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Late Quaternary environments and prehistoric occupation in the lower White Nile valley, central Sudan.

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ABSTRACT:

Despite the major contributions provided over fifty years ago by A.J. Arkell and J.D. Tothill to our understanding of late Quaternary environments and prehistoric occupation near the confluence of the Blue and White Nile in central Sudan, three key questions have remained unresolved since then. (a) Was the decline in Nile flood levels from early Holocene times onwards caused by a reduction in Nile discharge, or by channel incision, or both? (b) Was the regional climate wetter during times of high Nile floods and drier during times of low Nile floods? (c) Given the high degree of disturbance of Mesolithic and later prehistoric sites, is it possible to identify primary-context, stratified and undisturbed occupation? Drawing upon dated evidence from three sites to the east of and three to the west of the lower White Nile, we provide a qualified answer to the first question and documented affirmative answers to the second and third questions.

KEYWORDS: White Nile, Sudan, Quaternary, Holocene, Mesolithic, Neolithic, lakes, dunes, climate change.

1. Introduction

Our knowledge of late Quaternary environments and prehistoric occupation in central Sudan was negligible until the pioneering efforts of A.J. Arkell (1949, 1953) and J.D. Tothill (1946, 1948) placed it on a modern footing. Tothill was the first to demonstrate that the Gezira clays between the lower Blue and White Nile rivers (Fig. 1) were alluvial clays transported from Ethiopia and laid down on the late Quaternary flood plain of the Blue Nile under wetter than present conditions. He based his conclusions on the presence of aquatic snail shells within the clays and on the presence of volcanic heavy minerals, including pyroxene, indicative of a volcanic (i.e., Ethiopian) provenance. Williams (1966) later provided the first radiocarbon ages for alluvial clays along the lower White Nile, which proved to be terminal Pleistocene and early Holocene, as surmised by Tothill (1946, 1948). The alluvial history of the lower White Nile is now known in some detail (Williams and Adamson, 1980; Adamson et al., 1982; Williams, 2009, 2012; Williams and Talbot, 2009; Williams et al., 2010; Barrows et al., 2014), and extends back at least 0.25 Ma (Williams et al., 2003).

Arkell (1949) conducted extensive excavations of a Mesolithic site near the central railway station at Khartoum (Fig. 1) in which he speculated that the Mesolithic or 'Early Khartoum Culture' would prove to be about 8000 years old, a prediction later confirmed by calibrated ^{14}C ages of 8-9 kyr from the Mesolithic sites of Tagra (Adamson et al., 1974), Shabona (Fig. 2) (Adamson et al., 1982; Clark, 1989), and, more recently, from the sites at El Khiday, all of which we discuss in section 3. From the abundant swamp fauna at the Early Khartoum site and the presence of *Celtis integrifolia* seeds, Arkell concluded that the Mesolithic climate at Khartoum was probably as wet as the present-day climate in South Sudan, with a longer-than-present wet season and precipitation at least three times that of today (i.e., > 500 mm as against 175 mm). He also inferred that Nile flood levels at the time the site was occupied were ~10 m higher than today. However, he was frustrated by the lack of any obvious stratification within the occupation deposit, an issue that has remained a thorny problem for all later archaeologists working in the region (Salvatori et al., 2011; Zerboni, 2011; Salvatori, 2012; Usai, 2014).

At the site of Esh Shaheinab (Fig. 1) located 50 km north of Omdurman on the west bank of the main Nile, Arkell (1953) excavated a Neolithic site and another putative Mesolithic site situated one km west of the Neolithic site. He concluded that Nile flood level had been at least 10 m higher than present at the presumed Mesolithic site and 5 m above present flood level at the Neolithic site. The fauna at the Shaheinab Neolithic site was distinctly different from that at the Mesolithic site, where antelopes were dominant, and contained three domesticated species, comprising "the earliest record of domestication and of the presence of Sheep and Goat in the Sudan" (op. cit., p.17; later revised by Peters, 1986). Arkell concluded that desiccation had set in at Esh Shaheinab by Neolithic times and that the fossil fauna was entirely consistent with a climate like that of the present.

Several key questions have remained unanswered since the seminal work of Tothill and Arkell over sixty years ago. First, was the decline in the height of Nile flood levels from early Holocene times onwards a result of a reduction in Nile discharge, or a consequence of channel incision, or both? Second, was the regional climate wetter during times of high Nile floods and drier during times of low Nile floods? Third, given the high degree of disturbance of Mesolithic and later prehistoric sites, is it possible to identify primary-context, stratified and undisturbed occupation? Our aim in this paper is to provide answers to each of these questions, focusing on three localities west of and three east of the lower White Nile where the field evidence allows these issues to be resolved. Our reason for selecting the lower White Nile valley is because that river has a very gentle gradient and a regular flow regime, so that the late Quaternary depositional evidence is still very well preserved, in contrast to the Blue Nile and Main Nile valleys, where there are major erosional gaps in the sedimentary sequence.

2. The White Nile

The White Nile originates in the highlands of Ruanda and Burundi and in the equatorial lake plateau of Uganda and flows into the vast Sudd swamps of South Sudan (Fig.1), where over half of its previous 40 km^3 of discharge is lost in seepage and evapotranspiration. The Sobat (Fig.1), which rises in the Ethiopian highlands, flows past the Machar marshes in South Sudan and joins the White Nile near Malakal, bringing the total annual discharge of that river to 23 km^3. The unregulated White Nile contributed a mere 2 million tonnes of sediment to the main Nile at Khartoum, in contrast to the 41 and 14 million tonnes provided by the Blue Nile and Atbara rivers, respectively, before they were dammed (Hurst, 1952; Williams et al., 1982). This is because much of the sediment load coarser than fine silt and clay is filtered out in the lakes and swamps of the upper White Nile. Were the swamps not there, the sediment load of the White Nile would be both greater in amount and coarser, as it has been on occasion in the past (Williams et al., 2010). The White Nile only provides 10% of the peak flow (cf. 68% and 22 % for the Blue Nile and Atbara), and has a ratio of peak to low flow of 5:2, compared to 40:1 for the highly seasonal Blue Nile. However, the White Nile comes into its own during the low flow season, when it provides a remarkable 83% of the Nile flow, in strong contrast to the 17% provided by the Blue Nile. The Atbara dries up in this season. From this we can infer that during times of extreme drought in the past, such as the Last Glacial Maximum (LGM: 21±2 kyr: Mix et al., 2001) when flow from the White Nile was reduced to a seasonal trickle, the main Nile would also have had its low season flow severely curtailed, possibly causing it to dry up into a series of pools during the winter (Williams, 2009).

The alluvial history of the White Nile is intimately bound up with that of the Blue Nile. Although it is not widely appreciated, we have known for over a century that when the Blue Nile was in full spate it dammed the flow of the White Nile and created a seasonal lake that extended up to 300 km upstream of its confluence with the Blue Nile (Willcocks, 1904, p. 42). This was before completion of the Jebel Aulia dam (Fig. 2) on the White Nile 35 km south of Khartoum in 1937, the reservoir from which now extends for nearly 300 km upstream. The terminal Pleistocene 382 m White Nile lake was initiated by overflow from Lakes Albert and Victoria 15.0-14.5 kyr ago (Talbot et al., 2000; Williams et al., 2006), coinciding with the onset of the African Humid Period identified by DeMenocal et al. (2000) in a marine sediment core retrieved off the west coast of Mauritania. The White Nile 382 m shell-bearing lake sediments have very similar ^{14}C ages to the Blue Nile shell-bearing alluvial clays laid down across the Gezira low-angle alluvial fan (Adamson et al., 1980, 1982; Williams and Adamson, 1980; Williams, 2009) after resumption of flow from Lake Tana in Ethiopia (Lamb et al., 2007; Marshall et al., 2011). During the last interglacial, when flood flow in the Blue Nile was even greater than in the terminal Pleistocene, the White Nile formed a seasonal lake 650 km long and up to 80 km wide (Barrows et al., 2014), with a surface elevation of 386 m and prominent beach ridges along its eastern shore (Williams et al., 2003; Barrows et al., 2014).

During the late Quaternary, the Blue Nile has oscillated between two primary depositional modes, one characteristic of colder drier climates in its Ethiopian headwaters, the other synchronous with warmer wetter conditions in that region (Adamson et al., 1980; Williams and Adamson, 1980; Williams 2012). For example, during the LGM small glaciers were present above 4200 m in the Semien Highlands (Fig.1) and periglacial solifluction was active down to ~3000 m, mean annual temperatures were 4-8°C lower than today (Williams et al., 1978; Hurni, 1982), the timberline was lowered by 800-1200 m, and summer rainfall was greatly reduced. As a result of these changes in precipitation and vegetation, surface erosion increased and the Blue Nile became a highly seasonal river transporting a bed load of sand and gravel across the Gezira fan and into the main Nile. With the return of a strong summer monsoon from ~14.5 kyr onwards, the Blue Nile became a sinuous suspension load stream and began to deposit clay across its floodplain. These hydrological changes were a response to the return of warmer wetter conditions in the Ethiopian headwaters, leading to a renewal of the forest cover and to soil formation on weathered basalts and tuffs.

At times when the Uganda lakes were full and overflowing and the Sudd swamps were re-established, such as from 14.5 kyr onwards, the White Nile deposited clays along its flood plain, and reworked pre-existing sands and gravels brought in by the late Pleistocene Blue Nile channels to form point-bars, sandy alluvial islands and mid-channel bars. Once the Holocene flood levels of the White Nile had fallen sufficiently, these sand and gravel ridges became preferred occupation sites for groups of Mesolithic hunter-fisher-gatherers, as at Esh Shaheinab, discussed earlier, and at Shabona and El Khiday, discussed below. We now consider three sites east of the lower White Nile (Esh Shawal, Tagra, and Shabona) and three sites west of the lower White Nile (Wadi Mansurab, Jebel Baroka wetland, and El Khiday) (Fig. 2). These sites collectively provide accurately dated and precise information about White Nile flood levels, local and regional climate, and prehistoric occupation patterns. We provide more information about El Khiday than we give for the five other sites because the archaeological sites at El Khiday have been studied in most detail.

3. Methods

3.1 Stratigraphy

For each stratigraphic section examined by MAJW a record was kept of the thickness of each stratigraphic unit, the nature of its contact with adjacent units, its Munsell Chart colour (both wet and dry), soil structure, consistence and hardness, field texture (to within ~5% clay content, for sixteen soil textural classes), sand particle shape and degree of roundness (under x10 and x20 magnification), sedimentary structures, carbonate concretions (shape, size and %), and presence of any shells, charcoal or other material. Where appropriate, samples were also collected for OSL and/or ^{14}C analysis. In the case of samples from Esh Shawal and Tagra, the chemical properties of the soils were also determined, including salinity (electrical conductivity) and alkalinity (pH; exchangeable sodium percentage) to provide further information on the depositional environment. Excavation procedures were those described by Usai and Salvatori (2006a, b) and Salvatori et al. (2011). Salvatori (2012) and Dal Sasso et al. (2014a) give full details of techniques of pottery identification and Zerboni (2011) explains the methods of micro-morphological analysis used in this work, which are discussed in detail by Bullock et al. (1985), Stoops (2003) and Stoops et al. (2010).

3.2. Radiocarbon dating

Table 1 shows the 22 Accelerator Mass Spectrometer radiocarbon (AMS^{14}C) and Radiometric ages obtained on archaeological remains from the El Khiday and Jebel Baroka sites and Table 2 shows the 2 AMS^{14}C ages obtained from shells in the upper 12 cm of the Jebel Baroka wetland clays. All 24 radiocarbon ages were calibrated using OxCal 4.2 (Bronk Ramsey, 2009) and were calibrated against the IntCal13 calibration curve (Reimer et al., 2013).

3.3. Optically stimulated luminescence (OSL) dating

Seventeen samples were collected for OSL dating from alluvial sediments at the Jebel Baroka former wetland and El Khiday prehistoric site (Figs. 5 and 6). Details of procedures and interpretation of data are given in the supplementary data and the ages obtained are shown in Table 3.

