655 ± 60	9890–9530	7940–7580	settlement	Mesolithic II	Ostrich eggshell
72	ETH-40942	8680 ± 40	9740–9540	7790–7590	settlement	Mesolithic II	Ostrich eggshell
73	ETH-35682	8705 ± 55	9890–9550	7940–7600	settlement	Mesolithic II	Ostrich eggshell
74	ETH-40938	8715 ± 45	9890–9550	7940–7600	settlement	Mesolithic II	Ostrich eggshell
75	ETH-31784	8765 ± 65	10,30–9550	8180–7600	settlement	Mesolithic II	Ostrich eggshell
76	ETH-40949	8795 ± 40	10,30–9630	8180–7680	settlement	Mesolithic II	Ostrich eggshell
77	ETH-40941	8820 ± 40	10,50–9700	8200–7750	settlement	Mesolithic I	Ostrich eggshell
78	ETH-40950	8820 ± 40	10,50–9700	8200–7750	settlement	Mesolithic I	Ostrich eggshell
79	ETH-40939	8835 ± 40	10,60–9710	8210–7760	settlement	Mesolithic I	Ostrich eggshell
80	ETH-43718	8865 ± 35	10,70–9790	8220–7840	settlement	Mesolithic I	Ostrich eggshell
81	ETH-31789	8870 ± 70	10,90–9710	8240–7760	settlement	Mesolithic I	Ostrich eggshell
82	ETH-47147	8980 ± 39	10,230–9930	8280–7980	settlement	Mesolithic I	Ostrich eggshell
83	ETH-31788	8990 ± 65	10,250–9910	8300–7960	settlement	Mesolithic I	Ostrich eggshell
Busharia I							
84	ETH-30345	8465 ± 70	9550–9310	7600–7360	settlement	Mesolithic II	Charcoal
85	ETH-31783	8560 ± 65	9680–9460	7730–7510	settlement	Mesolithic II	Nile shell
86	ETH-30044	8815 ± 70	10,70–9630	8220–7680	settlement	Mesolithic I	Nile shell
87	ETH-40528	8845 ± 45	10,60–9740	8210–7790	settlement	Mesolithic I	Ostrich eggshell
88	ETH-31782	8860 ± 65	10,80–9710	8230–7760	settlement	Mesolithic I	Ostrich eggshell
89	ETH-35679	8880 ± 55	10,90–9770	8240–7820	settlement	Mesolithic I	Ostrich eggshell
90	ETH-30046	9040 ± 70	10,390–9920	8440–7970	settlement	Mesolithic I	Ostrich eggshell

Calibration based on Reimer et al. (2013).

Table 2
Radiocarbon ages of geological samples collected from the Holocene alluvial plain, Kerma area, northern Sudan. Calibrated using software package of Fairbanks et al. (2005). For location of samples see Fig. 5.

Field sample no	Site	Depth (m)	Laboratory no	Material	Uncalibrated age (yr BP)	Calibrated age (cal yr BP)
K12/4-1	4	0.9	ETH-47138	Unio shells	9044 ± 38	10,214 ± 19
K12/4-2		0.45	ETH-47139	Corbicula shells	8453 ± 37	9475 ± 25
K12/11-4	11	1.45	ETH-47142	Charcoal	8876 ± 38	9495 ± 23
K12/11-2		0.9–0.75	ETH-47141	Gastropod shells	7448 ± 36	8279 ± 54
K12/14-2	14	1.6	ETH-47144	Gastropod shells	8094 ± 38	10,011 ± 107

BP, whilst the later ones are partially eroded by the wind. The third site, named El-Barga, has yielded a hut base dug into the Nubian sandstone dating from 9.5 kyr BP. Close-by extends a Mesolithic cemetery containing approximately 50 tombs dated between 9.8 and 9 kyr BP (Honegger, 2004b, 2006). A second necropolis, further south, contained some 100 tombs dating from the Early Neolithic between 8 and 7.5 kyr BP. The contrast between the Mesolithic and Neolithic burials is striking (Honegger, 2006) and evokes those brought to light in central Sahara (Sereno et al., 2008). The individuals from the earlier burials have a robust morphology and are seldom buried with personal adornments. By contrast, the later ones are more gracile and are accompanied by offerings and personal effects, mostly made up of tools and adornments made of polished stone, which was a new technique in the region (axe blades, beads, labrets and ear-rings). The pottery presents either surfaces covered in impressed decorations as was evidenced from inception (Sudanese Style) (Jesse, 2010), or a burnished surface, whose evolution has been traced in the western desert and which was diffused from the north to the south from ca. 8.5 kyr BP, and which could be more or less synchronous with the flow of Neolithic diffusion (Riemer, 2007). Finally, a bucranium was deposited on top of a tomb, which must of necessity have been from a domesticated bovid, given that the wild aurochs is not present during the Neolithic south of the second cataract (Linseele, 2004). This cemetery, which is the oldest known for the African Neolithic, announces at an early date the rites that were practiced in the Nubian necropolises from the 7th millennium BP (Chaix, 2011).

Once again, the Initial Neolithic in north-east Africa does not appear to date from earlier than 8 kyr BP (Close, 2002; Kuper and Riemer, 2013; Linseele et al., 2014). This observation reinforces the idea that the Neolithic diffused from the Near East at this time, and weakens the hypothesis of an earlier Neolithic in the direction of Nabta Playa, to the south of the Egyptian western desert, where bovines were supposedly domesticated ca. 10.5 kyr BP (Wendorf and Schild, 2001). This hypothesis has been the subject of debate these past 20 years (Wengrow, 2003). It is based on fragmented remains of bovines (*Bos primigenius* or *Bos taurus*), which are present in small numbers at sites dated between 10.5 and 8 kyr BP. After this period their number increases following the appearance of domesticated caprines. Whether the bovines were hunted or “manipulated”, they appear in very small numbers prior to 8 kyr BP and the phenomenon is not diffused into neighbouring regions. It would therefore seem to be a local affair, which does not seem to have influenced the Neolithisation process in Africa. This process occurs at a time of marked aridity between 8.5 and 7.3 kyr BP (Macklin et al., 2015) or, for the western desert, the return of drier conditions around 7.3 kyr BP (Riemer et al., 2013). Hassan (2002) suggested earlier that a part of the Neolithisation process occurred during arid conditions, which could have stimulated its dissemination.

