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Paleoclimatic and archeological implications of Pleistocene and Holocene environments in Azraq, Jordan

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ABSTRACT

Wetlands are a key archive for paleoclimatic and archeological work, particularly in arid regions, as they provide a focus for human occupation and preserve environmental information. The sedimentary record from 'Ayn Qasiyya, a spring site on the edge of the Azraq Qa, provides a well-dated sequence through the last glacial–interglacial transition (LGIT) allowing environmental changes in the present-day Jordanian desert to be investigated robustly through this time period for the first time. Results show that the wettest period at the site preceded the last glacial maximum, which itself was characterised by marsh formation and a significant Early Epipaleolithic occupation. A sedimentary hiatus between 16 and 10.5 ka suggests a period of drought in the region although seasonal rains and surface waters still allowed seasonal occupation of the Azraq region. Archeological evidence suggests that conditions had improved by the Late Epipaleolithic, about the time of the North Atlantic Younger Dryas. The changes between wet and dry conditions at the site show similarities to patterns in the eastern Mediterranean and in Arabia suggesting the Jordan interior was influenced by changes in both these regions through the LGIT climatic transition.

Introduction

Wetlands and their environs form important resource bases for hunting and gathering groups around the world (Nicholas, 1998) and also preserve critical paleoenvironmental archives of past climatic and environmental change. Studying the paleoenvironmental evidence in conjunction with archeological data from such localities provides critical insights into the relationship between human occupation, cultural change, subsistence, and settlement patterns alongside local effects of climatic and environmental change.

In southwest Asia, in particular, excavations at late Pleistocene sites have indicated the importance of wetland and lake settings to late hunter–gatherer groups prior to the advent of agriculture. Schuldenrein and Clark (e.g., 1994) have discussed Upper and Epipaleolithic site locations dotted along the shoreline of the former Lake Hasa, located to the east of the Dead Sea in southwest Jordan (Fig. 1). In a review of the Epipaleolithic occupation of the central Jordan valley, Edwards (2001) described the relationship of settlement with the Lake Lisan shoreline and the nature of the local archeological sequence there. The el-Kowm oasis in the Palmyra Basin in central Syria has a multitude of prehistoric sites (e.g., Cauvin and Couqueugniot, 1988; Tensorer et al., 2007) and the well-preserved Early Epipaleolithic site of Ohalo II on the southwest shore of the Sea of Galilee (Fig. 1) (e.g., Tsatskin and Nadel, 2003) demonstrates how critically important such lakeshore and wetland settings were and what multiple subsistence opportunities they provided. All these cases indicate that lakeshore and wetland settings formed important settlement locations during the Epipaleolithic period (23–11.7 ka; Maher et al., 2011), providing rich environments with numerous opportunities for human occupation. Monitoring these southwest Asian locations with respect to settlement patterns and changes in paleoenvironment can provide critical insights into localised landscape use and subsistence strategies.

The paleoenvironmental data for the late Pleistocene and Holocene from Jordan compared to surrounding regions is sparse and disjointed. To the north and west, lake level changes from Konya (Roberts, 1983) and Van (Landmann et al., 1996), in central and eastern Turkey, respectively, and the Dead Sea (Fig. 1) (e.g., Stein et al., 2010) have described dramatic changes from last glacial maximum (LGM) highstands to early Holocene drying. To the south, early Holocene lake highstands are reported from Arabia (e.g., Parker et al., 2006). These lake-level changes (Quade and Broecker, 2009), and evidence from other archives such as speleothems (Bar-Matthews et al., 2003) and lake isotope records (Roberts et al., 2008), have led to questions regarding potential changes in rainfall source area, and of precipitation amount and evaporation variability (e.g., Robinson et al., 2006; Enzel et al., 2008) in the eastern Mediterranean through the last glacial–interglacial transition (LGIT). Jordan, sitting geographically in between well-established paleoclimate records, and climatically between North Atlantic-Mediterranean

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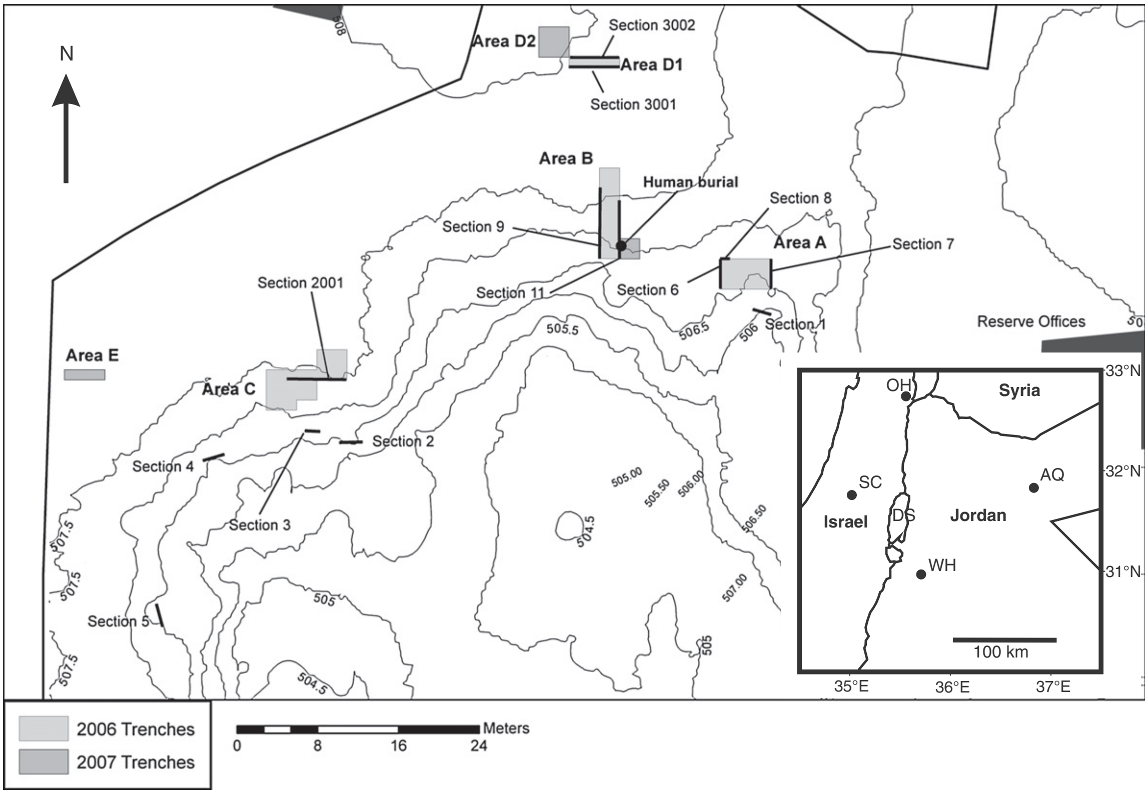

Figure 1. Site plan of 'Ayn Qasiyya excavations showing relative locations of trenches (Areas A–D) and stratigraphic sections (1–5; Fig. 2). Inset shows location of 'Ayn Qasiyya (AQ) relative to other major archeological (Ohalo II (OH), Wadi Hasa (WH)) and paleoclimate archives (Soreq Cave (SC), Dead Sea (DS)) discussed in the text.

and Asian Monsoon systems, potentially holds important information as to the timing, extent and cause of past climate events (cf. Roberts and Wright, 1993).