4. The six study sites in the lower White Nile valley

4.1. Esh Shawal

The village of Esh Shawal is located at 13°35′N, 32°41′E on the east bank of the White Nile 265 km upstream from the Blue and White Nile confluence at Khartoum (Fig. 2). The alluvial clays for 3.5 km east of the river contain occasional Nile perch (*Lates niloticus*) vertebrae as well as abundant gastropod shells at depths of 1.0-1.2 m (Fig. 3a), which have yielded ^{14}C ages of 15.4-14.0 cal kyr (Williams, 1966; Williams and Adamson, 1980; Adamson et al., 1982; Williams, 2009). The ^{14}C ages for the shells are consistent with OSL ages on quartz grains obtained from the same horizon (Williams et al., 2003). The gastropods flourished when Lakes Victoria and Albert overflowed (Talbot et al., 2000) and the White Nile formed a seasonal lake up to 382 m in elevation (Williams et al., 2006), or 6 m above the 375.7 m modern unregulated mean high flood level (Adamson et al., 1982, Fig. 9.9). This may seem trivial until we note that the flood gradient of the White Nile is only 1:100,000 and that the land adjoining the river also slopes very gently, so that a slight increase in flood height leads to widespread flooding. As the lake dried out the gastropods died, and over a horizontal east-west distance of 3.5 km they delineate the gradual regression of the seasonal lake shoreline (Fig. 3a).

4.2. *Tagra*

Tagra village lies 40 km downstream of Esh Shawal and 2 km east of the White Nile (Fig. 2). A pit dug 1 km southwest of Tagra at 13°56′N, 32°22′E contained two layers of unbroken aquatic and semi-aquatic snail shells (Fig. 3b). The lower shell-bed (depth 1.6-1.9 m) gave a ^{14}C age of 8700 ± 350 BP (cal 9750 ± 440 BP), and the upper shell-bed (depth 1.2-1.4 m) gave a ^{14}C age of 8130 ± 225 BP (cal 9060 ± 300 BP). At a depth of 1.3 m there were fragments of two barbed bone points characteristic of the Early Khartoum tradition or Khartoum Mesolithic (Arkell, 1949), fragments of small bones of mammal, and fish bones, including catfish spines (Adamson et al., 1974). These were the first radiocarbon dates ever obtained for the Khartoum Mesolithic. The surface elevation of the trench is 378.4 ± 0.2 m, which is 3 m above the local unregulated mean flood level of the White Nile (375.4 m), so that the White Nile attained a flood level at least 3 m above its modern unregulated flood level towards 9.7-9.1 kyr, equivalent to a drop of 3 m in flood level relative to the 14 kyr flood level at Esh Shawal. The progressive drop in White Nile flood levels during the course of the Holocene appears to have been caused by incision of the Blue Nile, which resulted in beheading of the Blue Nile distributary channels that flowed across the Gezira fan (Adamson et al., 1982; Williams 2009), as well as a reduction in Blue Nile peak flow from early Holocene times onwards, leading to reduced seasonal ponding of the White Nile.

4.3. Shabona

Shabona Mesolithic site differs from the two sites discussed above in being situated within the complex of wind-blown sand dunes that extends for 150 km between Hashaba in the south and Jebel Aulia in the north. The site derives its name from the village of Sabuna Salaha, 4 km to the north. This village lies 8 km east of the White Nile and midway between Wad ez Zaki 26 km to the south and El Geteina 24 km to the north (Fig. 2). The dunes are Pleistocene in age and have been partly submerged in alluvial clays laid down by the White Nile at intervals from 15 kyr onwards. The prehistoric site is 8 km east of the river and almost exactly midway between Khartoum to the north and Esh Shawal to the south. It is located on a sand dune situated at 14°36′N, 32°14′E, which rises 2-3 m above the adjacent clay plain (Fig. 3c) at the northern end of a former shallow embayment of the river (Adamson et al., 1982).

The occupation debris extends across at least 50 000 m^2. Clark (1989) considered that different portions of the site were occupied during the dry season by Mesolithic bands of about 20 people engaged in fishing, hunting and gathering. Barbed bone points, abundant quartz microliths, sandstone grindstones, and pottery tempered with quartz or grass all bring to mind the Early Khartoum site excavated by Arkell (1949). *Pila* shells were especially abundant at the site and would have been easy to collect from the nearby mudflats during the dry season. The *Pila* shells yielded two ^{14}C ages: 7050 ± 120 BP (7880 ± 120 cal BP) and 7130 ± 40 BP (7970 ± 30 cal BP), and human bone gave a ^{14}C age of 7470 ± 240 (8382 ± 236 cal BP). *Pila* shells embedded in dark clay at 100-120 cm depth just east of the site (Fig. 3c) yielded a ^{14}C age of 2700 ± 140 BP (2810 ± 160 cal BP), indicating that swampy conditions persisted intermittently until at least 2.8 kyr. The clay has a surface elevation of 378.8 m, so that the 2.8-kyr fossil shells lie 2 m above modern unregulated flood level. (All flood levels mentioned here are specified relative to the surveyed Khartoum gauge at Mogren, which is 360 m above the Alexandria sea level datum).

Apart from *Pila* shells, fauna at the site included abundant fish and tortoises, monitor lizard (*Varanus niloticus*), lizard, snake (*Mahelya* sp.), crocodile (*Crocodylus niloticus*) and hippo (*Hippopotamus amphibius*). Savanna bovids are common, including reedbuck (*Redunca redunca*), kob (*Kobus kob*) and Cape buffalo

(*Syncerus caffer*). There were also bones of the African elephant (*Loxodonta africana*) and warthog (*Phacochoerus aethiopicus*).

Pits full of *Pila* shells suggest that they were eaten, perhaps boiled up in the pots whose fragments litter the site. Grindstones and grass seed remains resembling *Digitaria* suggest that wild grass seeds were collected, ground and eaten. *Digitaria* today grows in moister regions well over 300 km to the south of Shabona. It seems likely that Shabona was occupied during the dry season as the floods receded and bovids and other savanna animals began to concentrate near permanent sources of water (Clark, 1989), of which the Shabona White Nile embayment was one (Adamson et al., 1982).

The faunal evidence from the Shabona Mesolithic site is consistent with higher precipitation and a longer wet season during the time it was occupied between 8.4 and 7.9 kyr ago. The extreme rainfall events of August-September1999 led to widespread ponding of water between the dunes of the lower White Nile valley and provide a possible analogue for the early Holocene environment at Shabona Mesolithic site (Williams and Nottage, 2006). The flood level of the White Nile was between 2 and 3 m higher at that time, so that times of high White Nile flow were also times of regionally wetter climate, as suggested also by the evidence from the Early Khartoum Mesolithic site (Arkell, 1949) and the Mesolithic site one km west of the Shaheinab Neolithic site on the main Nile (Arkell, 1953). We now consider three localities west of the lower White Nile.

4.4. Wadi Mansurab

A series of shallow clay pans located 10-12 km west of the lower White Nile and 1-6 km north of ephemeral Wadi Mansurab in latitude 15°20′N (Fig. 4a-d) contain abundant aquatic, semi-aquatic and terrestrial snail shells in the upper 10-50 cm of silty sediment. The sites lie at elevations of 400-420 m above the Alexandria datum, or well above the 382 m maximum flood level attained by the White Nile during the terminal Pleistocene at 14.5 kyr (Williams et al., 2006). The present-day vegetation consists of scattered *Acacia* (now *Vachellia*) *nubica*, *Ziziphus spinachristi* with *Acacia* (now *Vachellia*) *tortilis* subsp. *raddiana* on the slightly higher and sandier terrain, and sparse *Aristida* grasses on the otherwise bare pans.

The abundance of the land snail *Limicolaria flammata* in the shell samples prompted Williams et al. (1974) to suggest that at the time the pans contained water (between 9900 and 7600 2σ cal BP: Williams and Jacobsen, 2011, Table 1), the local vegetation was an acacia-tall grass savanna, with a mean annual rainfall of 400-800 mm, as opposed to the present-day 150-200 mm of precipitation in this area. The large land snail *Limicolaria flammata*, today inhabits the acacia-tall grass savanna region to the south of Sennar where the annual rainfall is at least 450-500 mm. *Limicolaria* was at its most widespread in the central Gezira region ~5.2 kyr ago (Adamson et al., 1982). It is true that there is a long record of isolated instances of *Limicolaria flammata* living in sheltered microhabitats well north of the acacia-tall grass savanna (Arkell, 1945, but written in 1926; Haynes and Mead, 1987), so that the presence of *Limicolaria* is not in itself unequivocal evidence of a wetter climate. However, the dominance of the semi-aquatic species *Pila wernei* and *Lanistes* *carinatus* and the seasonal pool- and swamp-dweller *Biomphalaria sudanica* (Brown, 1980, 1994) over the truly aquatic species such as *Bellamya unicolor*, *Cleopatra bulimoides*, *Melanoides tuberculata* and *Lymnaea natalensis* is strongly indicative of a seasonally flooded grassy plain.

Williams and Jacobsen (2011) obtained ten AMS ^{14}C ages for the shells from three of the pans to supplement the four earlier conventional ^{14}C ages. The calibrated ages all lie between 9.9 and 7.6 cal kyr, with a concentration of ages (11 out of 14) within the six hundred year interval 9.0-8.4 cal kyr. These ages are similar to the ages obtained for the Mesolithic barbed bone harpoon sites at Tagra and Shabona east of the lower White Nile, discussed earlier, and to the ages obtained for the Mesolithic sites at El Khiday west of the lower White Nile, discussed in section 3.6. It could be argued that the ponds came into existence as a result of a rise in local groundwater levels. However, the oxygen isotopic composition of four species of gastropod from the pans shows highly variable and strongly depleted values, indicative of a distant, possibly South Atlantic precipitation source, and local runoff from a seasonal rainfall regime with a high degree of inter-annual variability (Ayliffe et al., 1996). The oxygen isotopic composition of the semi-aquatic species *Biomphalaria sudanica* showed greater variability than that of the three aquatic species analysed (*Melanoides tuberculata*, *Cleopatra bulimoides* and *Lymnaea natalensis*). This suggests that higher water tables sustained more enduring pans inhabited by aquatic snails, while variable seasonal runoff fed more intermittent pans inhabited by semi-aquatic snails. Individual pans were sometimes intermittent and sometimes more enduring. A stronger southwest monsoon and a northward shift of the summer rainfall zone were most likely responsible for flooding in this region at a time of reduced evapotranspiration and possibly lower summer temperatures (Ayliffe et al., 1996). This hypothesis is supported by many other studies from lakes in northern Sudan and the eastern Sahara, which all point to a northward shift in the isohyets across the eastern Sahara (Abell and Hoelzmann, 2000; Hoelzmann et al., 2004).

A thin section from a block collected from one of the Wadi Mansurab clay-pans (15°23´N, 32°21´E; Fig. 4d) shows a massive to sub-angular blocky microstructure, with common voids. The most common type of void consists of channels formed by intense bioturbation. The deposit consists of a clayey and organic groundmass with common to abundant poorly sorted quartz grains displaying an open to single-spaced porphyric c/f (Fig. 4d) related distribution. The organic fraction consists of very dark, finely comminuted organic fragments mixed with the clayey groundmass and common slightly weathered snail shells (complete or fragmented; Fig. 4d). Micro-features related to calcium carbonate redistribution are common (nodules, infilling, hypocoating along voids, and coating on voids) and most of the groundmass is impregnated by calcite. The presence of amorphous organics in the micro-mass, typical of wet environments (Babel, 1975), suggests that the formation of the Wadi Mansurab pan sediments occurred in an environment wetter than today, causing a rise in the local water table, consistent with the presence of aquatic gastropods in some of the pans. In contrast, the strong redistribution of calcite may be related to the end of the Holocene humid phase and the prevalence of processes related to enhanced evapotranspiration and a fluctuating water table (Sehagal and Stoops, 1972; Durand et al., 2010).

Archaeological finds are very sparse in this area. They mostly consist of isolated fireplaces of uncertain age and a few tethering stones, the occurrence of which may suggest occasional visits to the area by Holocene hunters (Pachur, 1992; Cremaschi et al., 2006), possibly under more humid environmental conditions.