After the abandonment of the early Neolithic cemetery of El-Barga in the Kerma region at 7.5 kyr BP, we have not found any sites dated between 7.5 and 7.1 kyr BP. This is the period during which occupation moved onto the alluvial plain due to the drier conditions known around 7.3 kyr BP and the earlier sites on its margins were abandoned. The absence of sites during 400 years may reflect site destruction but could also denote that the region was partially depopulated during this period. On the plain, the

Please cite this article in press as: Honegger, M., Williams, M., Human occupations and environmental changes in the Nile valley during the Holocene: The case of Kerma in Upper Nubia (northern Sudan), Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.06.031

earliest dated sites are represented by a series of villages found either on the surface or in stratigraphic contexts in the Kerma cemetery, as well as by some 20 cemeteries at Kadruka (Reinold, 2000). Both of these ensembles cover between them virtually the whole of the 7th millennium BP. This millennium is well represented in Nubia and central Sudan, especially in cemeteries, giving the impression of being a prosperous period, given the material wealth in the funerary complexes. During this period the economy is primarily based on pastoralism (Chaix and Honegger, 2014), and whilst agriculture is attested, it appears to play a secondary role.

This millennium of prosperity precedes that in Upper Egypt by several centuries, where the first cemeteries dating from the Neolithic are no earlier than 6.5 kyr BP, becoming more frequent ca. 6.2 kyr BP with the development of the Badarian (Wengrow et al., 2014). These cemeteries are similar to those known elsewhere in Sudan, whether in terms of the material culture or of the funerary rites. The period of prosperity lasted for no more than a millennium in Sudan. Not a single site is known in the valley after 6 kyr BP with the exception of the cemetery at Kadada in central Sudan, dated ca. 5.6 kyr BP (Reinold, 2006). At Kerma, this hiatus lasted until 5.4 kyr BP at least, but in most of the regions of Upper Nubia, virtually nothing has been found prior to the beginning of the Kingdom of Kerma around 4.5 kyr BP. It would appear that around 6 kyr BP there was collapse of a prosperous and stable society, which had lasted a millennium. Although we cannot rule out that sedimentary processes may have obliterated the sites of this period, this chronological gap seems to be too recurrent in Upper Nubia - even in the context of small branches of the Nile (see Section 4.2) — for us to accept this as a convincing explanation.

Beginning in 5.4 kyr BP, traces of settlements are again found on the alluvial plain. These settlements belong to a cultural horizon known as Pre-Kerma and correspond to agro-pastoral populations with affinities with A Group from Lower Nubia, whilst also showing precursor affinities with the Kingdom of Kerma (Honegger, 2004). The archaeological remains at Busharia II have been severely damaged by agricultural practices, but the same is not the case at the Kerma cemetery where a vast complex dating from ca. 5 kyr BP has been excavated over a surface area of two hectares (Honegger, 2007, 2014). Huts, rectangular buildings, fortifications and animal pens have been uncovered, but the most important remains are almost 300 pits for the storage of cereals. Other sites of the same period have also yielded a large number of pits, such as that on the Sai Island between the second and third cataracts (Geus, 2004). This type of structure has never been found in Neolithic sites in Sudan, leading to the conclusion that agriculture played only a secondary role at that time. It is only with the advent of the 5th millennium that the concept of grain storage appears to have developed. This practice not only assures a subsistence based on grain during the entire year, it also supposes a more productive agriculture, possibly already based on irrigation. From this time on, the settlements grew steadily until the emergence of the Kingdom of Kerma around 4.5 kyr BP, which was destroyed a millennium later by the Egyptians of the New Kingdom. The study of the faunal remains associated with the Kingdom of Kerma shows that after 3.7 kyr BP caprines become much more important than bovines, which become rare, probably indicative of very arid conditions (Chaix, 2007).

To summarize the main results, we can schematically demonstrate two well represented archaeological phases, which evoke a certain level of prosperity. The first corresponds to the Mesolithic between 10 and 8 kyr BP and the second during the Neolithic between 7 and 6 kyr BP. These two periods are each followed by a chronological gap during which sites are almost absent (7.5–7.1 kyr BP and 6–5.4 kyr BP). We discuss the possible reasons for these gaps in Section 4.

3.4. *Holocene environments in the Kerma area*

Fig. 6 shows four dated Holocene sites. Methods used to describe the sediments and the procedures used in the optical dating are given in the appendix (supplementary data S1 and S2).

We obtained an OSL age of 10.7 ± 1.5 kyr from a depth of −125 cm in the sand unit exposed during the January 2012 excavation at Wadi el-Arab (Fig. 6: site 25; see Table 3. This unit was formed by weathering of the Nubian Sandstone and has not been subject to much disturbance. Such weathering is not occurring today, which suggests wetter conditions in this area ~11 kyr ago. The other Holocene sites were on the alluvial plain.

At site 4 (Fig. 6) we obtained ages of 8.3 ± 0.4 kyr (OSL) and 10, 214 ± 19 cal yr BP (^{14}C) for *Unio* shell from a depth of 90 cm in the penultimate clay (vertisol) unit, and a ^{14}C age from *Corbicula* shells at the top of this unit (45 cm depth) of 9, 475 ± 25 cal yr BP. Site 5 (Fig. 6) yielded an OSL age of 10.2 ± 0.4 kyr for sand unit S1 at −1.0 m depth. The upper clay unit (V1 or vertisol 1) overlies S1 with no sharp erosional break and so may be about the same age. Above sand unit S2 at site 11 (Fig. 6) there is a clay unit (V2) overlain by sand unit S1, from which we have three ages: a ^{14}C age of 9, 495 ± 23 cal yr BP at −1.45 m depth, a ^{14}C age of 8, 279 ± 54 cal yr BP at −0.9 to −0.75 m depth, and an OSL age of 11.5 ± 1.0 kyr at −1.05 m depth. Above the eroded surface of sand unit S1 is another clay unit at least 1.6 m thick (vertisol V1), indicative of Nile floods after 8.3 kyr ago. Another Holocene floodplain site (site 14, Fig. 6) yielded a ^{14}C age of 10, 011 ± 107 cal yr BP for shells at −1.6 m depth within a penultimate vertisolic clay unit (V2). Finally, near the western margin of the Holocene alluvial plain at the eastern cemetery two empty graves (geological sites 36A and 36B, Fig. 5) gave OSL ages for the top of the fluvial sand unit (at depths of −1.55 m in each site) of 7.6 ± 0.3 kyr and 7.9 ± 0.3 kyr, respectively. A vertisolic clay unit up to 1.5 m thick overlay the fluvial sands.

Intervals of Holocene fluvial sand deposition (Plates 3 and 4) from the Nile and one of its anabranches thus range from early to mid-Holocene (10.2 ± 0.4, 7.9 ± 3, 7.6 ± 0.3 kyr). Clay deposits were laid down across the floodplain 11.5, 10.2, 10.0, 9.5, 8.3 and after

Table 3
OSL ages of geological samples collected from the Holocene alluvial plain, Kerma area, northern Sudan. For location of sites see Fig. 5.