There is an apparent scarcity of Holocene sediments preserved in the Jordan desert interior. Davies (2005) describes sediments from the Qa' el-Jafr, in which the top 11-m unit has uncalibrated radiocarbon dates of 16,000 ± 140 ^{14}C yr BP and 24, 470 ± 240 ^{14}C yr BP. However, the top of this unit is undated and there are few significant shifts in the proxies so far analysed that would fit with late Pleistocene global climate changes. Other evidence for past climate change in Jordan is also largely Pleistocene in age. Moumani et al. (2003) describe lake marls from the Wadi Burma dated between 40 and 100 ka, although again the most recent sediments are undated. Schuldenrein and Clark (1994) show evidence of high lake stands between 26 and 20 ka in the Wadi el Hasa, as well as probably at around 70 ka. Holocene sediments in the Wadi el Hasa comprise largely riverine sands and gravels, but Schuldenrein and Clark (1994) suggest that most Holocene evidence has been removed by late Holocene erosion. Hunt et al. (2007) also describe Holocene river deposits from Wadi Faynan. There is therefore paleoenvironmental evidence of change over the late Quarternary at various locations across the Jordanian plateau, but the evidence is sparse in time and space.

Here we describe a sedimentary succession from 'Ayn Qasiyya, a spring site at the margins of the Qa' al-Azraq that spans the LGIT. The Azraq Basin occupies a central location in the eastern semi-arid to arid zone of the Transjordanian plateau (Fig. 1). Previous authors have discussed the possibility of an Azraq mega-lake at times past (e.g., Abed et al., 2008), although shoreline deposits such as those found for many of the Pleistocene mega-lakes to the north and west appear absent around the basin. The 'Ayn Qasiyya site shows extensive evidence of Early and Late Epipaleolithic, as well as early Neolithic, occupations and contains artefacts spanning from the Middle Paleolithic to recent times. Radiocarbon and optically stimulated luminescence (OSL) dating confirms that the sequence contains late Pleistocene and Holocene sediments and allows us to investigate changes in this marginal wetland site at a number of key times during this important transitional period and to add to an emerging regional picture of both cultural and climate change.

Study area

The Azraq basin encompasses a series of wadi tributaries and a low depression totaling ca. 12,000 km^2 in extent. At its lowest point (ca. 500 m.a.s.l.) a number of groundwater fed springs created the Azraq Oasis. Until the early 1990s the oasis consisted of two spring systems that supplied extensive marshlands, providing a unique habitat for migratory bird species, other wildlife and a diverse plant community (Nelson, 1973; Garrard, 1998). The smaller wetland of north Azraq covered an area of approximately 1.8 km^2, while the southern marshes extended across ca. 5.6 km^2 (Nelson, 1973). With an average of 84 mm of rainfall per year, present-day precipitation in the Azraq Oasis is low, but around the Jebel Druze area toward the northwestern edge of the basin it reaches ca. 200 mm/yr. Despite the scarcity and unpredictability of rainfall, the aquifers' low discharge-to-replenishment ratio resulted in a more or less permanent supply of water even in the face of environmental and climatic change (Macumber, 2001). Following winter and early spring rainfalls, surface water runoff is also available and results in the flooding of an extensive seasonal playa (Qa) to the south and east of the springs. The principal Azraq Qa can flood to a depth of 2 m and can extend to ca. 50 km^2 in wetter years (Nelson, 1973; Garrard and Byrd, 1992). The principal geology of the region consists of Cretaceous and Tertiary chalky limestone that contains abundant sources of tabular and nodular flint. It is overlain to the north and northeast by Oligocene basalt and tuffs (Bender, 1974).

The Azraq springs are fed from the upper of 3 aquifers in the Azraq basin (El-Naqa et al., 2007). The upper aquifer is largely recharged from rainfall on the high grounds of southern Syria as well as through

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infiltration from winter rains and flash floods across the basin, and the current recharge is estimated at between 25 (Al-Kharabsheh, 2000) and 34 million m^3/yr (MCM/yr) (El-Naqa et al., 2007), with infiltration rates estimated between <2 and 3% (Al-Kharabsheh, 2000 and Abdulla et al., 2000, respectively). Estimates of residence time in the upper aquifer range between 4 and 20 ka (El-Naqa et al., 2007). Prior to significant water extraction beginning in 1981, the combined discharge from the Azraq springs was around 15 MCM/yr (El-Naqa et al., 2007) but since 1981 groundwater levels for the upper aquifer have fallen between 0.3 and 0.8 m/yr (Bajjali and Al-Hadidi, 2005) with the major springs, including 'Ayn Qasiyya, drying up in the early 1990s. From spring discharge data (Bajjali and Al-Hadidi, 2005) and groundwater levels (El-Naqa et al., 2007) there appears to be a clear relationship between groundwater level in the upper aquifer and spring discharge in the Azraq springs, including 'Ayn Qasiyya.

Following preliminary investigations in the Azraq Basin by Waechter et al. (1938), Zeuner et al. (1957) and Field (1960), research into the Pleistocene and early Holocene human occupation of the Azraq Basin intensified during the late 1970s and 1980s (see Richter et al., 2010a for references). This series of investigations has revealed a well-established regional sequence of final Pleistocene occupations, which appears to indicate a relative continuity of settlement from ca. 20 to 11.5 ka.

'Ayn Qasiyya (31°50.041′N, 36°49.089′E) is the second largest spring in the southern Azraq marshlands (Fig. 1). It is situated ca. 150 m north of the largest south Azraq spring, 'Ayn Soda, where a number of prehistoric sites were found by Rollefson et al. (1997). The archeological sediments at 'Ayn Qasiyya were spotted in the north wall of a pool that was excavated in the modern era around the spring head for water extraction. Rollefson et al. (2001) described two separate localities, the first located in the eastern part (Locality I) of the northern wall, the second located in the western part (Locality II). From Locality II Rollefson et al. (1997) reported the recovery of Middle Paleolithic artefacts from the base of the standing section, as well as a microlithic assemblage from a deposit ca. 50 cm above this layer. At Locality I, further microlithic artefacts, some of which were geometric, were collected. The results reported here formed part of a series of excavations between 2005 and 2007 that aimed to understand in detail this potentially important Epipaleolithic site (see also Richter et al., 2007, 2010a,b, 2011).