4.5. Jebel Baroka wetland

The southern margin of a large late Quaternary swamp or seasonal lake (Cremaschi et al., 2006) lies 20 km north of the Wadi Mansurab shell-bearing clay pans in latitude 15°33.3´N. This feature extends for over 30 km from west to east and has a mean width of 4 km (Fig. 5a, b). It occupies a broad shallow valley that once extended east to the White Nile and is very clearly delineated on the 1988 Geological Research Authority of Sudan 1: 1,000,000 map sheet 9 (Khartoum), as is the Wadi Mansurab valley to the south. Jebel Baroka, a conspicuous rocky Nubian Sandstone hill, lies just south of the western sector of this clay-floored depression, prompting the informal name Jebel Baroka wetland for this feature. A thin section from a block collected at the bottom of Wadi Abu Asheem (15°34´N, 32°10´E) shows characteristics very similar to those at Wadi Mansurab. The deposit has a massive to sub-angular blocky microstructure, with common channels and chamber voids and some planar voids. The groundmass consists of clay and amorphous organic matter interspersed with common to abundant poorly sorted quartz grains, from silt to medium-coarse sand, displaying an open to single spaced porphyric c/f related distribution (Fig. 5b). The smaller quartz grains are generally poorly rounded, while the larger ones are generally well rounded, suggesting two different mechanisms of accumulation, possibly related to surface runoff and wind. A few coarse sandstone fragments (probably from the surrounding Nubian Sandstone hills) and occasional igneous minerals belonging to the silt and fine sand fractions (wind transported?) are also present. The coarse organic constituents consist of sporadic microscopic charcoal in the groundmass and common slightly weathered mollusc shells (complete or fragmented; Fig. 5b). Occasional siliceous phytoliths, diatom frustules and sponge spicules are also present. Micro-features related to calcium carbonate redistribution are also common and most of the groundmass is impregnated by calcite. The presence of organics in the groundmass of the deposits points to the occurrence of wet environments, confirmed by the occurrence of diatoms and sponge spicules, which are typical of ponded or poorly drained sedimentary environments (Gutierrez-Castorena and Effland, 2010).

Abundant Mesolithic and more sporadic Neolithic sites have been mapped along the southern margin of the wetland (Usai and Salvatori, 2002; Usai, 2003; Cremaschi et al., 2006). There were no direct ages for most of this evidence except for site 10-W-4 extensively investigated in 2004-2005 (Salvatori et al., 2011, 2014; Usai, 2014) and dated to a Late Mesolithic phase (Table 1). This archaeological site is a settlement with semi-subterranean huts up to 7 m long and about 4 m wide (Usai and Salvatori, 2005; Salvatori et al., 2011, 2014) that produced abundant cultural and biological remains. The fauna from 10-W-4 is predominantly composed of hunted game, including small, medium and large antelopes and black/white rhinos, which may have been caught in the dry season when concentrated near remaining food and water sources around the Jebel Baroka wetland (Salvatori et al., 2014).

At three sites on the former wetland floor north of Jebel Baroka we collected six samples of fine sandy clay for luminescence dating, five samples for dosimetry and four shell samples for taxonomic analysis and radiocarbon dating. At geological site EK11/4 (15°34.411′N, 32°10.789′E) shells in the upper 10 cm of the wetland floor yielded an AMS ^{14}C age of 7719 ± 25 BP (8554-8426 2σ cal BP: Table 2), and OSL ages of 6.6 ± 0.5 kyr at 1-13 cm, 10.0 ± 0.7 kyr at 34-43 cm and 35.6 ± 2.8 kyr at 103-108 cm depth (Table 3).

At geological site EK11/6 (15°33.217′N, 32°15.592′E) shells in the upper 10 cm yielded an AMS ^{14}C age of 6199 ± 25 BP (7164-7002 2σ cal BP: Table 2), and OSL ages of 5.9 ± 0.5 kyr at 1-12 cm and 10.1 ± 0.7 kyr at 48-43 cm depth (Table 3).

The shells were mainly *Pila*, *Lymnaea* and *Limicolaria*, once again suggesting a seasonally flooded depression flanked by acacia-tall grass savanna, with a mean annual precipitation of at least 400 mm, or three times that received in this area today. The two radiocarbon and two OSL ages for the upper 10 cm of sediment (a grey-brown fine sandy clay) indicate that the depression was still receiving water from local runoff between 8.5 and 6 kyr ago and began to dry out thereafter. The two OSL ages of 10 kyr at depths of 40-50 cm indicate that the depression was seasonally flooded between 10 and 6 kyr, with a mean sedimentation rate of 0.1-0.3 mm/yr between 10 and 8.5-6 kyr, which is consistent with reworking of eolian dust and fine sand by seasonal runoff. The single OSL age of 35 kyr at a metre depth shows that the Jebel Baroka wetland was already in existence during the late Pleistocene and doubtless much earlier.

4.6. El Khiday

Among a number of Mesolithic and Neolithic sites recorded along the western bank of the White Nile and usually severely disturbed by post-depositional wind and water erosion, animal and anthropic activity (Usai and Salvatori 2005, 2006a, 2006b) a cluster of five archaeological sites of varying size and age was located about 20 km south of the confluence of the two Niles at Khartoum, not far from the modern village of El Khiday (Fig. 6a). These sites, in common with most of the Mesolithic sites located by the Italian Archaeological Mission in central Sudan, are situated on low sandy ridges that stand up to 4 m above the surrounding plain. They form discontinuous knolls oriented north-south a few km west of the present White Nile, a situation similar to that found along the Main Nile north of Khartoum (Marcolongo, 1983). The knolls on which El Khiday and other archaeological sites are found were associated with the terminal Pleistocene phase of higher White Nile floods associated with the 15.0-14.5 kyr transgression discussed in section 2. The sites are scattered across an alluvial terrace, which corresponds to the eastern limit of the dark alluvial clays deposited during the terminal Pleistocene and early Holocene flooding of the White Nile.

The low rises on which the sites are located consist of sand bodies intercalated with lenses of fine gravel. They probably formed as point-bars or mid-channel bars. The flat area surrounding the knolls is characterized by patches of dark, sandy to loamy sediment (Fig. 6b), extremely rich in organic matter, with well-developed polyhedric aggregates, and calcium carbonate cement increasing with depth. Under the microscope, this sediment shows a fissured porphyric fabric and a strongly developed blocky microstructure, with scarce quartz grains and comminuted bone fragments dispersed in an organic amorphous micro-mass, showing strong bioturbation (Fig. 6b). This deposit suggests a locally swampy or wetland environment, possibly corresponding to small basins fed by the seasonal floods of the White Nile. The wetland sediment has yielded a ^{14}C age of 7740 ± 50 yr BP (8597–8420 2σ cal BP: Table 1) (Zerboni, 2011). The formation of this kind of sediment is consistent with seasonal flooding from the White Nile during a phase of higher flood levels. We infer that during the wet season, shallow depressions were flooded for at least several months and organic material accumulated in the ponds. Desiccation during the dry season led to weak soil development and production of a blocky microstructure, much as in the early Holocene Gezira plain east of the White Nile.

Excavations and test trenches conducted since 2004 at the sites near El Khiday have revealed a stratigraphic sequence relating to the Khartoum Mesolithic, Neolithic, Meroitic and Post-Meroitic phases. Among the sites 16-D-5 is a Mesolithic settlement with a poorly preserved Neolithic layer and partly disturbed by Post-Meroitic tumuli (15° 27.105′N, 32° 24.392′E). 16-D-4 is a multiphase site with a consistent pre-Mesolithic cemetery (90 graves), a Mesolithic functional area with 104 pits, with different functions, and an almost complete Mesolithic circular hut with entrance to the east, 32 Neolithic graves, 43 Classic/Late Meroitic graves (15° 27.165′N, 32° 24.419′E). 16-D-4B is a second Mesolithic functional area with a large number of garbage-pits, eight of which were excavated (15° 27.230′N, 32° 24.434′E). 16-D-3 is a large Mesolithic mound-like site excavated in 2013 (15° 27.260′N, 32° 24.305′E). Finally, 16-D-6 is a Neolithic, possibly seasonal, settlement (15° 27.038′N, 32° 24.265′E) (Usai and Salvatori, 2005; Salvatori and Usai, 2007, 2008; Usai et al., 2010; Salvatori et al., 2011, 2014; Zerboni, 2011; Salvatori, 2012).

The archaeological stratigraphic sequence at site 16-D-5 can be divided into two main periods. The earliest one seems to be characterized by a seasonal presence with lightly constructed huts on an ancient White Nile bar. The most popular types of pottery decoration in this phase are Incised Wavy Line (IWL), Incised Lunula and combed Deep Drops motifs (Dal Sasso et al., 2014; Salvatori et al., 2011; Salvatori, 2012). The chronology of this first period could cover at least the first 300 to 350 years of the 7th millennium cal. BC (Table 1). An older layer bearing the same pottery types was excavated immediately above the White Nile sandy channel bar but, unfortunately, no datable material was found within it (Salvatori, 2012).

The second period at the site can be divided into two phases. The first phase is characterized by the almost complete disappearance of the Lunula motif, the persistence of IWL and Deep Drops, and the appearance of a Rocker Stamp Drops decoration. The second phase is characterized by the disappearance of the Deep Drops decoration, a decrease in the IWL production, a strong increase in Rocker Stamp drops together with the Rocker Stamp dotted packed decoration (Dal Sasso et al., 2014; Salvatori et al., 2011; Salvatori 2012). The alternating Pivoted Stamp technique, though at a very low percentage, appears during this second phase. The upper part of the original stratification at the site was completely destroyed by Post-Meroitic tumuli and partly relocated on the preserved stratigraphy as a colluvial layer (Zerboni, 2011; Salvatori 2012). The second period of the sequence preserved at 16-D-5 is well represented and better dated by the 16-D-4 and 16-D-4B Mesolithic pits

(Salvatori et al., 2011) where, as expected, there is a general increase in Rocker Stamp Drops (with stylistic variations illustrated in Salvatori, 2012).

Other cultural material related to the occupation of the sites includes quartzite tools, grinding equipment, bone tools (finished and unfinished) and scarce jewels made from ivory or from animal bones. Quartzite microlithic tool production does not evolve much in the 500/600 years when the sites were occupied and is characterized mainly by backed pieces accompanied by geometrics. A significant object found in one of the most ancient layers, dated 7980 ± 40 BP (8999-8700 2σ BP), is a pebble with a painted representation of a Nile boat (Usai and Salvatori, 2007), the oldest known for the Nile valley.

At present the Mesolithic sequence reconstructed at El Khiday covers part of the Early and Middle periods of the Mesolithic (Salvatori et al., 2011; Salvatori, 2012). A gap of about 700 years separates the most recent date at 16-D-4 from the single date (6490 ± 40 BP: 7476-7316 2σ cal BP) actually available from the Late Mesolithic site 10-W-4, on the Jebel Baroka wetland margin.

The Neolithic of the area is, from the point of view of pottery remains supported by four radiocarbon ages, strongly linked to the Shaheinab phase of the Early Neolithic of central Sudan. The ^{14}C samples come from a residual Neolithic layer preserved at the base of the western slope of site 16-D-5 (5470 ± 50 BP: 6397-6184 2σ cal BP), from two of the 39 Neolithic graves excavated at 16-D-4 (5690 ± 30 BP: 6553-6405 2σ cal BP and 5550 ± 80 BP: 6500-6188 2σ cal BP), and from the single phase 16-D-6 site tested in 2009 (5360 ± 80 BP: 6295-5944 2σ cal BP) (Table 1).

The composition of the fauna from 16-D-4, 16-D-4B and 16-D-5 is similar to what is known from contemporary sites in Sudan (Salvatori et al., 2014). The faunal remains often seem to represent short depositional events, undisturbed in later times, as reflected by concentrations of bones of the same species and the occurrence of articulated bone remains. This has especially been observed in the pits in 16-D-4B. In general, fish are markedly predominant. The samples are rich in species but mainly composed of clariid catfish (Clariidae). Size reconstructions show that they were usually over 40 cm in standard length, indicating that people were probably fishing at the beginning of the flood season, when spawning clariid catfish are easy to catch in shallow waters (Van Neer, 2004). Clariid skeletons preserve well and are easy to recognise, adding further explanation to their predominance in the archaeological samples. Apart from clariid catfish, there are also fish from marshes and open water habitats. In addition, other freshwater taxa occur, including softshell turtles (Trionychidae) and crocodile. Hunted game as a group is much less common than fish, but nevertheless indicates a rich, savanna type of terrestrial environment. Some excavated units contained large numbers of *Pila* shells, presumably collected in drying out swamps.