Field sample no (Lab ID no)	Site	Depth (m)	Total dose rate (Gy/ka)	Cosmic dose (Gy/ka)	No sub-samples run/no accepted	Over dispersion	Analysis method	Equivalent dose Gy	Age ka
SUK1243 (Ad12057)	4	0.90	1.52 ± 0.04	0.18 ± 0.02	1200/95	47%	FMM	12.5 ± 0.6	8.3 ± 0.4
SUK1251 (Ad12058)	5	1.00	1.24 ± 0.03	0.18 ± 0.02	1200/106	47%	FMM	12.7 ± 0.4	10.2 ± 0.4
SUK12116 (Ad12066)	11	1.05	0.99 ± 0.02	0.18 ± 0.02	1100/74	21%	CAM	11.4 ± 1.0	11.5 ± 1.0
SUK12253 (Ad12067)	25	0.80	0.62 ± 0.02	0.18 ± 0.02	1000/39	101%	FMM	6.6 ± 0.9	10.7 ± 1.5
SUK12361 (Ad12068)	36	1.52	1.20 ± 0.03	0.17 ± 0.02	800/137	14%	CAM	9.1 ± 0.2	7.6 ± 0.3
SUK12362 (Ad12069)	36	1.55	0.91 ± 0.02	0.17 ± 0.02	800/61	14%	CAM	7.2 ± 0.2	7.9 ± 0.3

Notes: FMM = Finite Mixture Model; CAM = Central Age Model. See text for explanation. All samples had a measured water content of <1%.

Please cite this article in press as: Honegger, M., Williams, M., Human occupations and environmental changes in the Nile valley during the Holocene: The case of Kerma in Upper Nubia (northern Sudan), Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.06.031

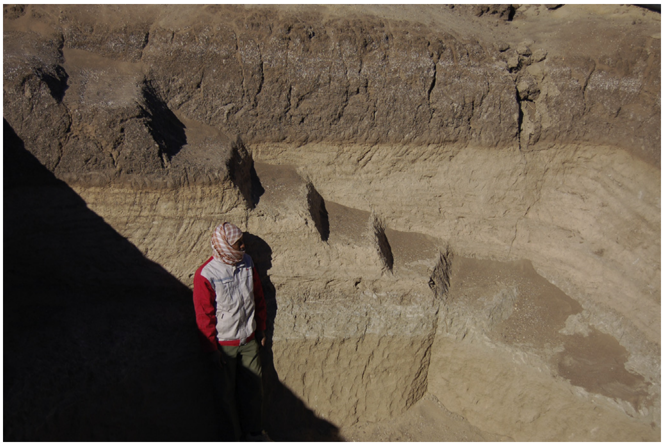

Plate 3. Well section showing calcareous brown Holocene clay overlying horizontally bedded and massive fluvial sands. Holocene alluvial plain, Kerma area, north Sudan.

8.3 kyr ago. These clays later underwent moderate pedogenesis to form vertisols or cracking clay soils.

4. Discussion

4.1. Gaps in occupation

Our results indicate chronological gap during which sites are almost absent (7.5–7.1 kyr BP and 6–5.4 kyr BP). These gaps in occupation may well correspond to periods of greater aridity. The first is well known throughout the Sahara, but our region is unique in having produced a cemetery dating from just prior to this arid phase, which corresponds to the very beginning of the African Neolithic. The second hiatus is more difficult to interpret, since in Upper Egypt this period is very well represented in the valley with the development of the Badarian Culture, which is itself followed by the Pre-Dynastic Period. It is therefore when Egypt sees a real acceleration in its social development that Nubia appears to decline to a lower level. Sites reappear in Nubia starting at the earliest by 5.4 kyr BP, which reveal for the first time more intensive agricultural practices. It would seem that these agricultural practices and the much greater width of the Nile floodplain in Egypt, allowing for many more people and greater material wealth, offer some explanation for the differences between Upper Egypt and Nubia.

Plate 4. Brown calcareous Holocene clay with thin interbeds of fluvial sand. Holocene alluvial plain, Kerma area, north Sudan.

4.2. Occupational density

To consider the rhythm of occupation of a region leads one to the question of density of occupation over time. It is not certain, however, that the density observed today is representative of the past. On the one hand, recent phenomena, such as the extension of cultivated land, can lead to considerable destruction, whilst on the other, the discovery of surface finds or finds close to the surface, should not lead to the conclusion that there are none at greater depths. On the alluvial plain in particular, it is possible that sites belonging to certain periods are buried below several metres of silt from the Nile.

It is evident that in the region of Kerma, the importance of the cultivated surfaces has had an impact on the distribution of archaeological sites. In fact, it is only in the Kerma cemetery, which is a vast complex covering 70 ha and protected from agricultural practices, that numerous sites have been discovered, especially for the Neolithic Period. Sites are rare elsewhere on the alluvial plain, unless further south in the region of Kadruka, where desert sands have long invaded the plain, effectively reducing the expansion of cultivated lands (Fig. 2). For this reason, we have compared our results with those of another region, which was first surveyed some twenty years ago (Osman and Edwards, 2011) and where we began work again in 2012. This region, named Wadi Farjar, corresponds to a former channel of the Nile located near the third cataract, 20 km north of Kerma. This isolated area is currently uninhabited and not subject to agricultural practices. The team which first worked in this area concluded that Wadi Farjar must have been active during most of the Holocene, as attested by the presence of oyster (*Etheria elliptica*) shells in the alluvial deposits radiocarbon dated to the 7th millennium BC (Osman and Edwards, 2011). In all, 88 sites with distinct occupation were checked or discovered during our recent survey. Except for the sites without associated archaeological material, like low stone walls or rock carvings, the other were dated by typology, based on the pottery classification elaborated at Kerma. Finally, we counted 53 dated Holocene sites in Wadi Farjar while there are 112 dated sites of the same period in the Kerma area.

A comparison of these two regions shows up certain differences (Fig. 4). At Wadi Farjar, the Mesolithic is less well represented, possibly due to an ecologically less rich environment, and the post-Kerma sites are rare because of the aridity. The number of 7th millennium BP sites is proportionally much lower than at Kerma, a contrast reflecting the intensive research in the cemetery at Kerma, which has resulted in a substantial increase in the number of sites. At Wadi Farjar, however, the proportion of these sites is also attenuated, due to the fact that Pre-Kerma and especially Kerma sites are considerably more abundant than in the Kerma area, where they have been largely obliterated by agricultural practices. The picture at Wadi Farjar therefore appears to be more representative of the historic reality, due to its isolated location and the minimal impact of modern human activities. As is the case at Kerma, there appear to be few sites dating from the 8th millennium BP, but without ^{14}C dates it is difficult to know whether the few sites identified are older or younger than 7.5 kyr BP. The drop in the number of sites from the 6th millennium BP is equally apparent and it is only at the end of this millennium that the number of sites increases again, to reach a peak during the period of the Kingdom of Kerma.