Methods

Five sections through the sedimentary succession were described from the edge of the 'Ayn Qasiyya pool to place the excavation trenches in a wider environmental context (Fig. 1). We relabelled Rollefson et al.'s (2001) Locality I as Section 1, and Locality II as Section 4 to create a continuous sequence of sections.

Contiguous samples were taken through Section 1 to allow for sedimentological analysis. Subsamples were gently disaggregated with a pestle and mortar and fully air dried. Using a Bartington MS20B sensor, 18 ml of each sample was used for magnetic susceptibility measurements. These samples were then used to perform volume specific Loss on Ignition (LOI) following Dean (1974). For particle-size analysis, disaggregated samples were sieved at 1.4 mm; ~0.5 g of the <1.4-mm fraction was placed in 25 mm of 30% H_2O_2 to further disaggregate the sediment and remove any organic material, prior to grain-size analysis using a Coulter® LS230 analyser.

For radiocarbon dating, individual charcoal fragments were identified to genus level and samples chosen from short-lived species where possible to reduce chronological errors from long-lived species (Table 1). Samples were dated at the Poznan and Oxford radiocarbon laboratories.

Where possible, samples were taken for OSL dating by cutting intact blocks of silt from the sections (Fig. 2). One sample (J13) was taken by hammering an opaque tube into the sediments as they were not suitably consolidated. OSL dating was undertaken at the Sheffield Centre for International Drylands Research. For estimation of the dose rate concentrations of U, Th, Rb and K were determined by inductively coupled plasma mass spectrometry at SG laboratories, Ontario, Canada. Elemental concentrations were converted to annual dose rate using data from Adamiec and Aitken (1998), Marsh et al. (2002) and Aitken (1998), taking into account grain size, density and paleomoisture. A moisture value of 10 ± 5% was taken for all samples as the units are known to have dried out since deposition. Samples for paleodose determinations were prepared under subdued red lighting following Bateman and Catt (1996). Samples came from the size range 90–250 μm and were analysed using the single aliquot regenerative (SAR) approach (Murray and Wintle, 2000) using an upgraded Riso TL DA-12 luminescence reader with radiation doses administered using a calibrated strontium-90 beta source. A 150 W filtered halogen lamp provided the stimulation and luminesence was detected using a Hoya U-340 filter. Up to 24 replicate aliquots were analysed for each sample to give an indication of error and to assess sample bleaching behaviour. Checks using infrared stimulated luminescence found no evidence of feldspar contamination. Following a dose recovery preheat plateau test, preheat temperatures of 200°C were applied to each sample for 10 s prior to OSL measurement to remove errors due to laboratory irradiation.

Results and interpretation

Stratigraphy

The sedimentary record at 'Ayn Qasiyya is split into 5 major stratigraphic units based on visual descriptions in the field from the sections (Fig. 2) and trenches (Areas A–D; Fig. 1) as well as dating evidence (see below). Sections 1 and 4 show a similar stratigraphy to that observed in Areas A and B, whereas Sections 2 and 3 relate to the stratigraphy of Area C. The stratigraphic succession in Section 5 was not observed in any of the archeological trenches. Below, each of the sedimentary units is described in turn.

Table 1
Radiocarbon dates from 'Ayn Qasiyya. Radiocarbon ages are calibrated using Calib 6.0.1 (Stuiver and Reimer, 1993) and Intcal09 (Reimer et al., 2009).

Lab. number	Trench or section	Archeological context	Sedimentary unit	Charcoal type	^{14}C Age (^{14}C yr BP)	Calibrated age (cal yr BP)
OxA 18829	Section 1	56	III	Amygdalus	17,550 ± 75	20,490–21,310
OxA 18830	Section 1	56	III	Amygdalus	17,490 ± 75	20,440–21,260
OxA 18832	A	60	III	Amygdalus	17,500 ± 70	20,450–21,260
OxA 18831	A	80	III	Chenopodiaceae	17,560 ± 75	20,500–21,310
Poz-33101	A	81	III	Chenopodiaceae	19,690 ± 150	22,960–23,980
Poz-33103	B	1008	III	Tamarix	16,960 ± 110	19,820–20,420
Poz-33104	C	2001	IV	Tamarix	9060 ± 60	10,150–10,410
Poz-33105	C	2006	IV	Tamarix	8800 ± 60	9610–10,150
OxA 18833	C	2011	IV	Chenopodiaceae	9200 ± 40	10,250–10,490
Poz-33106	D	3004	III	Tamarix	16,080 ± 100	18,920–19,430

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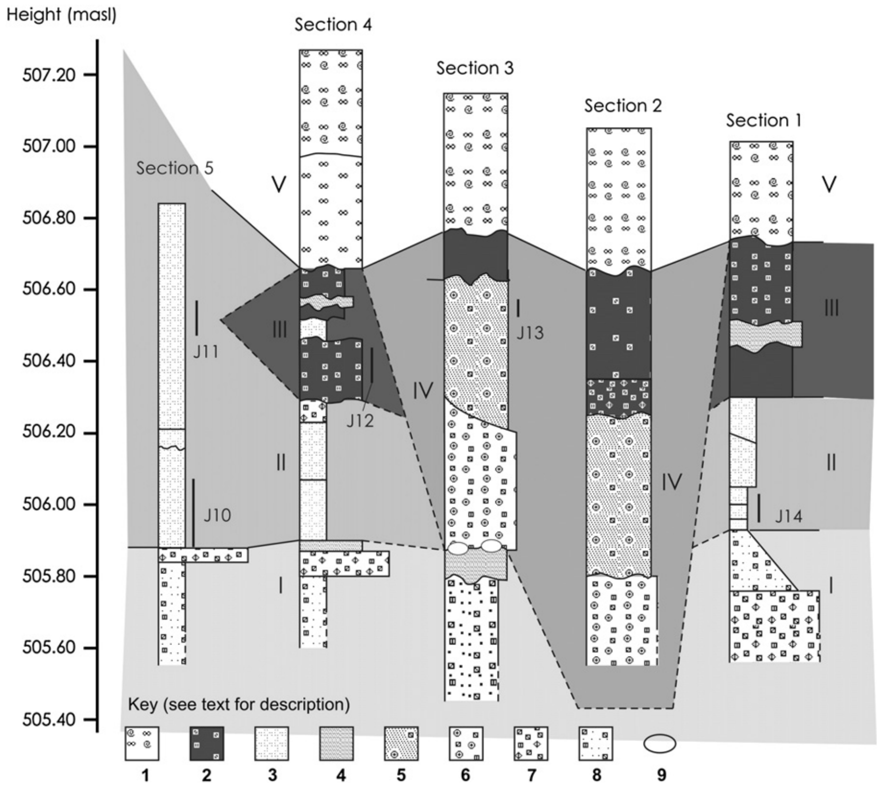