Different diagenetic processes were recorded from the analysis of a set of human bones from the various burial phases at site 16-D-4, indicating a relative chronological sequence of the events operating during and after burial. The occurrence of secondary phases (Mn oxides only in the pre-Mesolithic and Mesolithic burials, and calcite in all except the Meroitic ones), as well as the amount/extent of microscopic focal destruction (MFD), clearly describes a different pattern of diagenetic alterations for burial phases of different ages. These diagenetic alterations reflect changes in the environmental conditions (Dal Sasso et al., 2014b).

At the El Khiday archaeological site 16-D-5, twelve samples were collected for OSL dating (two for modern calibration) and a further 5 samples for determining the dosimetry (Table 3). Five samples came from a trench dug in a low sand ridge just south of the main site (geological site EK 11/1). Using a specially designed soil auger and red light inside a black plastic tent, we collected samples of fine sandy clay to a depth of 236 cm. These sediments accumulated on the late Quaternary White Nile floodplain. They yielded OSL ages of 8.7 ± 0.7 kyr at -67 cm, 42.5 ± 4.9 kyr at -84 cm, 64.7 ± 18.8 kyr at 136-145 cm depth, 61.2 ± 6.1 kyr at 196-202 cm and 49.4 ± 10.0 kyr at 229-236 cm. The sample at -67 cm depth was overlain by organic black loamy sand with two AMS ^{14}C ages between 9.0 and 8.5 cal kyr (Salvatori, 2012).

The remaining five samples were collected from sediments adjoining four burial sites, one pre-Mesolithic, one Mesolithic, one Neolithic and one Meroitic. The pre-Mesolithic burial was not amenable to dating by radiocarbon since the bone collagen had been degraded, so we hoped that the luminescence age would provide a numerical age for this burial. The sediment next to the Neolithic burial site 164 (site EK11/2) yielded an OSL age of 9.6 ± 0.8 kyr, that next to the pre-Mesolithic burial site 160 (site EK11/3) yielded OSL ages of 8.1 ± 0.7 and 8.6 ± 0.7 kyr, and that adjoining the Meroitic grave site 159 (site EK 11/7) yielded OSL ages of 11.9 ± 1.3 and 11.5 ± 1.1 kyr. These ages do not relate to the actual times of burial but indicate that the graves were dug into sediments that were accumulating in this locality between 12 and 8 kyr. The site stratigraphy is complex, even leaving aside the thorny problem of periodic disturbance by humans, animals, plants, wind and water. Two distinct carbonate horizons are evident at the El Khiday archaeological site. The younger carbonate horizon is a fossil soil formed within an eolian sand unit. The older carbonate horizon is formed within a sandy clay unit that accumulated on the late Quaternary White Nile floodplain.

5. Discussion

The aim of this paper was to provide answers to three key questions arising from the pioneering work of Tothill (1946, 1948) and Arkell (1949, 1953) over fifty years ago. (a) Was the decline in the height of Nile floods from early Holocene times onwards caused by a reduction in Nile discharge, channel incision, or both? (b) Was the local and regional climate wetter during times of high Nile floods and drier during times of low Nile floods? (c) Given the high degree of disturbance of Mesolithic and later prehistoric sites, is it possible to identify primary-context, stratified and undisturbed occupation?

(a) The dated alluvial deposits at Esh Shawal, Tagra and Shabona show a progressive decline in White Nile high flood levels from a maximum elevation of 382 m at 14.5-13 kyr. Between 14.5-13 kyr and 9.7-9.1 kyr there was a 3 m drop in maximum flood levels, with a further drop of 2-3 m between then and 2.8 kyr. The total decline in White Nile flood level over the past 14.5 kyr amounts to at least 5 m, consistent with the 10 m drop identified by Arkell (1949; 1953) on the Main Nile at Esh Shaheinab and close to the Blue Nile at the Early Khartoum Mesolithic site. The fall in White Nile flood levels is consistent with but does not *demand* a reduction in White Nile discharge, since it could just as well result from incision by the Blue Nile and Main Nile, causing a fall in local base level at the Blue and White Nile confluence. The causes of Blue Nile incision are still unresolved. One possibility is a reduction in bed and bank friction as a result of a change from a broad and shallow bed-load channel during the late Pleistocene to a relatively deep and narrow suspension load channel during the Holocene, with smooth clay-lined bed and banks. The kinetic energy released by the reduced friction would then be available for channel incision. Another option is tectonic uplift along the lower Blue Nile valley. The matter is best left open.

However, several independent lines of evidence do support the concept of a reduction in White Nile discharge during the course of the terminal Pleistocene and Holocene. One comes from lake fluctuations near the headwaters of the White and Blue Nile rivers; another from a marine sediment core collected from the Nile cone in the eastern Mediterranean; and a third comes directly from White Nile flood deposits.

(i) The diatom record from Pilkington Bay in Lake Victoria (Stager et al., 2003) shows evidence of high rainfall at 8.8-8.3 ka, becoming more seasonal thereafter, with sharp drops at about 8.2 and 5.7 ka, and sharp century-scale increases in rainfall at about 8.5, 5.8 and 4 ka. The present climatic regime was established after 2.7 ka and there was an interlude of major droughts between about 1200 and 600 BP. Verschuren et al. (2009) provide a detailed late Quaternary chronology (based on 188 AMS ^{14}C ages) of wet and dry phases evident from Lake Challa, a crater lake on the eastern flank of Mt. Kilimanjaro within the White Nile headwaters region. The lake was very low and the inferred climate was very dry at 20.5-14.5 kyr (especially at 17.0-16.4 kyr), and again at 12.9-12.0, 8.0-6.7, 5.9-4.7, 3.6-3.0 and 0.7-0.6 kyr. Especially moist intervals at Lake Challa were at 13-14 kyr and 10-5-8.5 kyr, the former coeval with the 382 m White Nile transgression and the latter coeval with the Mesolithic wet phase(s) in the lower White Nile valley. Marshall et al. (2011) used variations in the titanium content in sediment cores from Lake Tana to argue for low stands at 13-12.5, 8.4, 7.5 and especially 4.2 ka, with reduced flow after 6.8 ka, while Brown and Fuller (2008) equated Member 4 of the Kibish Formation to an early Holocene interval of very high flow in the lower Omo and overflow of Lake Turkana into the White Nile via the Sobat.

(ii) Marine core P362/2-33 collected from the Nile deep-sea fan shows that the relative intensity of Blue Nile discharge was greater during the early and late Holocene when spring insolation was high in the BN headwaters but was reduced between 8 and 4 ka when autumn insolation was high and the White Nile came to the fore (Blanchet et al., 2013). The core also revealed evidence of an arid event at 8.5-7.3 ka and again at 4.5-3.7 ka.

(iii) Williams et al. (2010) observed that the dimensions of cross-bedded units in White Nile alluvial sands laid down west of the present river become progressively smaller between 28 and 4.5 kyr ago.

(b) The faunal evidence from the Shabona and El Khiday Mesolithic sites is entirely consistent with a wetter early Holocene climate, as is the shell fauna from Wadi Mansurab. It thus appears that high White Nile floods during the early Holocene were indeed coeval with a wetter climate in the lower White Nile valley.

(c) Finally, it is possible to recognize undisturbed primary-context sites using very careful excavation techniques buttressed by micro-morphological analysis of the deposits and thorough taxonomic evaluation of changes in pottery styles and modes of manufacture. The presence of prehistoric human burials, of pits used for disposing of edible snail shells and other rubbish, and the remains of hut structures furnish additional strong evidence of former human occupation at the Mesolithic sites of El Khiday and Shabona. Furthermore, work at the El Khiday sites did not proceed according to the 'Pompei premise' (Ascher, 1961, p. 324) with the idea that the archaeological record represents one moment in a living community, but rather with a conscious awareness that the record results from intense and continuous human activities performed over a long time. The outcome of this approach is that for the first time the once monolithic image of the Mesolithic period in Sudan covering about three thousand years is now starting to appear in all its complexity (Salvatori, 2012; Usai, 2014).

6. Conclusions

Macro-scale and micro-scale interdisciplinary analysis, as illustrated in this paper, are essential in reconstructing the evolution of past populations. Without being deterministic, it is evident from our work that studies of contemporary environments are a prerequisite for archaeological enquiry. This is true of both the White and Blue Nile valleys, where ecosystems have been subject to both anthropic and natural modification, or what Shiffer (1976) has described as 'event transforms'.

The lower White Nile has an unusually low flood gradient of 1:100,000. As a result, its alluvial sediments have undergone minimal subsequent fluvial erosion and are often very well preserved. The terminal Pleistocene and Holocene White Nile flood plains slope very gently towards the river and have partially submerged the late Pleistocene and younger dunes that were active during times of drier climate and reduced plant cover. In addition, former mid-channel bars and point-bars that were active during times of higher White Nile flow are now isolated from the present river channel and flanked by alluvial clays and silts. A number of the dunes and relict sand-bars situated near the former river banks or close to seasonally flooded ponds and wetlands were occupied by groups of seasonally mobile fisher-hunter-gatherers during the Mesolithic and possibly also during the Upper Palaeolithic. By paying careful attention to local site stratigraphy it is possible to distinguish between primary-context sites and sites disturbed by later human activity, plant and animal action, and erosion from wind and water. The Mesolithic sites at El Khiday are a case in point. The White Nile floods were relatively high between 9.7 and 9.1 kyr ago, at which time the climate in the lower White Nile valley was significantly wetter than today, with a longer wet season and precipitation up to three times greater than now. Seasonal swamps and wetlands were ubiquitous at this time, and were a source of abundant fish and edible snails for the Mesolithic people as well as attracting antelopes and other game during the dry season. In the lower White Nile valley climatic desiccation had set in by late Neolithic times 4.5 kyr ago although there have been short-lived wetter phases since then (Williams et al., 2010).

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Figure captions

Figure 1. Nile basin.

Figure 2. Lower White Nile valley and location of sites discussed in the text.

Figure 3. (a) Esh Shawal. (b) Tagra. (c) Shabona. Key: d, dark; p, pale; g, grey; b, brown; ol, olive; y, yellow; c, clay; sc sandy clay; cfs, clayey fine sand; sgr, sandy gravel; si, silt; cs, clayey sand; fs, fine sand.

Figure 4. (a) Wadi Mansurab general location, after Williams and Jacobsen, 2011. (b) Location of two stratigraphic sections, after Williams and Jacobsen, 2011. (c) Stratigraphic sections. Key: Si, silt; SiL, silt loam; Cl, clay loam. (d) View of pan surface and thin sections of pan sediments. (i) Thin section of the pan deposit showing shell fragments and heterometric quartz grains dispersed in the groundmass (cross-polarized light). (ii) Features relating to calcium carbonate redistribution in the micro-mass and infilling of voids (cross-polarized light).

Figure 5. (a) Jebel Baroka wetland and location of archaeological sites. (b) View of wetland surface overlain by wind-blown sands, and Google image of wetland. (c) photomicrograph of the sediment in Wadi Abu Asheem (Jebel Baroka area) displaying a groundmass rich in clay and amorphous organic matter with interspersed heterometric mineral grains and mollusk shells (cross-polarized light).

Figure 6. (a) El Khiday landform map showing location of Mesolithic archaeological sites discussed in the text. Key: 1 glacis, 2-4 Nile alluvium, 5 sand dune, 6 longitudinal sand bar, 7 sandstone outcrops, 8 terrace margin, 9 palaeochannel, 10 present-day ephemeral channel network, 11 Mesolithic sites. (b) Former swamp deposit near site 16-D-6. (c) Photomicrograph of the swamp deposit showing a micro-mass rich in organic material with a blocky microstructure (normal polarized light). (d) Infilling with bow-like structure related to bioturbation (normal polarized light. (e) Calcite nodules reflecting redistribution of calcium carbonate (cross-polarized light).