The estimation of the density of occupation from these two separate regions confirms some of the previous observations, and in particular the fact that there is a dramatic drop in the number of sites in the 6th millennium BP, which could explain why the growth seen in Predynastic Egypt does not find its equivalent in Nubia.

What is unique about Kerma is the presence of a very ancient settlement in close proximity to the Nile, at the time when the

Please cite this article in press as: Honegger, M., Williams, M., Human occupations and environmental changes in the Nile valley during the Holocene: The case of Kerma in Upper Nubia (northern Sudan), Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.06.031

desert regions were being repopulated. The observations made at the level of the second cataract (Wendorf, 1968) and in central Sudan (Caneva et al., 1993) allow us to hypothesise that the same situation prevailed along the length of the Nile in Sudan, with Kerma being only the most graphic illustration of this phenomenon. This is in marked contrast with Egypt, where sites are rare in the valley and its close environs for the period between 10.3 and 6.5 kyr BP.

4.3. Holocene environments in the Dongola region south of Kerma

Dongola lies 40 km south of Kerma on the left (west) bank of the Nile. The alluvial plain to the east of the North Dongola Reach of the Nile has been the focus of detailed recent archaeological and geological study (Welsby, 2001; Woodward et al., 2001; Welsby et al., 2002; Macklin et al., 2013). During the early to mid-Holocene a series of two main anabranching Nile channels east of the present river conveyed high flows throughout the year and supported abundant Neolithic and later settlements scattered across the alluvial plain. At this time also the western branch of the Nile (or Dongola Nile) overflowed westwards into the Qaab Depression to form a shallow lake between 9.5 and 7.5 kyr BP (Williams et al., 2010). The presence of Neolithic settlements across the Dongola study area on all of the channels belts at this time provides independent evidence in support of a much greater area of the valley floor occupied by flowing channels before 5.5 ka than is seen today. Floodwater farming was probably widespread at this time making use of the enhanced Nile flows. A brief reduction in flow towards 8.2 kyr BP is suggested by the deposition of an eolian unit at this time. Flow remained high until about 5.5 kyr BP when a progressive decline set in, with a major trend towards more arid conditions at about 4.4 kyr BP with the inception of the Kerma Period and a change to location of occupation sites along the channel margins rather than out in the alluvial plain as Nile flow diminished and the climate became drier (Macklin et al., 2013).

4.4. Holocene environments in and near the Blue and White Nile headwaters

The depositional history of the Nile reflects that of its three major tributaries: the Blue Nile, the Atbara and the White Nile. The Blue Nile/Abbai and Atbara/Tekezze are both highly seasonal rivers that rise in the volcanic highlands of Ethiopia and provide the bulk of the total sediment load (61% and 22%, or 140 ± 20 million t/yr and 82 ± 10 million t/yr, respectively) (Garzanti et al., 2006) and much of the summer flood peak flow (68% and 22%, respectively). The White Nile has a far less seasonal flow regime and provides 83% of Nile discharge during the month of lowest flow but only about 7 million t/yr of sediment, since most of its sediment load is filtered out in the lakes of Uganda and in the vast Sudd swamps of South Sudan (Garzanti et al., 2006; Woodward et al., 2007; Padoan et al., 2011). A number of sites in and near the Blue and White Nile headwaters have well dated Holocene histories. We begin with the Blue Nile.

Lake Tana near the source of the Blue Nile/Abbai river was low or dry during the Last Glacial Maximum (LGM: 21 ± 2 kyr BP: Mix et al., 2001), but had became deeper by 15.3 kyr BP, after which it overflowed quite suddenly (Marshall et al., 2011; Costa et al., 2014). The titanium record in sediment cores collected from Lake Tana (Marshall et al., 2011, Fig. 9) can be used as a rough proxy record of past changes in Blue Nile sediment load and river discharge. During times of high precipitation and dense plant cover, erosion around the lake was curtailed but runoff was still high. Although Lake Tana only contributes about 8% of the annual Blue Nile flow, this situation would also have been true of the Didessa and other major Blue Nile tributaries. Marshall et al. (2011) argue for low stands at 13–12.5, 8.4, 7.5 and especially 4.2 kyr BP, with reduced flow after 6.8 kyr BP. They stressed that the 8.4 kyr low stand precedes the 8.2 kyr BP cold event evident in high northern latitudes (Rohling and Pälike, 2005; Rohling et al., 2009), a point also made by Gasse (2000a, 2000b) in relation to cold/arid events in North Africa. A more seasonal Blue Nile would probably have contributed more sediment than during wetter intervals with reduced catchment erosion. The sediment input may have been a lot coarser during episodes of reduced plant cover and enhanced seasonality.

Lakes in or near the White Nile headwaters provide further information. The diatom record from Pilkington Bay in Lake Victoria (Stager et al., 2003) shows evidence of high rainfall at 8.8–8.3 kyr BP, becoming more seasonal thereafter, with sharp drops at about 8.2 and 5.7 kyr BP, and sharp century-scale increases in rainfall at about 8.5, 5.8 and 4 kyr BP. The present climatic regime was established after 2.7 kyr BP and there was an interlude of major droughts between about 1200 and 600 yr BP. Here, as always, the age control is a key element in the conclusion. There seems to be a conflict between the 8.4 kyr BP low stand of Lake Tana and the 8.5 kyr BP high stand in Lake Victoria. Within the error terms, both are synchronous.

A more detailed record is available from Lake Challa, a crater lake on the eastern flank of Mt Kilimanjaro and relatively close to Lake Victoria (Verschuren et al., 2009). With 188 AMS dates spanning the last 25,000 years, it is exceptionally well dated. Low stands (denoted L) in the lake are interpreted as drier climatic intervals. These include four Holocene low lake events: 8.0–6.7 (L4), 5.9–4.7 (L3), 3.6–3.0 (L2), and 0.7–0.6 kyr BP (L1). An especially moist interval was the one centred at around 13–14 kyr BP (when the White Nile flooded to 382 m in central Sudan: Williams et al., 2006), and a very wet phase at 10.5–8.5 kyr.

Additional information comes from an ice core record from Mt Kilimanjaro obtained by Thompson et al. (2002). However, as both these authors and Gasse (2002) have pointed out, the chronology of the ice core records from Kilimanjaro is open to question and is not really absolute. If we accept the chronology, we can accept the suggestion of abrupt climate change at about 8.3 and about 5.2 kyr BP. The severe drought at 4 kyr seems solidly established and corroborates Stanley et al. (2003) and the strontium isotope record from Lake Albert (Williams et al., 2006). More fundamental, marked depletions in the $\partial^{18}O$ ice core record could reflect heavy snowfall and intense convective precipitation, rather than lower temperature. Gasse (2002) and other workers have pointed this out when discussing the Mt Kenya records.