Figure 2. Stratigraphy of the 5 'Ayn Qasiyya sections showing OSL sample locations (J10–J14). See text for descriptions of each unit (I–V). Stratigraphic key: 1. Creamy-colored hard "top soil" containing numerous snail shells and carbonate concretions. 2. Black to dark gray organic-rich, sandy to silty soil containing large clasts of (> 5 cm) flint and bone. 3. Clay to silty clay. 4. Fine sand and sand. 5. Dark gray silty sand containing occasional large clasts (>5 cm) of bone and flint. 6. Clast supported gravel composed of flint and bone with a silty sand matrix. 7. Gravel composed of flint with a sand or clay matrix. 8. Light green clay and fine sands containing clasts of flint (2–10 cm). 9. Basalt balls.

Unit I

The basal unit of Sections 1, 3, 4 and 5 all contain large, unworked flint clasts (1–5 cm), within light green silty clays. The presence of the clasts suggests an environment with sufficient energy nearby, possibly a river, to move this material into an open water environment represented by the silty clays.

Unit II

This unit is composed largely of green silty clay visible in Sections 1, 4 and 5. At the base of Unit II in Section 1 are three red silty sand layers (Fig. 2) showing distinct surfaces in which root or stem holes can still be seen. These red sandy layers represent at least 3 wetting and drying phases at the site, although they are not visible in any of

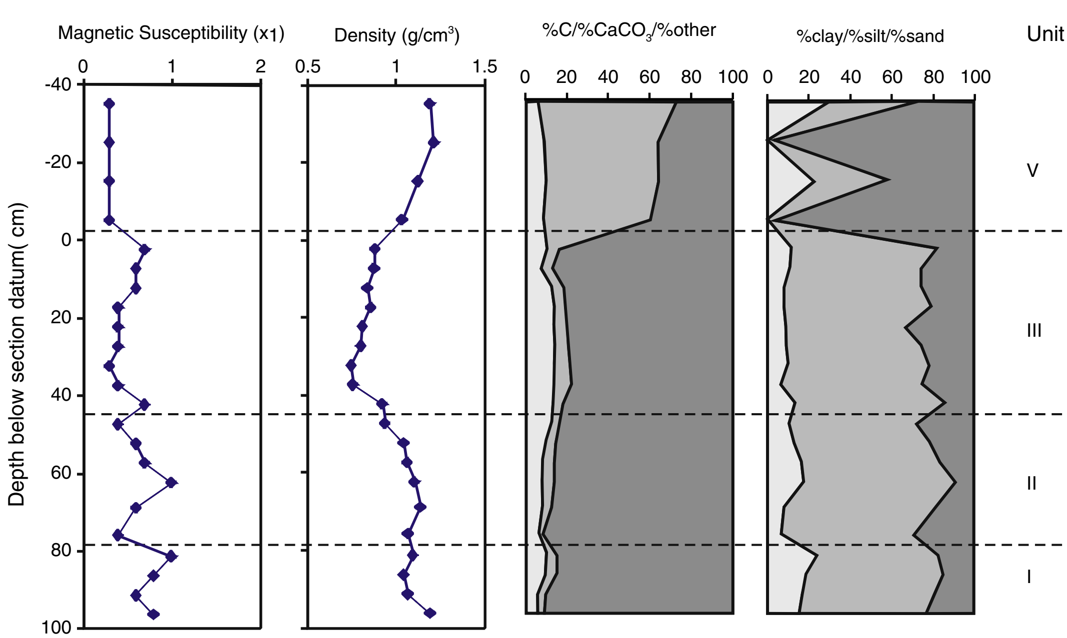

Figure 3. Sediment data from Section 1 showing change in magnetic susceptibility, sediment density, change in organic and inorganic carbon content and matrix grain size through Units I, II, III and V.

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the other sections. The rest of Unit II, which is archeologically sterile, represents calm, open-water conditions. The gradual increase in organic carbon content and grain size (Fig. 3) towards the top of the unit in Section 1 suggests a gradual transition into Unit III.

Unit III

This is a dark, organic-rich deposit containing large numbers of archeological artefacts, particularly flint and bone. Although clearly visible in Sections 1 and 4 there is no evidence of this unit in Section 5, where Unit II extends to the base of Unit V (see further discussion below). The organic nature of this deposit (Fig. 3) suggests a shallower water environment compared to Unit II. It is not laterally continuous across the site and it appears that open-water conditions persisted at Section 5, or that there was some local erosion into Unit II prior to the deposition of these marsh deposits at Sections 1 and 4.

Unit IV

Although at a similar height this unit is much less organic and much coarser than Unit III. There are clear channel shapes within this unit in Section 3 and in Area C. This unit appears to be river deposits of sand and gravels, with larger material, particularly found towards the base of Section 3 and in parts of Area C, which included rounded "balls" of basalt decimetres in size, suggesting possible flood events. The top of Unit IV is similar in appearance to the top of Unit III suggesting a return to marsh deposits following the river deposition.

Unit V

This hard, creamy-colored unit, containing carbonate concretions and snail shells, caps the entire site. The presence of concretions suggests an environment with regular wetting and drying, with relatively warm conditions. The rapid transition from Unit III into Unit V (Fig. 3) suggests there may have been a hiatus in deposition at this point of the sequence. The drop to negligible magnetic susceptibility values (Fig. 3) suggests there is little disturbance of the site during the deposition of this unit, so any water is probably from the spring and rainfall only rather than from any inflowing rivers or flood events.

Fauna

The details and archeological significance of the faunal remains found at 'Ayn Qasiyya will be discussed elsewhere. However, the species present in Unit III, from Area A, include porcupine, water vole, gerbil, hare, fox and wolf/jackal as well as high numbers of cattle and boar, which are unusual for a steppic Epipaleolithic assemblage (Richter et al., 2010a), adding to the interpretation of this unit as a marshland or lake-edge environment. The majority of the faunal material retains fresh, spiky edges, suggesting that the material was not rolled post-depositionally. Bone surface modification is also largely absent (Richter et al., 2010a). Both of these observations indicate that the faunal assemblage appears to be in situ and was buried gradually in a low-energy setting.