List of Tables

Table 1. Calibrated radiocarbon ages of archaeological sites in the El Khiday area.

Table 2. Calibrated rediocarbon ages of shells from upper 12 cm of Jebel Baroka wetland.

Table 3. OSL ages, El Khiday and Jebel Baroka, lower White Nile valley, Sudan.

Lab. No.	**Feature**	**Material**	**Date bp**	**1 σ cal BP**	**2 σ cal BP**	**Cultural Period**
Beta-201728	16-D-5 SU6	Charcoal	7980 ± 40	8984-8776	8999-8700	Early Mesolithic
Beta-279538	16-D-5 SU250	Org.Sed.	7960 ± 40	8977-9727	8990-8649	Early Mesolithic
Beta-239622	16-D-5 SU455a	Charcoal	7940 ± 40	8971-8650	8981-8640	Early Mesolithic
Beta-213892	16-D-5 SU48	Charcoal	7870 ± 40	8716-8595	8953-8553	Early Mesolithic
Beta-239621	16-D-5 SU455b	Shell	7830 ± 40	8640-8555	8761-8538	Early Mesolithic
Beta-239619	16-D-4 SU6a	Shell	7760 ± 90	8626-8426	8780-8382	Middle-Mesolithic
Beta-239620	16-D-4 SU29	Shell	7770 ± 40	8395-8481	8627-8445	Middle-Mesolithic
Beta-257255	16-D-5 Peat	Org.Sed.	7740 ± 50	8560-8454	8597-8420	Middle-Mesolithic
Beta-213891	16-D-5 SU37	Charcoal	7710 ± 40	8540-8450	8580-8416	Middle-Mesolithic
Beta-279537	16-D-4 Pit 75	Shell	7640 ± 110	8551-8357	8645-8188	Middle-Mesolithic
Beta-257258	16-D-4 Pit 52	Shell	7620 ± 50	8454-8376	8539-8358	Middle-Mesolithic
Beta-279536	16-D-4 Pit 74	Shell	7600 ± 90	8518-8338	8582-8203	Middle-Mesolithic

Beta-257257	16-D-4B Pit 6	Charcoal	7540 ± 50	8404-8329	8423-8205	Middle-Mesolithic
Beta-279535	16-D-4 Pit 73	Shell	7530 ± 100	8415-8205	8548-8161	Middle-Mesolithic
Beta-318869	16-D-4 Pit 97	Shell	7510 ± 40	8387-8224	8400-8204	Middle-Mesolithic
Beta-318868	16-D-4 Pit 108	Shell	7430 ± 40	8312-8200	8345-8179	Middle-Mesolithic
Beta-385158	16-D-4 SU126d	Shell	7770 ± 30	8594-8523	8600-8455	Middle-Mesolithic
Beta-201726	10-W-4 US12	Charcoal	6490 ± 40	7438-7329	7476-7316	Late Mesolithic
Beta-361822	16-D-4 G158	Shell	5690 ± 30	6497-6415	6553-6405	Neolithic
Beta-302091	16-D-4 G103	Shell	5550 ± 80	6414-6281	6500-6188	Neolithic
Beta-213890	16-D-5 US5	Shell	5470 ± 50	6309-6210	6397-6184	Neolithic
Beta-302092	16-D-6 01	Shell	5360 ± 80	6274-6014	6295-5944	Neolithic

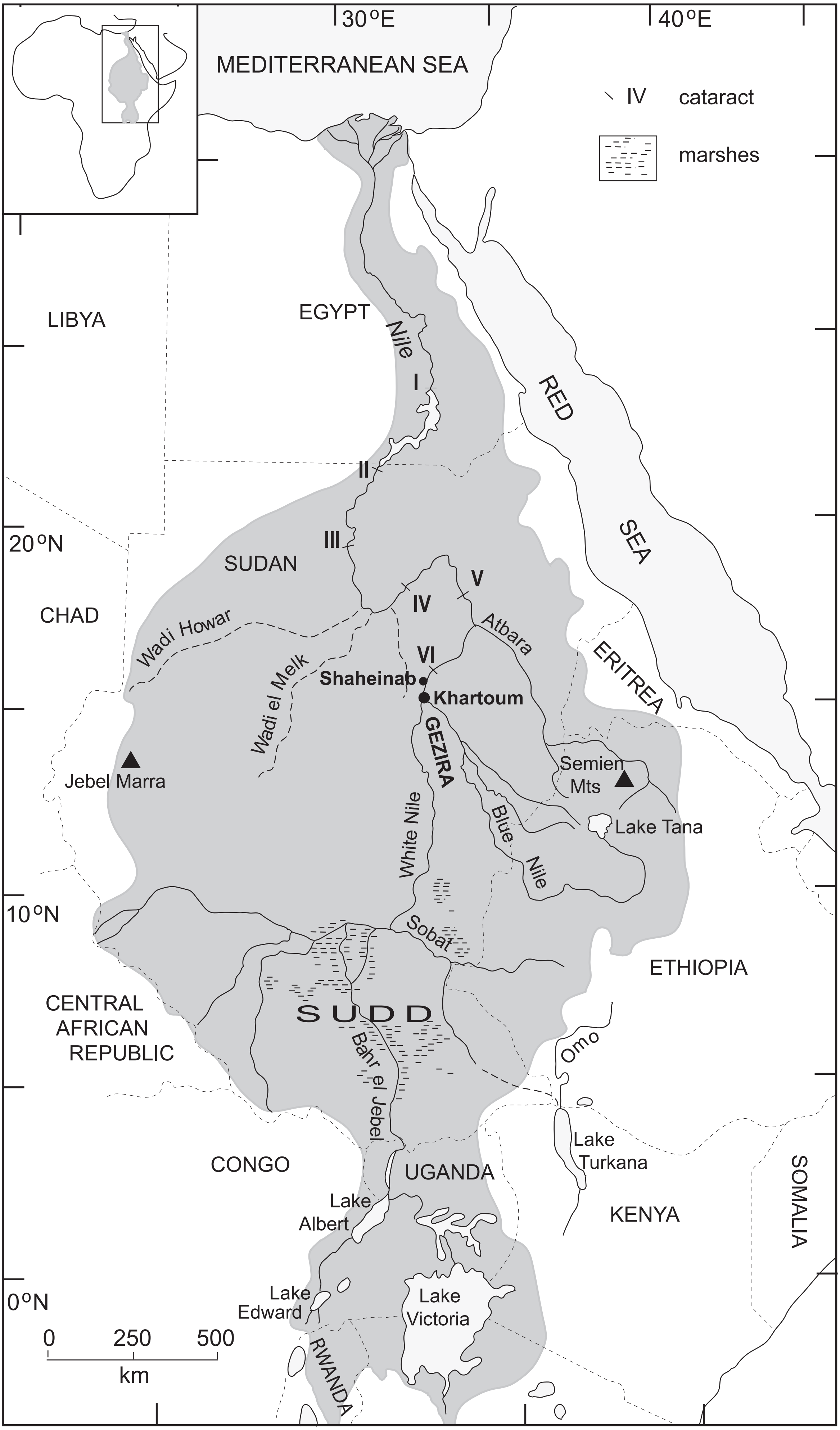
Table 1. ^{14}C ages of archaeological sites in the El Khiday area

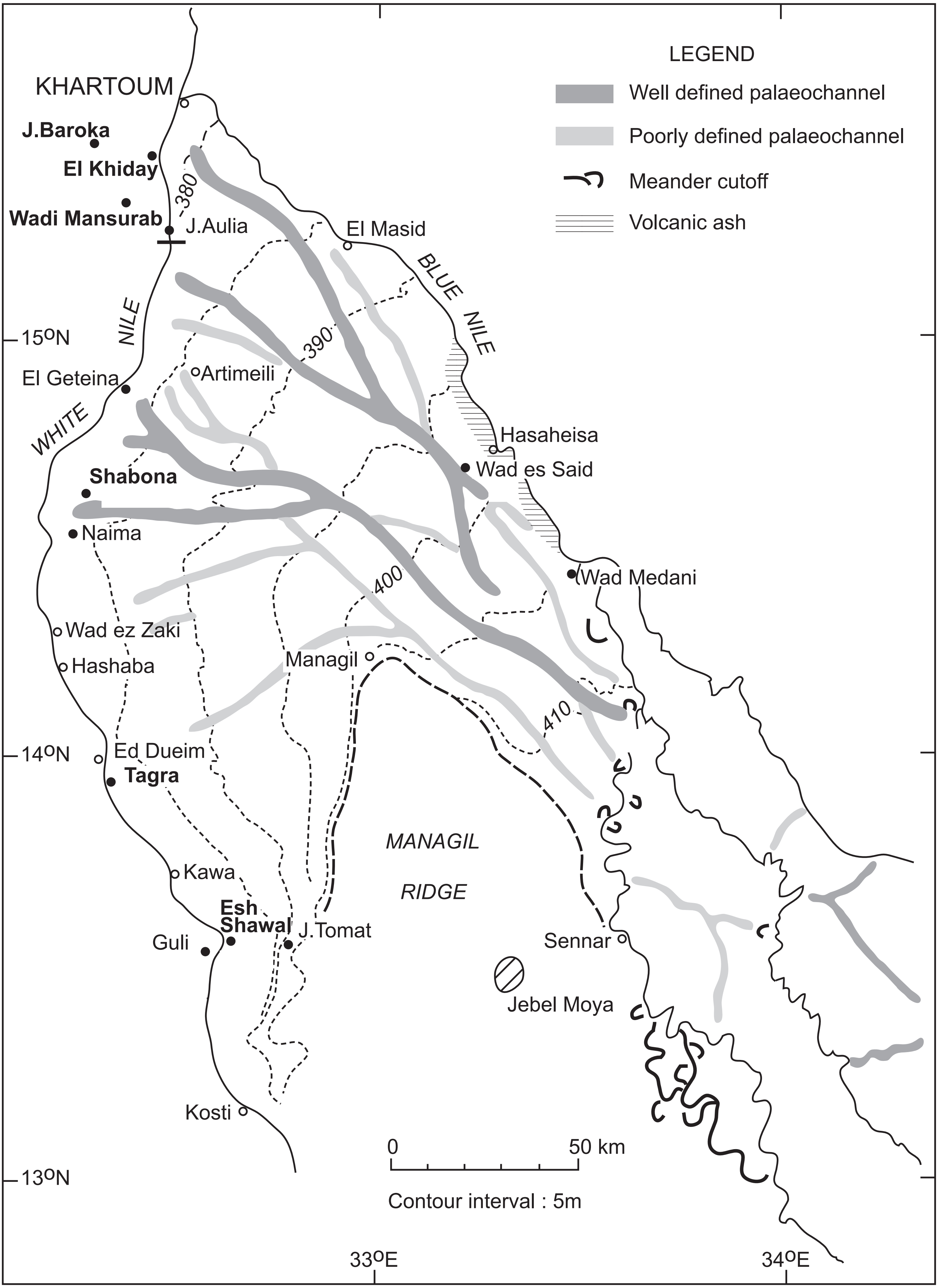
Sample	Lab. no.	Material	^{14}C age BP	1σ cal BP	2σ cal BP
EK11/4-1	Wk-33192	Shell	7719 ± 25	8540-8457	8554-8426
EK11/6-1	Wk-33191	Shell	6199 ± 25	7164-7026	7176-7002