A long debated issue concerns variations in the relative importance of the Blue and White Nile rivers in contributing runoff and sediment to the main Nile during the Holocene (Foucault and Stanley, 1989). Blanchet et al. (2013) have recently analysed mud samples from marine sediment core P362/2–33 retrieved from the Nile deep-sea fan in the eastern Mediterranean. They concluded that the relative intensity of Blue Nile discharge was greater during the early and the late Holocene when spring insolation was high in the Blue Nile headwaters, but was reduced between 8 and 4 kyr BP when autumn insolation was high and the White Nile came to the fore. The core also revealed evidence of an arid event at 8.5–7.3 kyr BP and again at 4.5–3.7 kyr BP.

4.5. Comparison between Holocene fluvial environments in the Kerma area and events in the Nile headwaters

The two major chronological gaps identified in the Holocene archaeological records (Fig. 4) suggest a decline in the prehistoric human population and/or major migrations out of the Nubian Nile valley between about 7.5 and 7.1 kyr BP and 6.0–5.4 kyr BP. The first

Please cite this article in press as: Honegger, M., Williams, M., Human occupations and environmental changes in the Nile valley during the Holocene: The case of Kerma in Upper Nubia (northern Sudan), Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.06.031

of these gaps coincides with the L4 low stand of Lake Challa discussed in Section 4.4; the second coincides with the L3 low stand of Lake Challa (Verschuren et al., 2009). Both of these lake regressions began with an abrupt decline in lake level, indicative of rapid and severe weakening of the East African summer monsoon, which would have affected the entire Nile. Precipitation over the Lake Tana basin declined after 6.8 kyr BP, following two earlier dry periods at 8.4 and at 7.5 kyr BP (Marshall et al., 2011).

OSL and ^{14}C ages obtained for fluvial sands and clays laid down during high Nile floods in the Kerma alluvial plain situated between the present-day Nile and the Nubian Sandstone plateau margin show episodes of flood flow at 11.5, 10.7, 10.2, 9.4, 8.3, 7.9 and 7.6 kyr BP and probably also thereafter (Section 3.4). It may be coincidental, but each of these episodes can be matched with evidence of high lake stands in the headwaters and high Blue or White Nile floods upstream of the confluence of these two great rivers at Khartoum (Williams et al., 1982; Williams, 2012a,b).

4.6. Additional insights provided by a meta-analysis of the Holocene fluvial archive in the Nile Valley

Macklin et al. (this issue) have carried out a comprehensive meta-analysis of published and publically available radiocarbon and OSL ages of fluvial units in the Nile Valley, including the Blue and White Nile, the Main Nile and the Nile Delta. They concluded that dated floodplain units represented overbank river flows and time of widespread flooding. Dated palaeochannel units they considered more likely to represent periods of major flooding associated with channel abandonment and contraction, as well as a transition to phases of low river flow and greater aridity. Although this latter conclusion may not always be valid, as Williams et al. (this issue) have shown for the Pleistocene Blue Nile and Atbara Rivers, their overall conclusions are relevant to our investigations in the Kerma region. They identified major changes in river flow and channel dynamics at ca. 8.3–5.8, 6.5–5.6, 4.8–4.45, 3.35–2.85 and 2.45 kyr BP. It is interesting to note that the 8.3–5.8 kyr phase identified by Macklin et al. (this issue) coincides with the L4 low stand of Lake Challa dated to 7.5–7.1 kyr and the 6.5–5.6 kyr phase coincides with the L3 low stand of Lake Challa (Verschuren et al., 2009), discussed earlier in Section 4.4. We have too few dated sections to be able to relate the fluvial sand units on the Kerma Holocene alluvial plain to the meta-analysis of Macklin et al. (this issue). We find support from their meta-analysis that the dated alluvial clays at Kerma do indeed appear to indicate times of widespread overbank flooding.

5. Summary and conclusions

The archaeological sequence at Kerma permits the reconstruction of the pattern and tempo of Holocene human occupation according to a scenario reasonably close to that observed in the Sahara. The principal events may be summarized as follows. (a) The 10.3 kyr BP start of occupation on the fringes of the alluvial plain, which lasted for 3 millennia, covering the entire Mesolithic and the Initial Neolithic, established as beginning at 8 kyr BP. (b) The first hiatus in occupation at 7.5–7.1 kyr BP, possibly linked to a decline in Nile flow at this time. (c) A move down to the alluvial plain at ca. 7.3 kyr BP, following the first episode of aridity and the development of prosperous pastoral societies between 7 and 6 kyr BP. (d) A second hiatus in occupation at 6–5.4 kyr BP, possibly linked to a reduction in flow from the White Nile, yet at a period when Upper Egypt was highly prosperous with the appearance of the Predynastic Period (5.8–5 kyr BP) and the development of agro-pastoral societies. (e) The emergence of a state society (Kingdom of Kerma: 4.5–3.5 kyr BP) focused progressively more on agriculture, with a marked decline in the breeding of cattle from 3.7 kyr BP.

The correspondence between Holocene human occupation and climatic fluctuations seems valid provided the observations regarding the alluvial sediments at Kerma are complemented with observations from other sites in the region and with events in the Nile headwaters. Thus, the return of increased humidity is marked at Kerma by the first deposits of Nile silt starting in 11.5 kyr BP. Human occupation commences later, and this time lag has already been noted for the Sahara. The two ensuing gaps in occupation are coeval with two sudden drops in the level of Lake Challa (L4 and L3), indicating weakening of the summer monsoon. As regards the first hiatus, it can be seen in the Sahara as a reduction in population density in favour of the Nile valley, and for the second as a slight reduction in the number of sites. The Neolithic appears shortly before the first hiatus, hence the present difficulties in tracing the Neolithisation process in north-east Africa, caused by the scarcity of sites or their degree of erosion. At present, most of the commentaries tend to set the beginning of the Neolithic ca. 8 kyr BP, as is the case with Kerma.

Kerma and Upper Nubia show a greater continuity of occupation than the Egyptian Nile Valley, which shows an important gap between 8.5 and 6.5 kyr BP, especially in Upper Egypt (Midant-Reynes, 2006; Vermeersch, 2002). This hiatus does not necessarily imply a fall in population, but seems rather to be the result of erosion or burial of sites by the Nile. Alternating phases of incision process in the Nile Valley and periods of higher floods could have obliterated the remains of ancient occupation. Channel incision further south at the Blue and White Nile confluence seems to have begun by 8 kyr BP (Williams et al., 1982), and may have led to sedimentation and aggradation downstream. The different sectors of the Nile do not in any case need to have had the same alluvial history, and the comprehension of the contrasts between Kerma and the Egyptian valley is complex. It not only brings into play the climatic data, but also silting or erosional processes, to which need to be added the influence of the cataracts (local base-levels) and of possible neo–tectonic activity, as well as possible differences in culture or technological advances.