Lithic artefacts

A principal component of Unit III is worked flint. Worked stone artefacts have long been used in the discussion of site formation processes (e.g., Hull, 1987; Schick, 1987) and as such provide a further proxy to discuss the formation of the marsh sediments at the site. The principal observations resulting from a comprehensive analysis of more than 40,000 individual pieces of chipped stone from areas A, B and D, suggest that the three assemblages from the Early Epipaleolithic horizon show a high degree of technological and typological conformity (Richter et al., 2007, 2010a). Dominated by variously backed and retouched bladelets they can be clearly assigned to the Early Epipaleolithic. No intrusive elements were observed in the lithic assemblages in these areas, which contrasts sharply with the worked stone assemblage recovered from Area C. This material represents a highly mixed assemblage, containing Early and Late Epipaleolithic, as well as Pre-Pottery Neolithic B (10.4 to 9 ka; Maher et al., 2011) diagnostic tools, cores and debitage. This suggests that the principal archeological horizons in this area represent episodes of erosion.

More detailed analysis of the Area A, B and D assemblages provides further insights into site formation processes. Mass classification of debitage as well as size measurements provide a clear indicator that micro-debitage and small debitage are well-represented in the sample. Table 2 details the overall lithic artefact count, showing a high representation of flakelets (defined as complete pieces of debitage between 10 and 20 mm in size) and chips/shatter. The presence of this micro- and small debitage strongly indicate in situ knapping activities. On the basis of experimental work carried out by Schick (1987), the presence of such small debitage closely resembles undisturbed experimentally produced assemblages, suggesting that little post-depositional disturbance or removal of artefacts occurred. If such a scenario had occurred, small and micro-debitage should be underrepresented.

A last site-formation indicator accessible from the lithic artefact assemblages is surface condition and damage. Figure 4 demonstrates the overall lack of either edge damage, rolling/abrasion or re-patination of the flint assemblage. Instead, the overwhelming majority of the artefacts were judged to be 'fresh' with sharp edges and ridges that indicate little lateral movement has occurred. The lack of re-patination suggests that burial of the site was relatively rapid and that no disturbance or exposure of the site has occurred since deposition. The results from the lithic analysis closely match those from the faunal analysis, suggesting that the site was gradually buried in a low-energy depositional environment, which can be associated with a lake-margin setting.

Chronology

All the dating evidence from the site is summarised in Table 3. Archeological finds provide minimum ages for some of the sedimentary units. Middle Paleolithic artefacts were found at the top of Unit I in Section 4. Although these finds are likely to be residual, they nevertheless suggest that this unit is unlikely to date to much younger than ca. 30–40 ka. In Unit III the Early Epipaleolithic artefacts appear to be in-situ (see discussion above). The mixture of artefacts found in Unit IV in Area C represent a mixture of Early and Late Epipaleolithic, as well as PPNB artefacts, suggesting a minimum 10.4 to 9 ka age. Unit V contains a mixture of prehistoric, historic and modern artefacts.

Table 1 outlines the radiocarbon results from analysed charcoal. All dates from Unit III, from Section 1 and Areas A, B and D, give similar late Pleistocene dates of around $21{,}000 \pm 2000$ cal yr BP. Charcoal from Area C gives an early Holocene age of around 10,000 cal yr BP for Unit IV. These radiocarbon ages fit with the dating of the units suggested by the archeological finds.

Two of the OSL ages (J12 and J13; Fig. 2) give clear paleodose rate readings from multiple aliquots (Fig. 5). The other three samples show a wider range in paleodose determinations. Samples J10 and J14 contained saturated aliquots: 11 of 20 for J10 and 4 of 20 for J14. Age determinations from these samples are therefore taken as minimum possible ages. Sample J11 shows a bimodal distribution of paleodose

Table 2
Composition of the chipped stone from 'Ayn Qasiyya (after Richter et al., 2010a).

	Total samples	Percentage				
		Cores	Primary	Debitage	Chips	Retouched
Area A	8265	0.30	0.44	32.93	62.87	3.46
Area B	10,756	0.27	0.45	57.05	38.77	3.47
Area D	21,725	0.17	0.32	36.44	58.56	4.50
Total	40,746	0.25	0.4	42.14	53.4	3.81

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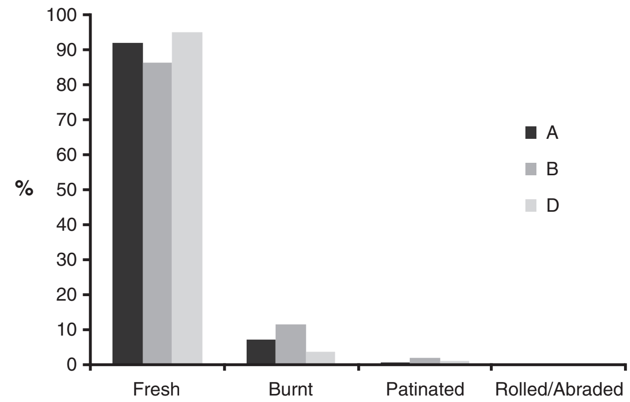

Figure 4. Distribution of lithic edge types from areas A, B and D.

determinations (Fig. 5) suggesting that the sample was not fully bleached prior to burial or has undergone some post-depositional disturbance. Using the finite mixture model (Galbraith and Green, 1990) two major De components were identified (Fig. 5; Table 4). Even given the possible errors due to saturation, samples J10 and J14 give age estimates (Table 4) consistent with the other dating evidence from the site, namely that Unit II is of late Pleistocene age, older than Unit III (i.e., older than 24 ka). The older age estimate for J11 (16.9 ± 1.1 ka) also fits with the general site pattern, given that stratigraphically Unit II continues into the late Pleistocene (Section 5) alongside the marshland of Unit III (Sections 1 and 4).

J13 gives an age that matches the early Holocene age of Unit IV as determined by the archeological and radiocarbon evidence (Table 3), which would therefore place Unit V into the late Holocene. Although there are no direct dates from this unit at 'Ayn Qasiyya, an OSL age determination from this unit from 'Ayn Soda (Cordova et al., 2008) corroborates this late Holocene age (see below). The age estimate from sample J12, 2.72 ± 0.2 ka, does not seem to fit with the stratigraphy of Unit III or with the other dating evidence of the site. The paleodose determinations for this sample show a clear, tight peak (Fig. 5); however, uranium concentrations are high in this sample (54.1 ppm; Table 4) and it is possible that uranium has moved into this unit through time and that the calculated dose rate is therefore much higher than it has been for much of the depositional history of the unit. It is also possible the sample was re-bleached at some point, although great care was taken when sampling and transporting the sample. Whatever the reason, we suggest there may be issues with this age determination given the evidence from the rest of the site and we still assume that Unit III has a late Pleistocene age.

Table 3
Chronological summary for the 'Ayn Qasiyya sedimentary units.