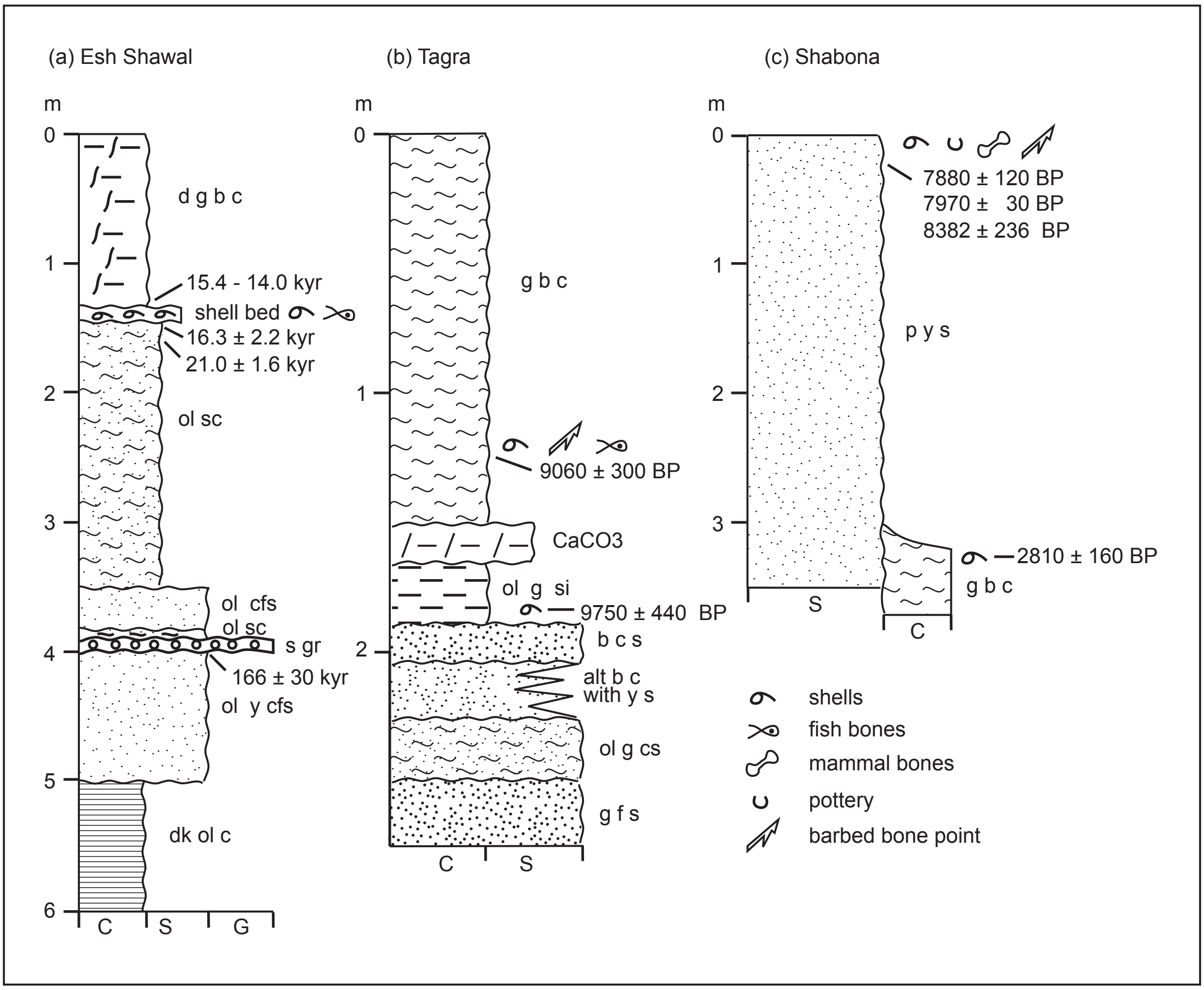
Table 2. AMS ^{14}C ages of shells from upper 12 cm of Jebel Baroka wetland

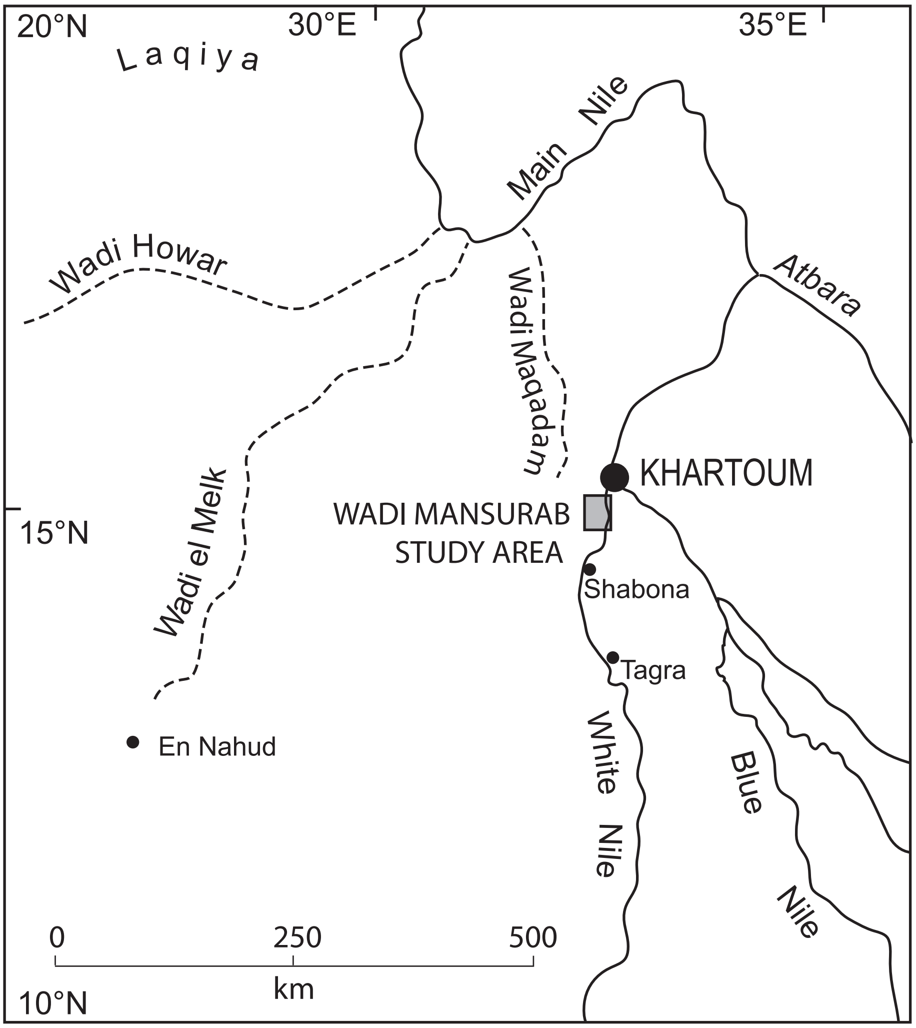
Field sample no	Laboratory no	Age kyr	Error
EK11/1-0	Ad12038	Modern	
EK11/1-1	Ad12039	8.7	± 0.7
EK11/1-2	Ad12040	42.5	± 4.9
EK11/1-3	Ad12041	64.7	± 18.8
EK11/1-4	Ad12042	61.2	± 6.1
EK11/1-5	Ad12043	49.4	± 10.0
EK11/2-1	Ad12044	9.6	± 0.8
EK11/3-1	Ad12045	8.1	± 0.7
EK11/3-2	Ad12046	8.6	± 0.7
EK11/4-1	Ad12047	6.6	± 0.5
EK11/4-2	Ad12048	10.0	± 0.7
EK11/4-3	Ad12049	35.6	± 2.8
EK11/5-1	Ad12050	Modern	
EK11/6-1	Ad12051	5.9	± 0.5
EK11/6-3	Ad12052	10.1	± 0.7
EK11/7-1	Ad12053	11.9	± 1.3
EK11/7-2	Ad12054	11.5	± 1.1

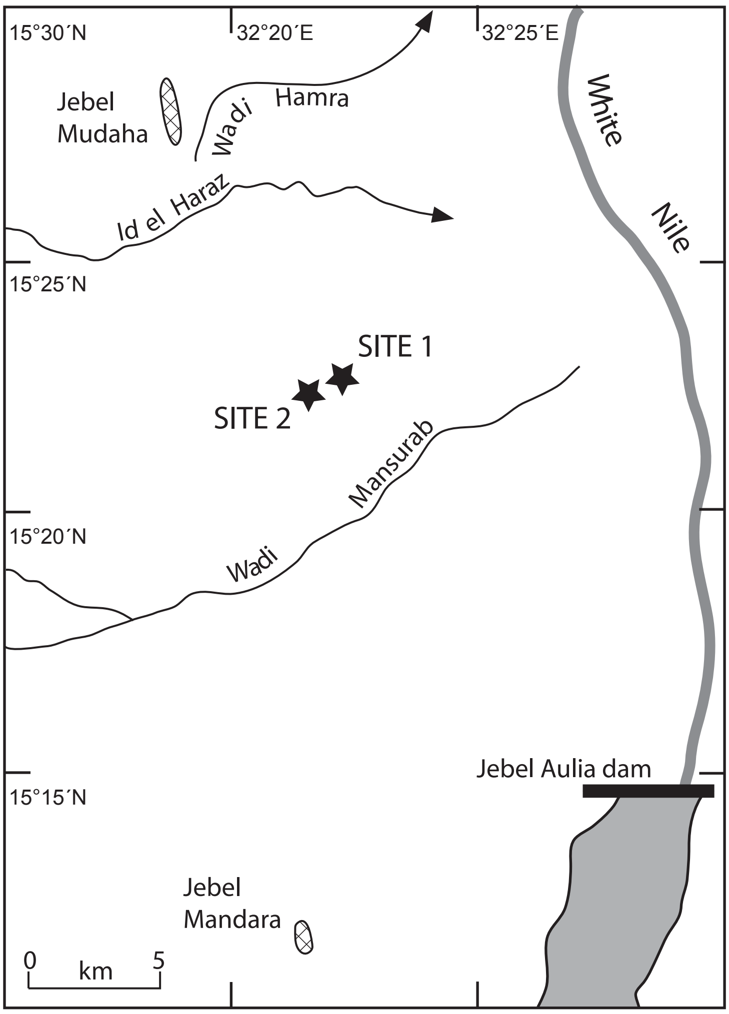
Table 3. OSL ages, El Khiday and Jebel Baroka, lower White Nile valley, Sudan.

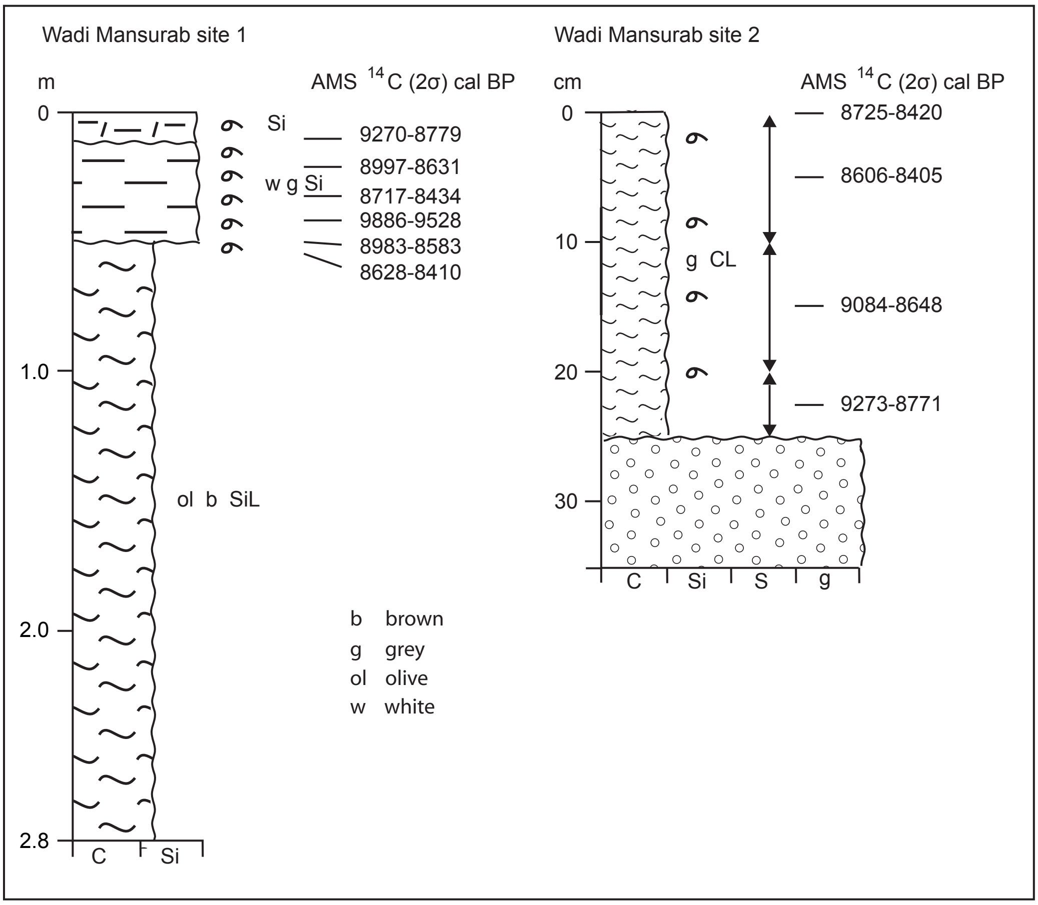

30ºE
40ºE
MEDITERRANEAN SEA
IV cataract
marshes
LIBYA
EGYPT
Nile
I
II
III
RED
SEA
20ºN
SUDAN
CHAD
V
IV
Atbara
Wadi Howar
Wadi el Melk
VI
Shaheinab
Khartoum
ERITREA
GEZIRA
Jebel Marra
Semien Mts
White Nile
Blue Nile
Lake Tana
10ºN
Sobat
ETHIOPIA
CENTRAL AFRICAN REPUBLIC
SUDD
Bahr el Jebel
Omo
Lake Turkana
CONGO
UGANDA
SOMALIA
KENYA
Lake Albert
Lake Edward
Lake Victoria
0ºN
0
250
500
km
RWANDA