Between 6 and 5.4 kyr BP, the second hiatus, which is clearly evident at Kerma and in Nubia, is not present in Egypt, where the population is prosperous with the development of the Predynastic Period. It could be that the arid episode was more marked in Nubia, but it is also possible that agricultural practices were more advanced in Egypt, already incorporating water catchment or irrigation systems, which allowed for a better resistance to shortfalls in precipitation or flooding.

Acknowledgements

This research was supported by the Swiss National Fund (SNF 100012_137784/1), the State Secretariat for Education, Research and Innovation of the Swiss Confederation, the Foundation *Kerma* and the Faculty of Literature and Human Sciences of the University of Neuchâtel (Switzerland). For more information, see www.kerma.ch. MW thanks the Australian Research Council for financial support (ARC Grant DP0878058 to MW) and Dr Yusif Elsamani, Director of the Geological Research Authority of the Sudan, for strong support during his 2012 visit to the Sudan. We thank Frances Williams for the optical ages and summary of procedures used, and the three anonymous reviewers for their careful and constructive reviews.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quascirev.2015.06.031.

References

Arkell, A.J., 1949. Early Khartoum. An Account of the Excavation of an Early Occupation Site Carried Out by the Sudan Government Antiquities Service in 1944-5. G. Cumberlege, London.

Blanchet, C.L., Tjallingii, R., Frank, M., Lorenzen, J., Reitz, A., Brown, K., Feseker, T., Brückmann, W., 2013. High- and low-latitude forcing of the Nile River regime during the Holocene inferred from laminated sediments of the Nile deep-sea fan. Earth Planet. Sci. Lett. 364, 98–110.

Bonnet, C., 1992. Excavations at the Nubian royal town of Kerma: 1975–1991. Antiquity 66, 211–225.

Bonnet, C., 2000. Edifices et rites funéraires à Kerma. Errance, Paris.

Bronk Ramsey, C., 2009. Bayesian analysis of radiocarbon dates. Radiocarbon 51 (1), 337–360.

Caneva, I., Garcea, E.A.A., Gautier, A., van Neer, W., 1993. Pre-pastoral cultures along the central Sudanese Nile. Quat. Nova 3, 177–252.

Chaix, L., 2007. Contribution to the knowledge of domestic cattle in Africa: the osteometry of fossil Bos taurus L. from Kerma, Sudan (2050-1750 BC). In: Grupe, G., Peters, J. (Eds.), Skeletal Series and Their Socio-economic Context, Documenta Archaeobiologiae; 5. Verlag Marie Leidorf GmbH, Rahden, pp. 170–249.

Chaix, L., 2011. A review of the history of cattle in the Sudan throughout the Holocene. In: Jousse, H., Lesur, J. (Eds.), People and Animals in Holocene Africa: Recent Advances in Archaeolozoology, Reports in African Archaeology, 2. Africa Magna Verlag, Frankfurt, pp. 13–26.

Chaix, L., Faure, M., Guérin, C., Honegger, M., 2000. Kaddanarti, a lower pleistocene assemblage from Northern Sudan. In: Krzyzaniak, L., et al. (Eds.), Recent Research into the Stone Age of Northeastearn Africa, Studies in African Archaeology; 7, pp. 33–46. Poznan.

Chaix, L., Honegger, M., 2014. New data on animal exploitation from the mesolithic to the neolithic periods in northern Sudan. In: Kerner, S., Dann, R., Bangsgaard, P. (Eds.), Climate Changes in Ancient Societies. Museum Tusculanum Press, Copenhagen, pp. 197–214.

Chiverrell, R.C., Thorndycraft, V.R., Hoffmann, T.O., 2011. Cumulative probability functions and their role in evaluating the chronology of geomorphological events during the Holocene. J. Quat. Sci. 26, 76–85.

Close, A., 2002. Sinai, sahara, Sahel: the introduction of domestic caprines to Africa. In: Jennerstrasse 8 (Ed.), Tides of the Desert. Gezeiten der Wilste, Africa Praehistorica; 14. Heinrich Barth Institut, Köln, pp. 459–469.

Costa, K., Russell, J., Konecky, B., Lamb, H., 2014. Isotopic reconstruction of the African humid period and Congo air boundary migration at Lake Tana, Ethiopia. Quat. Sci. Rev. 83, 58e67.

DeMenocal, P., Ortiz, J., Guilderson, T., Adkins, J., Sarnthein, M., Baker, L., Yarusinsky, M., 2000. Abrupt onset and termination of the African Humid Period: rapid climate responses to gradual insolation forcing. Quat. Sci. Rev. 19, 347–361.

Emberling, G., 2014. Pastoral states: toward a comparative archaeology of Early Kush. Origini 36, 125–156.

Fairbanks, R.G., Mortlock, R.A., Chiu, T.-C., Cao, L., Kaplan, A., Guilderson, T.P., Fairbanks, T.W., Bloom, A.L., Grootes, P.M., Nadeau, M.-J., 2005. Marine radiocarbon calibration curve spanning 0 to 50,000 years B.P. based on paired 230Th/234U/238U and 14C dates on pristine corals. Quat. Sci. Rev. 24, 1781–1796.

Foucault, A., Stanley, D.J., 1989. Late quaternary paleoclimatic oscillations in east Africa recorded by heavy minerals in the Nile Delta. Nature 339, 44–46.

Garzanti, E., Ando, S., Vezzoli, G., Megid, A.A.A., Kammar, A., 2006. Petrology of Nile River sands (Ethiopia and Sudan): sediment budgets and erosion patterns. Earth Planet. Sci. Lett. 252, 327–341.

Gasse, F., 2000a. Water resources variability in tropical and subtropical Africa in the past. In: Water Resources Variability in Africa during the XXth Century, vol. 252. International Association of Hydrological Sciences Publication, pp. 97–105.

Gasse, F., 2000b. Hydrological changes in the African tropics since the last Glacial Maximum. Quat. Sci. Rev. 19, 189–211.

Gasse, F., 2002. Kilimanjaro's secrets revealed. Science 298, 548–549.

Gatto, M., 2013. Preliminary Report of the Most Ancient Pottery from the Kerma Region. Kerma, pp. 4–10 documents de la mission archéologique Suisse au Soudan 5.

Geus, F., 2004. Pre-Kerma storage pits on Saï island. In: Kendall, T. (Ed.), Nubian Studies 1998. Proceedings of the Ninth Conference of the International Society of Nubian Studies. Boston, 76–51.

Hassan, F., 1985. Radiocarbon chronology of Neolithic and predynastic sites in Upper Egypt and the Delta. Afr. Archaeol. Rev. 3, 95–115.

Hassan, F.A., 1986. Chronology of the Khartoum ‘Mesolithic’ and ‘Neolithic’ and related sites in the Sudan: statistical analyses and comparisons with Egypt. Afr. Archaeol. Rev. 4, 83–102.