Stratigrahic unit	Environment	Chronological control			
		Artefacts		Dating	
		Evidence	Age (ka)	Evidence	Age (ka)
I	Shallow water	Middle Pal.	45–60		
II	Open water			OSL	16–65 (3 dates)
III	Marsh Cool	Early Epipal.	22–17	Radiocarbon OSL	24–19 (7 dates) *(2.7)*
IV	Channel fill ? Floods	Early Epipal. Late Epipal. PPNB	9–6	Radiocarbon OSL	11.3–9.5 (3 dates) 6.4
V	Marsh Warm	Historic–modern			Holocene

'Ayn Qasiyya and the local stratigraphic framework

A number of other spring deposits have been investigated, primarily for their archeological evidence, in and around South Azraq. Rollefson (1982) described the stratigraphy from excavations around Ain El-Assad, 1.4 km southwest of 'Ayn Qasiyya. The surface units here are tannish brown soils with a sandy silt texture. Dark, organic units between 1.25 and 2.25 m depth contained four pieces of worked flint that suggested a PPNB or Pottery Neolithic date. The upper parts of this unit contained carbonate nodules. Below this unit, between 2.25 and 3 m depth is a greenish gray marl, attributed by Rollefson to the Pleistocene, with a gradual transition between the marl and the overlying darker sediments. Some Upper Paleolithic artefacts were found in this clay layer. Below this layer, between 3 and 3.5 m depth, is a light olive green sand, which was culturally sterile. The base of the section, at 3.5 m, was bedrock.

At C-Spring, 1.5 km south of 'Ayn Qasiyya, Hunt and Garrard (1989) describe carbonate nodules in the lower parts of an upper section (0–1.5 m depth) of silty fine sands, interpreted as windblown deposits, that contain a Pre-Pottery Neolithic assemblage. Between 1.5 and 2.5 m there are greenish gray compacted silts with columnar jointing, with a calcrete horizon at around 2 m depth. The silts above the calcrete are attributed to the Upper or Epi-Paleolithic. Hunt and Garrard (1989) interpret these greenish gray silts as marsh deposits, although the description matches that of 'Ayn Qasiyya Unit II, interpreted here as open-water deposits. Between 2.5 and 3.1 m at C-Spring there is a series of blue-gray sandy silts thought to date from the early to middle Paleolithic and below this, at the base of the section, are clast-supported gravels with a gray sand matrix.

The stratigraphy from C-Spring and Ayn El-Assad are very similar to that described at 'Ayn Qasiyya, although there is no organic unit at C-Spring, as in Section 5 at 'Ayn Qasiyya. Apart from archeological finds, there is very little chronological information from these sites. Those available suggest that the organic units at 'Ayn El-Assad may be younger than those at 'Ayn Qasiyya, possibly associated with Unit IV at 'Ayn Qasiyya. The green silty clays at all three sites seem to date from the Epipaleolithic or older, and the OSL dates from 'Ayn Qasiyya confirm a probable Pleistocene, but pre-LGM, age for most of these units.

Further chronological control for the Azraq stratigraphy is available from 'Ayn Soda, approximately 100 m south of the 'Ayn Qasiyya sections (Rollefson et al., 1997; Cordova et al., 2008). The top-most units are carbonated silt deposits, similar to those found on the surface of 'Ayn Qasiyya. An OSL date of 1.4 ka has been obtained from this unit (Cordova et al., 2008). Below this there is an organic-rich unit similar to Unit III at 'Ayn Qasiyya. Two radiocarbon dates obtained from this unit give ages between 15,290 and 17,170 cal yr BP (13,200 ± 95 and 13,850 ± 85 ^{14}C yr BP, calibrated using Calib 6.0 (Stuiver and Reimer, 1993) and Intcal09 (Reimer et al., 2009)). Below the organic deposits at 'Ayn Soda is a green silty layer with many flint clasts, similar to Unit I at 'Ayn Qasiyya. Lithic finds in this unit are from the Middle and Upper Paleolithic and an OSL age estimate put this unit at around 29 ka (Cordova et al., 2008).

Paleoclimatic and archeological implications

Given the strong relationship between groundwater level and spring discharge apparent from recent monitoring, this relationship can be used to help reconstruct potential environmental conditions in the past based on the sedimentary record from 'Ayn Qasiyya. If driven solely by climate, past changes in spring discharge are more likely to be due to changes in input to the upper aquifer, rather than significant changes in discharge events, and so understanding potential changes in recharge is important. Spring discharge could also potentially vary due to tectonic events, which could change the groundwater flow paths through the basin. Unfortunately there is no evidence to rule

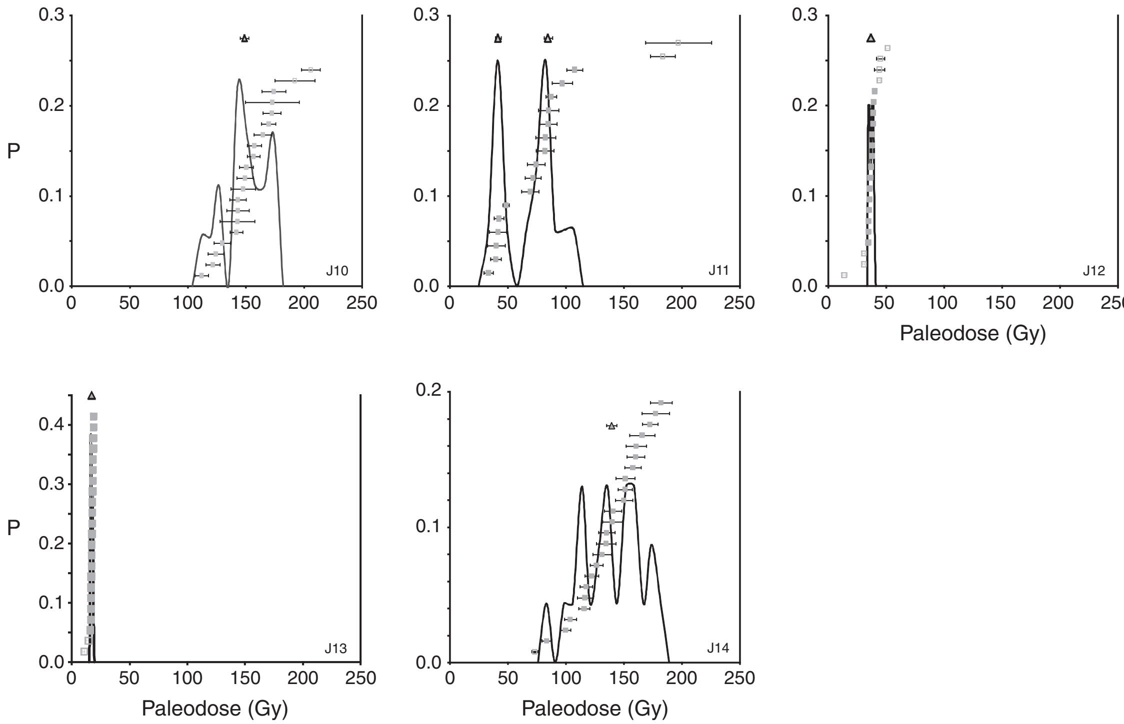

Figure 5. Paleodose plots for OSL samples (Fig. 2). Empty squares show aliquots not used in the probability density plot (solid line). Triangles show paleodose used for age estimates.

tectonic control in or out of potential interpretations. However, this does not impact on discussion of the archeological impacts of the environmental changes at 'Ayn Qasiyya, but paleoclimatic inferences are discussed with the caveat that tectonic controls cannot currently be discounted.