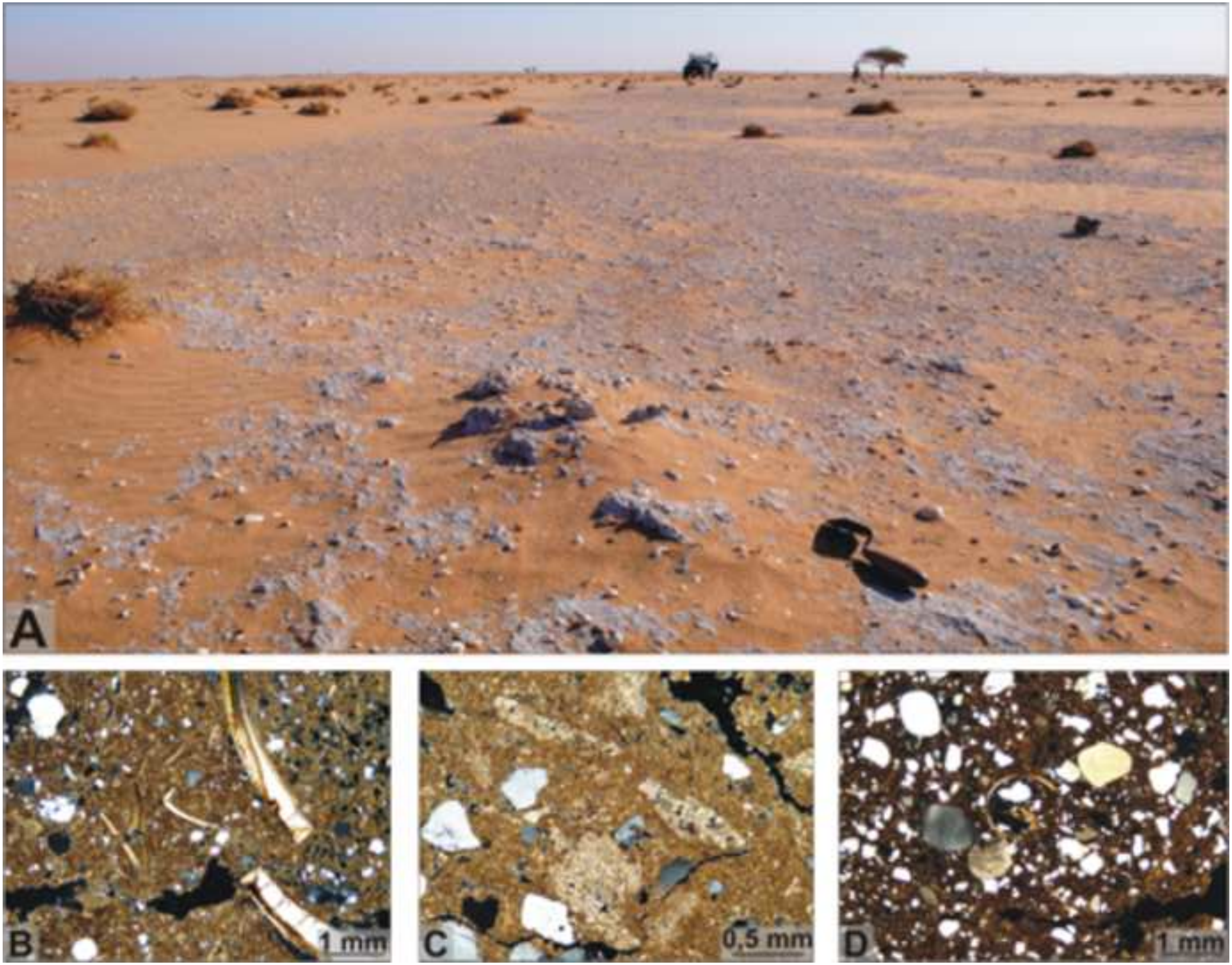

LEGEND
Well defined palaeochannel
Poorly defined palaeochannel
Meander cutoff
Volcanic ash
KHARTOUM
J.Baroka
El Khiday
Wadi Mansurab
J.Aulia
380
El Masid
BLUE NILE
WHITE NILE
15°N
390
Artimeili
El Geteina
Hasaheisa
Wad es Said
Shabona
Naima
Wad Medani
400
Wad ez Zaki
Hashaba
Managil
410
14°N
Ed Dueim
Tagra
MANAGIL RIDGE
Kawa
Esh Shawal
J.Tomat
Guli
Sennar
Jebel Moya
Kosti
0
50 km
Contour interval : 5m
13°N
33°E
34°E

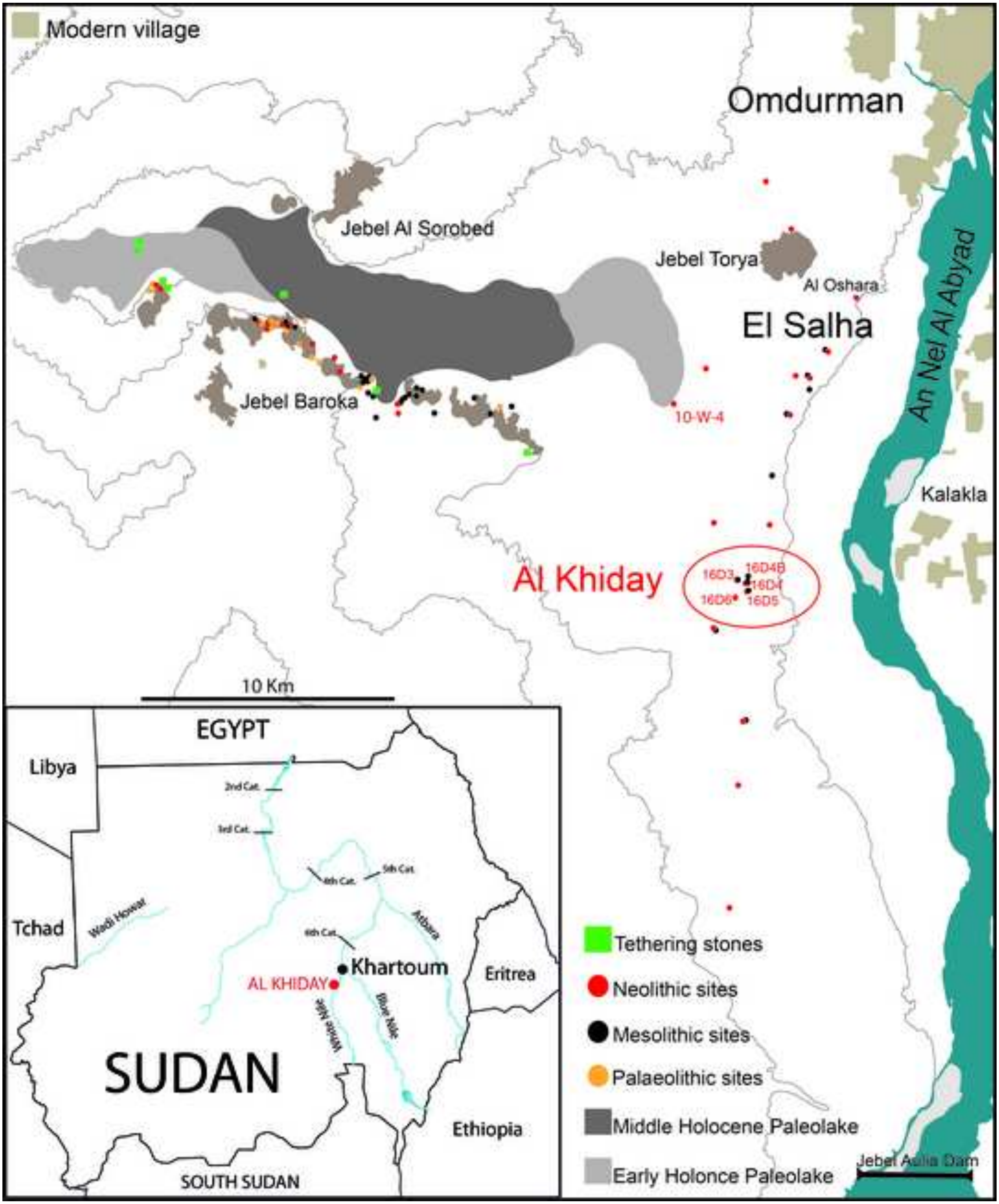

(a) Esh Shawal
(b) Tagra
(c) Shabona
m
0
1
2
3
4
5
6
d g b c
15.4 - 14.0 kyr
shell bed
16.3 ± 2.2 kyr
21.0 ± 1.6 kyr
ol sc
ol cfs
ol sc
s gr
166 ± 30 kyr
ol y cfs
dk ol c
C
S
G
g b c
9060 ± 300 BP
CaCO3
ol g si
9750 ± 440 BP
b c s
alt b c
with y s
ol g cs
g f s
C
S
7880 ± 120 BP
7970 ± 30 BP
8382 ± 236 BP
p y s
2810 ± 160 BP
g b c
S
C
shells
fish bones
mammal bones
pottery
barbed bone point