Hassan, F.A., 2002. Paleoclimate, food and culture change in Africa: an overview. In: Hassan, F.A. (Ed.), Droughts, Food and Culture: Ecological Change and Food Security in Africa's Later Prehistory. Kluwer Academic/Plenum Publishers, New-York, pp. 321–334.

Honegger, M., 2004a. The Pre-Kerma: a cultural group from upper Nubia prior to the Kerma civilisation. Sudan Nubia 8, 38–46.

Honegger, M., 2004b. Settlement and cemeteries of the mesolithic and early Neolithic at El-Barga (Kerma region). Sudan Nubia 8, 27–32.

Honegger, M., 2006. El-Barga: un site clé pour la compréhension du Mésolithique et du début du Néolithique en Nubie. Rev. Paléobiologie 10, 95–104.

Honegger, M., 2007. Le Pré-Kerma de Haute Nubie. Archéonil 16, 77–84.

Honegger, M., 2014. Recent advances in our understanding of prehistory in Northern Sudan. In: Anderson, J.R., Welsby, D.A. (Eds.), The Fourth Cataract and beyond. Proceedings of the 12th International Conference for Nubian Studies. Peeters, Leuven-Paris-Walpole, pp. 19–30.

Jesse, F., 2010. Early pottery in Northern Africa: an overview. J. Afr. Archaeol. 8 (2), 219–238.

Jones, A.F., Macklin, M.G., Benito, G., 2015. Meta-analysis of Holocene fluvial sedimentary archives: a methodological primer. Catena 130, 3–12.

Kuper, R., 2002. Routes and roots in Egypt's western desert: the early holocene resettlement of the eastern sahara. In: Friedman, R. (Ed.), Egypt and Nubia. Gifts of the Desert. British Museum Press, London, pp. 1–12.

Kuper, R., Kröpelin, S., 2006. Climate-controlled Holocene occupation in the Sahara: motor of Africa's evolution. Science 313, 803–807.

Kuper, R., Riemer, H., 2013. Herders before pastoralism: prehistoric prelude in the eastern sahara. In: Bollig, M., Schnegg, M., Wotzka, H.-P. (Eds.), Pastoralism in Africa. Past Present and Future. Berghahn, New York/Oxford, pp. 31–65.

Linseele, V., 2004. Size and size change of the African aurochs. J. Afr. Archaeol. 2 (2), 165–185.

Linseele, V., Van Neer, W., Thys, S., Phillipps, R., Cappers, R., Wendrich, W., Holdaway, S., 2014. New archaeozoological data from the Fayum “Neolithic” with a critical assessment of the evidence for early stock keeping in Egypt. PLoS One 9 (10), e108517. http://dx.doi.org/10.1371/journal.pone.0108517.

Macklin, M.G., Woodward, J.C., Welsby, D.A., Duller, G.A.T., Williams, F.M., Williams, M.A.J., 2013. Reach-scale river dynamics moderate the impact of rapid Holocene climate change on floodwater farming in the desert Nile. Geology 41, 695–698.

Macklin, M.G., Woodward, J.C., Toonen, W.H.J., Williams, M.A.J., Flaux, C., Marriner, N., Nicoll, K., Vertsaeten, G., Spencer, N., Welsby, D., 2015. Re-evaluating river dynamics, hydroclimatic change and the archaeological record of the Nile Valley using meta-analysis of the Holocene fluvial archive. Quat. Sci. Rev. (this issue).

Manning, K., Timpson, A., 2014. The demographic response to Holocene climate change in the Sahara. Quat. Sci. Rev. 101, 28–35.

Marshall, M.H., Lamb, H.F., Huws, D., Davies, S.J., Bates, R., Bloemendal, J., Boyle, J., Leng, M.J., Umer, M., Bryant, C., 2011. Late pleistocene and Holocene drought events at Lake Tana, the source of the Blue Nile. Glob. Planet. Change 78, 147–161.

Midant-Reynes, B., 2006. L'aridification du Sahara: quel rôle dans l'éclosion de la civilisation égyptienne ? C.R. Palevol 5, 405–408.

Mix, A.C., Bard, E., Schneider, R., 2001. Environmental processes of the ice age: land, oceans, glaciers (EPILOG). Quat. Sci. Rev. 20, 627–657.

Osman, A., Edwards, D.N., 2011. The Archaeology of a Nubian Frontier: Survey on the Nile Third Cataract, Sudan. Mauhaus Publishing, Bristol.

Otto-Bliesner, B.L., Russell, J.M., Clark, P.U., Liu, Z., Overpeck, J.T., Konecky, B., deMenocal, P., Nicholson, S.E., He, F., Lu, Z., 2014. Coherent changes of southeastern equatorial and northern African rainfall during the last deglaciation. Science 346, 1223–1227.

Padoan, M., Garzanti, E., Harlavan, Y., Villa, I.M., 2011. Tracing nile sediment sources by Sr and Nd isotope signatures (Uganda, Ethiopia, Sudan). Geochim. Cosmochim. Acta 75, 3627–3644.

Privati, B., 1999. La céramique de la nécropole orientale de Kerma (Soudan): essai de classification. CRIPEL 20, 41–69.

Reimer, P.J., et al., 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 Years cal BP. Radiocarbon 55 (4), 1869–1887.

Reinold, J., 1993. S.F.D.A.S. Rapport préliminaire de la campagne 1991-1992 dans la province du Nord. Kush 16 (150–157), 162–164.

Reinold, J., 2000. Archéologie au Soudan. Les civilisations de Nubie. Errance, Paris, p. 144.

Reinold, J., 2006. La nécropole néolithique d'El-Kadada au Soudan Central. Les cimetières A et B du kôm principal. Editions Recherche sur les civilisations, Paris, p. 307.

Riemer, H., 2007. Mapping the movement of pastro-foragers: the spread of desert glass and other objects in the eastern Sahara during the Holocene humid phase. In: Bubenzer, O., Bolten, A., Darius, F. (Eds.), Atlas of Cultural and Environmental Change in Arid Africa, Africa Praehistorica; 21. Heinrich Barth Institute, Köln, pp. 30–33.

Riemer, H., Lange, M., Kindermann, K., 2013. When the desert dried up: late prehistoric cultures and contacts in Egypt and northern Sudan. In: Raue, D., Seidlmayer, S.J., Speiser, P. (Eds.), The First Cataract of the Nile: One Region – Diverse perspectives.SDAIK, 36De Gruyter, Berlin, pp. 157–183.

Rohling, E., Abu-Zied, R., Casford, J., Hayes, A., Hoogakker, B., 2009. The marine environment: present and past. In: Woodward, J.C. (Ed.), The Physical Geography of the Mediterranean. Oxford University Press, Oxford, pp. 33–67.

Rohling, E.J., Pälike, H., 2005. Centennial-scale climate cooling with a sudden cold event around 8,200 years ago. Nature 434, 975–979.