Given the long residence time of water in the system (see Study area), changes in spring flow are also likely to reflect changes in recharge on millennial time scales, although this is consistent with the resolution available from the 'Ayn Qasiyya record. Given the current estimates of recharge and infiltration a 1% change in infiltration across the basin would lead to a 33–50% change in recharge amount, which could have a significant change on spring discharge at 'Ayn Qasiyya. Due to this sensitivity of the system to change we therefore do not attempt any quantitative estimates of past change but discuss the possible changes in the wider catchment that may lead to change in spring flow at 'Ayn Qasiyya.

Unit II represents a period of higher spring discharge during the late Pleistocene prior to the LGM, with open water at the spring site. Given the persistence of the spring discharge, changes in evaporation at the site (which were presumable reduced during the late glacial due to lower temperatures and higher humidity) will have limited effect on water level as it is, in effect, a hydrologically open system. Water levels fell during the LGM with the development of a marsh at the spring site, although open water was still accessible close by (Fig. 2; Section 5). This suggests that spring discharge was reduced or reducing through the LGM. Between 16 and 10.5 ka there is no net deposition at the site (Table 3). One potential reason for this would be if the springs completely dried out during this time period, as in Azraq today. However, we would expect some deflation and removal of material in such a dryland, particularly over the course of 5500 yr, and so we cannot say for sure that there were consistently dry conditions through this time period. Even if the springs were dry for a considerable period during this interval, water may still have been available due to surface runoff into the Qas, at least on a seasonal basis, particularly in the higher areas to the north of Azraq where rainfall is generally greater.

The early Holocene again shows deposition of material at the site, particularly large clasts and mixed sediments suggestive of flood deposits, rather than deposits from spring waters. During the later Holocene spring conditions were re-established with carbonate concretions forming in the marshland due to the warmer conditions during the Holocene compared to the LGM.

Quade and Broecker (2009), reviewing evidence from closed lake basins, note differences between the lake records of the Near East (Lake Lisan and Lakes Konya and Tuz in central Turkey), which are deep during the LGM and dry out during the North Atlantic Bölling (14.4 to 12.5 ka), and those from Saharan Africa and Arabia, which are highest prior to the LGM and during the early Holocene, and show a significant dry period during the LGM, Bölling-Allerod and Younger Dryas. Although the evidence from 'Ayn Qasiyya is not from a closed

Table 4
Details of OSL sample from 'Ayn Qasiyya. Contributions to dose rate from cosmic sources were calculated using the expression in Prescott and Hutton (1994).

Sample number	Lab code	U (ppm)	Th (ppm)	Rb (ppm)	K (%)	Cosmic dose (μGy/a^{-1})	Total dose rate (μGy/a^{-1})	De (Gy)	Age (ka)
J10	Shfd10042	2.89	5.0	37.3	1.4	182 ± 9	2404 ± 119	148.7 ± 3.7	62 ± 3.4
J11	Shfd10043	10.1	7.9	82.8	2.3	192 ± 10	5018 ± 260	41.6 ± 2.6	8.3 ± 0.7
								84.6 ± 3.6	16.9 ± 1.1
J12	Shfd10044	54.1	5.4	36.7	0.2	192 ± 10	13,562 ± 929	36.8 ± 0.5	2.7 ± 0.2
J13	Shfd10045	3.74	6.1	40.2	1.5	192 ± 10	2727 ± 134	17.5 ± 0.2	6.4 ± 0.3
J14	Shfd10046	7.81	6.1	57.5	1.8	182 ± 9	3873 ± 198	139.4 ± 4.4	36 ± 2.2

lake system and the controls are therefore different, the wet–dry pattern here follows more closely the north African–Arabian pattern of pre-LGM moisture maxima followed by a prolonged dry period and then an early Holocene wet phase (Sanlaville, 1992), rather than a Near Eastern pattern.

The regional picture of hydroclimatic change through the LGIT is complicated by the different responses of different archives to change and resulting interpretations. There was significant desiccation of glacial Lake Lisan during the northern hemisphere Bölling (Robinson et al., 2006), and Stein et al. (2010) suggest there was probably a lake-level rise during the regional Younger Dryas equivalent. If the Soreq cave speleothem record (Fig. 6) can be taken as a proxy of rainfall amount (Bar-Matthews et al., 2003) then the LGM was the driest period west of the Dead Sea with increased rainfall during the Near East Bölling-type event and a reduction during the Younger Dryas. Reduced precipitation during the LGM and Younger Dryas equivalent and increased precipitation during the local Bölling and the early Holocene has also been calculated from central Turkey (Jones et al., 2007), whereas Lake Konya is highest at and prior to the LGM and during the Bölling–Allerod equivalent, but dry in the Younger Dryas and early Holocene. Questions, therefore, remain about the relationship between reconstructed precipitation amount and regional lake levels as measurements of "wetness" or of resulting water availability for people (Robinson et al., 2006; Enzel et al., 2008). At 'Ayn Qasiyya the lack of deposition suggests a drying of the springs for a considerable time during the period 16 to 10.5 ka, although there is no evidence as to whether this was during the North Atlantic Bölling, Younger Dryas or both. There is a lack of groundwaters dated from the region between 16 and 11 ka (Bajjali and Abu-Jaber, 2001), again suggesting a reduction in aquifer recharge at this time and pointing towards a climatic forcing of this arid phase.