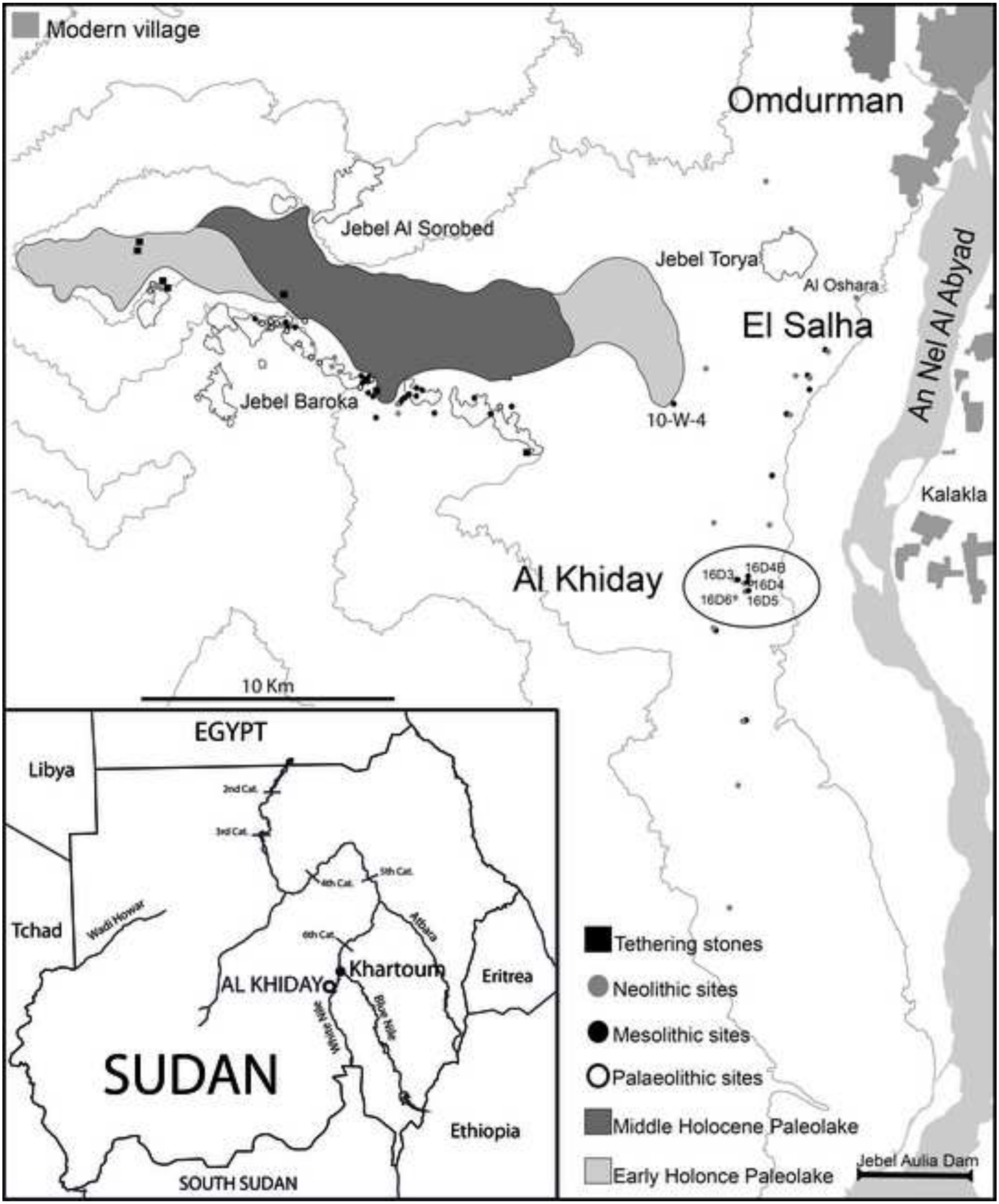

20°N
30°E
35°E
Laqiya
Main Nile
Atbara
Wadi Howar
Wadi Magadam
Wadi el Melk
KHARTOUM
WADI MANSURAB
STUDY AREA
15°N
Shabona
Tagra
White Nile
Blue Nile
En Nahud
0
250
500
km
10°N

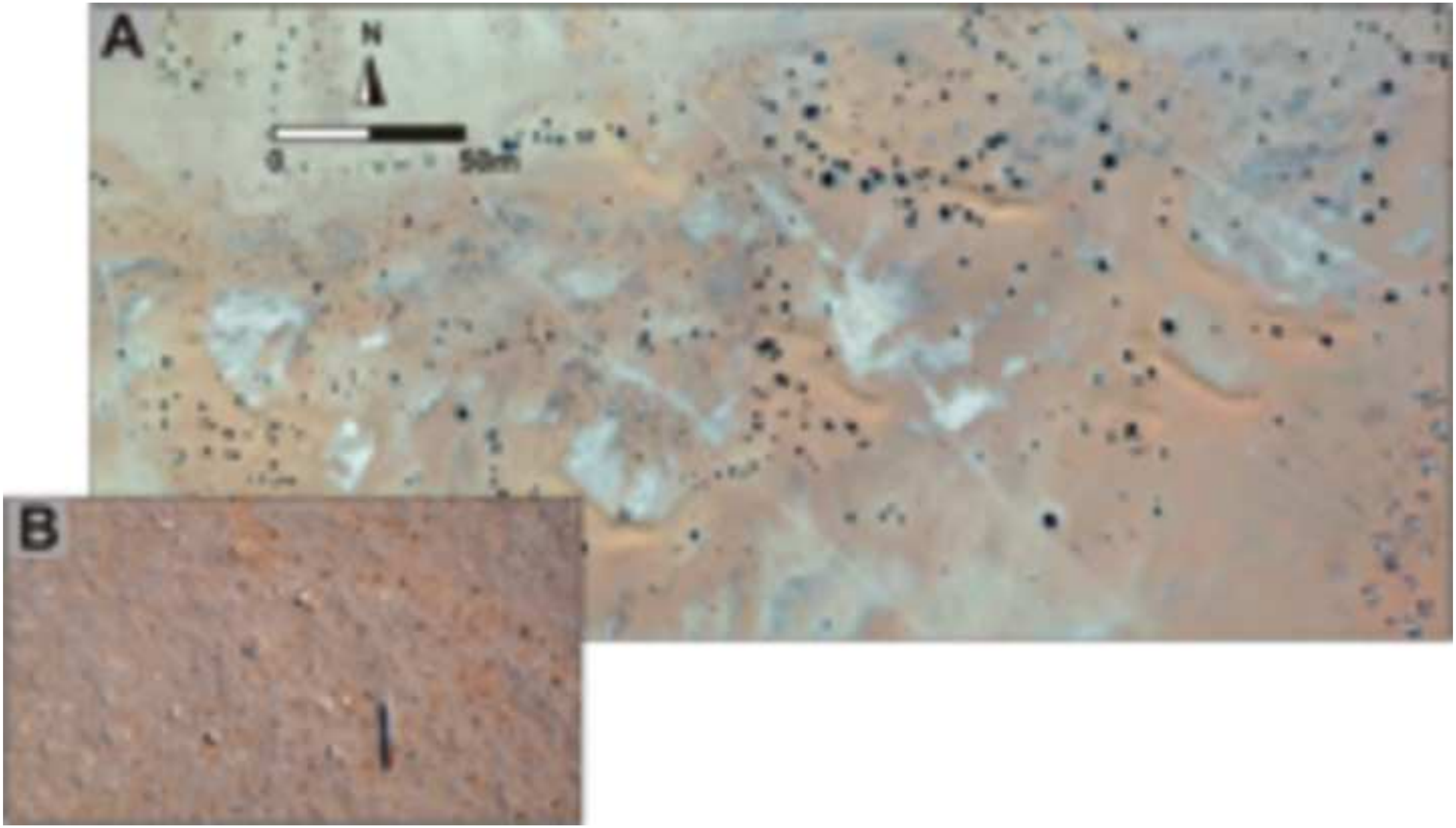

15°30´N
32°20´E
32°25´E
Jebel Mudaha
Wadi Hamra
White Nile
Id el Haraz
15°25´N
SITE 1
SITE 2
Wadi Mansurab
15°20´N
Jebel Aulia dam
15°15´N
Jebel Mandara
0 km 5


Wadi Mansurab site 1
m
AMS ^{14}C (2σ) cal BP
0
Si
9270-8779
8997-8631
w g Si
8717-8434
9886-9528
8983-8583
8628-8410
1.0
ol b SiL
2.0
2.8
C
Si
b brown
g grey
ol olive
w white
Wadi Mansurab site 2
cm
AMS ^{14}C (2σ) cal BP
0
8725-8420
8606-8405
10
g CL
9084-8648
20
9273-8771
30
C
Si
S
g


A
B
1 mm
C
0,5 mm
D
1 mm


Modern village
Omdurman
Jebel Al Sorobed
Jebel Torya
Al Oshara
El Salha
An Nel Al Abyad
Jebel Baroka
10-W-4
Kalakla
Al Khiday
16D3
16D4B
16D4
16D6
16D5
10 Km
EGYPT
Libya
2nd Cat.
3rd Cat.
4th Cat.
5th Cat.
6th Cat.
Atbara
Tchad
Wadi Howar
Khartoum
AL KHIDAY
Eritrea
White Nile
Blue Nile
SUDAN
Ethiopia
SOUTH SUDAN
Tethering stones
Neolithic sites
Mesolithic sites
Palaeolithic sites
Middle Holocene Paleolake
Early Holonce Paleolake
Jebel Aulia Dam


■ Modern village
Omdurman
Jebel Al Sorobed
Jebel Torya
Al Oshara
El Salha
An Nel Al Abyad
Jebel Baroka
10-W-4
Kalakla
Al Khiday
16D3
16D4B
16D4
16D6*
16D5
10 Km
EGYPT
Libya
2nd Cat.
3rd Cat.
4th Cat.
5th Cat.
6th Cat.
Atbara
Wadi Howar
Tchad
Khartoum
AL KHIDAY
White Nile
Blue Nile
Eritrea
Ethiopia
SUDAN
SOUTH SUDAN
■ Tethering stones
● Neolithic sites
● Mesolithic sites
○ Palaeolithic sites
■ Middle Holocene Paleolake
■ Early Holonce Paleolake
Jebel Aulia Dam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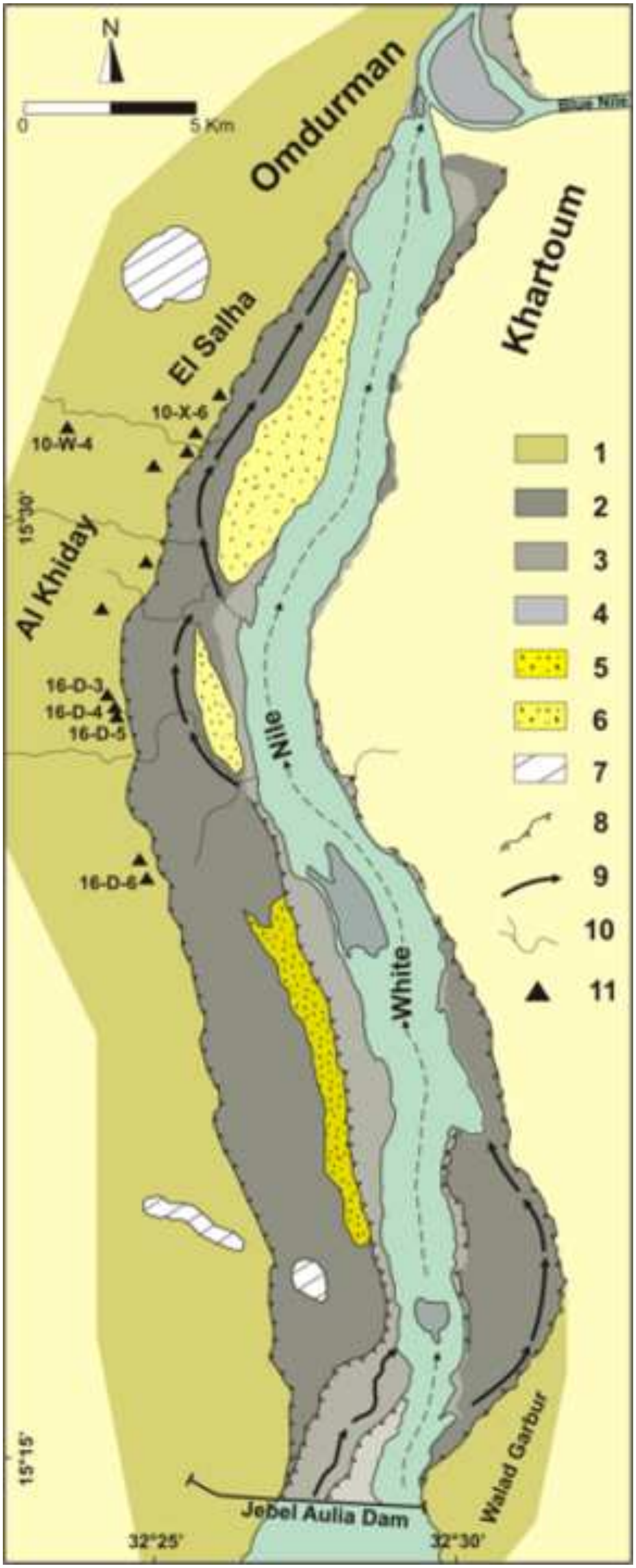
N
0
50m
B


N
0
5 Km
Blue Nile
Omdurman
Khartoum
El Salha
10-X-6
10-W-4
15°30'
Al Khiday
16-D-3
16-D-4
16-D-5
16-D-6
Nile
White
15°15'
Jebel Aulia Dam
Walad Garbur
32°25'
32°30'
1
2
3
4
5
6
7
8
9
10
11


A
B
1 mm
C
1 mm
D
1 mm