Sereno, P.C., Garcea, E.A.A., Jousse, H., Stojanowski, C.M., Saliège, J.-F., et al., 2008. Lakeside cemeteries in the sahara: 5000 Years of holocene population and environmental change. PLoS One 3 (8), e2995. http://dx.doi.org/10.1371/journal.pone.0002995.

Stager, J.C., Cumming, B.F., Meeker, L.D., 2003. A 10,000-year high-resolution diatom record from Pilkington Bay, Lake Victoria, East Africa. Quat. Res. 59, 172–181.

Stanley, D.J., Krom, M.D., Cliff, R.A., Woodward, J.C., 2003. Nile flow failure at the end of the Old Kingdom Egypt: strontium isotopic and petrologic evidence. Geoarchaeol. Int. J. 18 (3), 395–402.

Please cite this article in press as: Honegger, M., Williams, M., Human occupations and environmental changes in the Nile valley during the Holocene: The case of Kerma in Upper Nubia (northern Sudan), Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.06.031

Tassie, G.J., 2014. Prehistoric Egypt: Socioeconomic Transformations in Nort-east Africa from the Last Glacial Maximum to the Neolithic 24,000 to 6,000 Cal BP. Golden House Publications, London.

Thompson, L.G., Mosley-Thompson, E., Davis, M.E., Henderson, K.A., Brecher, H.H., Zagorodnov, V.S., Mashiotta, T.A., Lin, P.-N., 2002. Kilimanjaro ice core records: evidence of Holocene climate change in tropical Africa. Science 298, 589–593.

Tierney, J.E., deMenocal, P.B., 2013. Abrupt shifts in Horn of Africa hydroclimate since the last glacial Maximum. Science 342, 843–846.

Usai, D., 2014. Recent advances in understanding the prehistory of Central Sudan. In: Anderson, J.R., Welsby, D.A. (Eds.), The Fourth Cataract and beyond. Proceedings of the 12th International Conference for Nubian Studies. Peeters, Leuven, Paris, Walpole, pp. 31–44.

Vermeersch, P.M., 2002. The egyptian nile Valley during the early holocene. In: Jennerstrasse 8 (Ed.), Tides of the Desert. Gezeiten der Wilste, Africa Praehistorica; 14. Heinrich Barth Institut, Köln, pp. 27–40.

Vermeersch, P.M., 2006. La vallée du Nil et le Sahara oriental: une population préhistorique fluctuante sous l'effet des variations climatiques. C. R. Palevol 5, 255–262.

Verschuren, D., Sinninghe Damsté, J.S., Moernaut, J., Kristen, I., Blaauw, M., Fagot, M., Haug, G.H., CHALLACEA project members, 2009. Half-precessional dynamics of monsoon rainfall near the East African Equator. Nature 462, 637–641.

Welsby, D.A. (Ed.), 2001. Life on the Desert Edge: Seven Thousand Years of Human Settlement in the Northern Dongola Reach, Sudan. SARS, London.

Welsby, D.A., Macklin, M.G., Woodward, J.C., 2002. Human responses to Holocene environmental changes in the Northern Dongola Reach of the Nile, Sudan. In: Friedman, R. (Ed.), Egypt and Nubia: Gifts of the Desert. British Museum Press, London, pp. 28–38.

Wendorf, F., 1968. The Prehistory of Nubia, vols. 3. Southern Methodist Univ. Press, Dallas.

Wendorf, F., Schild, R., 2001. Holocene Settlement of the Egyptian Sahara. In: Vol. I: the Archaeology of Nabta Playa. Kluwer Academic/Plenum Publisher, London.

Wengrow, D., 2003. Review article on desert origins for the ancient Egyptians. Antiquity 77 (297), 597–600.

Wengrow, D., Dee, M., Foster, S., Stevenson, A., Bronk Ramsey, C., 2014. Cultural convergence in the Neolithic of the Nile Valley: a prehistoric perspective on Egypt's place in Africa. Antiquity 88, 95–111.

Williams, M., 2012a. Geomorphology and Quaternary Geology of the Region between Wadi El Arab and Kerma. Université de Neuchâtel, pp. 10–15. Documents de la mission archéologique suisse au Soudan 2012/4.

Williams, M., 2012b. River sediments. In: Vita-Finzi, C. (Ed.), River History. Philosophical Transactions of the Royal Society of London, Series a, vol. 370, pp. 2093–2122.

Williams, M.A.J., Adamson, D.A., Abdulla, H.H., 1982. Landforms and soils of the Gezira: a quaternary legacy of the Blue and White Nile rivers. In: Williams, M.A.J., Adamson, D.A. (Eds.), A Land between Two Niles: Quaternary Geology and Biology of the Central Sudan. A.A. Balkema, Rotterdam, pp. 111–142.

Williams, M., Talbot, M., Aharon, P., Abdl Salaam, Y., Williams, F., Brendeland, K.I., 2006. Abrupt return of the summer monsoon 15, 000 years ago: new supporting evidence from the lower White Nile valley and Lake Albert. Quat. Sci. Rev. 25, 2651–2665.

Williams, M.A.J., Williams, F.M., Duller, G.A.T., Munro, R.N., El Tom, O.A.M., Barrows, T.T., Macklin, M., Woodward, J., Talbot, M.R., Haberlah, D., Fluin, J., 2010. Late quaternary floods and droughts in the Nile Valley, Sudan: new evidence from optically stimulated luminescence and AMS radiocarbon dating. Quat. Sci. Rev. 29, 1116–1137.

Williams, M.A.J., Duller, G.A.T., Williams, F.M., Macklin, M.G., Woodward, J.C., El Tom, O.A.M., Munro, R.N., El Hajaz, Y., Barrows, T.T., 2015. Causal links between Nile floods and eastern Mediterranean sapropel formation during the past 125 kyr confirmed by OSL and radiocarbon dating of Blue and White Nile sediments. Quat. Sci. Rev. (this issue).

Woodward, J.C., Macklin, M.G., Krom, M.D., Williams, M.A.J., 2007. The Nile: evolution, quaternary river environments and material fluxes. In: Gupta, A. (Ed.), Large Rivers: Geomorphology and Management. John Wiley & Sons, Chichester, pp. 261–292.

Woodward, J.C., Macklin, M.G., Welsby, D.A., 2001. The Holocene fluvial sedimentary record and alluvial geoarchaeology in the Nile Valley of Northern Sudan. In: Maddy, D.M., Macklin, M.G., Woodward, J.C. (Eds.), River Basin Sediment Systems: Archives of Environmental Change. A. A. Balkema, Abingdon, pp. 327–356.

Please cite this article in press as: Honegger, M., Williams, M., Human occupations and environmental changes in the Nile valley during the Holocene: The case of Kerma in Upper Nubia (northern Sudan), Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.06.031