Archeological evidence indicates that occupation of the oasis area was continuous throughout the late Pleistocene but shifted from locality to locality, varying in density and type. It seems evident that toward the later part of the LGM the oasis, and the Azraq Basin more generally, provided ample opportunities for human settlement. It has been widely stated that the LGM was a harsh climatic setting with which human populations in southwest Asia had to contend (e.g., Bar-Yosef, 1996; Goring-Morris et al., 2009). The 'Ayn Qasiyya archeological sequence shows that there appears to have been a fairly continuous sequence of occupations here, especially through the LGM, which had a residential, as opposed to a short-term opportunistic, character, as suggested by the evidence for on-site carcass butchery and a lithic tool kit that includes many scrapers and large retouched pieces, as well as evidence for the maintenance of composite microlithic tools (Richter, 2009; Richter et al., 2010a). This follows evidence from elsewhere in the Azraq Basin, where numerous sites were established between ca. 20–16.5 ka, including the two very large sites at Kharaneh IV and Jilat 6 (Muheisen, 1988; Garrard and Byrd, 1992; Garrard et al., 1994).

The settlement and paleoenvironmental data shows that during what has often been considered as one of the harshest environmental regimes in the region, the Azraq Basin represented a 'buffer zone' or refugium for human populations. This was not restricted to the oasis alone, as other localities in the basin appear to have also been characterised by marsh- or lake-margin settings (e.g., Garrard and Byrd, 1992; Garrard, 1998). Here, we provide paleoenvironmental data linked to archeological settlement signatures for the LGM in the Azraq Basin, which show long-term occupations facilitated by a rich local environment characterised by a high carrying capacity.

This situation changed following the onset of the North Atlantic Bölling–Allerod. Sedimentary evidence from 'Ayn Qasiyya shows that there was a lack of deposition between 16 and 10.5 ka and human occupation appears to have shifted to other areas of the oasis. About 1.5 km southeast of 'Ayn Qasiyya, multiple small Middle Epipaleolithic (Geometric Kebaran) surface lithic scatters were identified within a ca. 3000 m^2 area (Richter, 2009). The analysis of the material suggests a highly specialised tool kit, dominated by geometric microliths. These sites indicate a certain degree of continuity in occupational history but also represent a more dispersed settlement pattern, which was not primarily focused on the spring localities. Given that these sites were short-term occupations they reflect tool preparation and hunting camps, the oasis was clearly still attractive to human groups although possibly no longer suitable for long-term occupation. This pattern would fit with continued seasonal wetting of the Qa but a lack of a permanent, spring-sourced water supply.

This change in environment is also reflected in the basin-wide settlement data with a lack of true Geometric Kebaran (17.5–14.8 ka; Maher et al., 2011) occupations. Only the Wadi el-Jilat, 50 km SW of 'Ayn Qasiyya, preserved numerous Middle Epipaleolithic sites. Jilat 22 shows a number of Middle Epipaleolithic horizons within marsh deposits (Garrard and Byrd, 1992) although the deposits are cemented suggesting frequent drying, especially during the occupation horizons themselves. These deposits are unlikely to be groundwater fed: the Wadi Jilat is 280 m above the Azraq Qa and probably reflect seasonal wetting of the site, with possible damming of the wadi allowing the development of localised marsh at this time.

By the Late Epipaleolithic (14.8–11.7 ka; Maher et al., 2011), the frequency of occupations in the oasis and elsewhere in the basin once

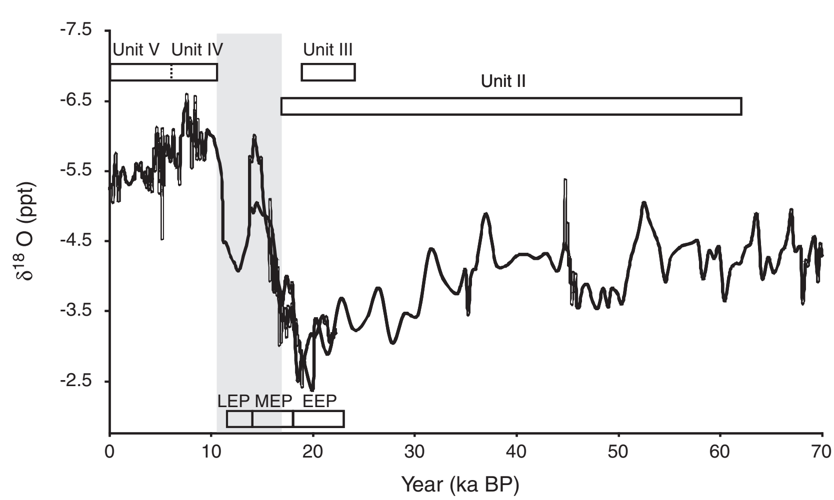

Figure 6. 'Ayn Qasiyya sedimentary units alongside the Soreq and Pequin Cave isotope records (Bar-Matthews et al., 2003). The timing of the Early- (EEP), Middle- (MEP) and Late Epipaleolithic (LEP) are shown for reference (after Maher et al., 2011). The period of non-deposition at 'Ayn Qasiyya is shaded in gray.

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again increased, although there is a perceptible shift in settlement from south to north (Richter and Maher, in press). A substantial site is attested to the south of the marshes at Azraq 18 (Garrard et al., 1994). Smaller, more ephemeral sites were found at the eastern edge of the marsh and Qa at Bawaab al-Ghazal (Rollefson et al., 1999), as well as at 'Ayn Qasiyya (Richter et al., 2007, 2010b). Numerous Late Epipaleolithic sites can now be found in the Badia to the north and east (Betts 1991; Richter and Maher, in press). Authors have widely discussed the impact of the Younger Dryas on human populations in southwest Asia and the role this climatic event may have had on the emergence of agriculture (e.g., Blockley and Pinhasi, 2011). Unfortunately, the 'Ayn Qasiyya sedimentary sequence provides little clue as to the local impact of the Younger Dryas environmentally or archeologically. Although there is no net deposition during the 16–10.5 ka time frame at Ayn Qasiyya, there is an artefactual signature for Late Epipaleolithic occupation near the spring area, as evident in the residual material washed in to Area C during the early Holocene. This shows that although the original occupation is eroded, there was human presence near the springs during the LGIT, sometime between 14.8 and 11.7 ka.

Conclusion

The sediments at 'Ayn Qasiyya represent a series of environmental shifts recording over 60,000 yr of hydrological change on the Jordanian plateau. The wider environmental settings within which the 'Ayn Qasiyya spring sat have clearly changed, at times dramatically. The sequence suggests a drying of the springs, potentially due to reduced recharge, for a significant time period between 16 ka and the beginning of the Holocene.

The intensity and type of settlement is likely to have varied in accordance with the fluctuation of spring activity. It appears that the local environment was sufficiently stable to support human settlement at most times, although subtle changes in site function and length of occupation are noticeable. The Middle Epipaleolithic was a period of reduced settlement intensity, linked to water only being available seasonally. Archeological evidence from the wider basin suggests the Younger Dryas was more suitable for large-scale occupation and therefore the harshest environmental conditions on the Jordanian plateau appear to have been during the North Atlantic Bölling–Allerod rather than during the LGM.

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