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Accepted Version

Jones, M. D., Maher, L. A., Macdonald, D. A., Ryan, C., Rambeau, C. , Black, S. and Richter, T. (2016) The environmental setting of Epipalaeolithic aggregation site Kharaneh IV. Quaternary International, 396. pp. 95-104. ISSN 1040-6182 doi: https://doi.org/10.1016/j.quaint.2015.08.092 Available at http://centaur.reading.ac.uk/44811/

The environmental setting of Epipalaeolithicaggregation site Kharaneh IV

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Abstract
The archaeological site of Kharaneh IV in Jordan's Azraq Basin, and its relatively near neighbourJilat6 show evidence of sustained occupation of substantial size through the Early to Middle Epipalaeolithic(c. 24,000 – 15,000 cal BP). Here we review the geomorphological evidence for the environmental setting in which Kharaneh IV was established. The on-site stratigraphy is clearly differentiated from surrounding sediments, marked visually as well as by higher magnetic susceptibility values. Dating and analysis of off-site sediments show that a significant wetland existed at the site prior toand during early site occupation (~ 23,000 – 19,000 BP). This may explain why such a substantial site existed at this location. This wetlanddating to the Last Glacial Maximum also provides important information on the palaeoenvironments and potential palaeoclimatic scenarios for today's eastern Jordanian desert, from where such evidence is scarce.

Keywords: Epipalaeolithic, Jordan, Last Glacial Maximum, Wetland, Azraq

1. Introduction and Background

There is much contemporary interest in people's relationships with their natural environment and how resources can be sustainablymaintained given changing climates, population sizes, and per capita demands (e.g. Al-Juaidi et al., 2014; Berndtsson et al., 2014). Today people are increasingly vulnerable to risk associated with a changing climate and a finite resource base (e.g. IPCC, 2014). Arguably these issues were also critical for prehistoric societies, although for hunter-gatherers their ability to move around the landscape represented a highly flexible strategy through which climatic change could be effectively mitigated, as long as population levels remained relativelylow. In the wider Levant region people's adaptation and mitigation strategies to a changing climate during the transition from the last glacial period into the Holocene interglacial have been widely discussed in relation to the beginnings of agriculture (e.g. Rosen, 2007; Blockley and Pinhasi, 2011; Maher et al., 2011a; Rosen and Rivera-Collazo, 2012). Yet our understanding of how the Levant experienced this global transition in climate is still somewhat unclear (e.g. Robinson et al., 2006; Enzel et al., 2008) and relies on palaeoclimatedatasets mainly from the west of the region.To improve our ability to test hypotheses about people's reactions to climatic and environmental change, or about their influence on climate and local environments (e.g. Ruddiman, 2015; Ramsey et al., in press), improved spatial and temporal resolution of our palaeoenvironmental and archaeological records is required (Maher et al., 2011a,).

The AzraqBasin of eastern Jordan has long been the focus of archaeological excavation and associated environmental investigations documenting a long history of human occupation dating back to the Lower Palaeolithic (e.g. Field, 1960; Copeland and Hours 1989; Rollefson et al., 1997; Betts, 1998; Garrard and Byrd, 2013). The latest set of excavations in the basin includes work by the Epipalaeolithic Foragers in AzraqProject (EFAP; e.g. Maher et al., 2011b, Maher et al. 2012; Richter et al., 2013; Maher et al., this volume) and this paper reportsthe results of geomorphological investigations around the site of Kharaneh IV, placing the site into its wider palaeoenvironmentalcontext.

1.1 KharanehIV

The Early to MiddleEpipalaeolithic site of Kharaneh IV (KHIV) is an important Late Pleistocene site in the Eastern Levant.Recent excavations at KHIV, building on the initial work of M. Muheisen (e.g. 1988), have shown the site to be of great archaeological interest. The high density of artefacts, given a relatively short occupation history(19,830-18,600 cal. years BP; Richter et al., 2013), as well as thethickness of archaeological deposits, large size of the site (22,000 m^2),and the presence of very early hut structures (Maher et al.,2012; this volume), are all rare for Epipalaeolithic sites and suggest frequent re-use of KHIV by hunter-gatherer groups.

The site is located approximately 40km west of the AzraqOasis (Fig. 1)at an elevation of ~640masl, lying on a sedimentary terraceof pale, cream-coloured silts, in the WadiKharaneh, just south of the Islamic castle of the same name. The local topography (Fig. 2) shows the site is the highpoint on the floor of the greater WadiKharaneh (Fig. 3);it sits at the confluence of two minor wadis with a general gradient of about 0.3m per 100m to the east, towards the central oasis.

The sediments around the site have been described very briefly before as part of regional reviews (Garrard et al., 1985; Besancon et al. 1989) but before EFAP were not dated or systematically surveyed to link KHIV into the wider landscape. Here we describe such work, providing a geomorphological background to the establishment of KHIV and adding to the palaeoenvironmental reconstructionof the local environment. In combination with faunal data(Martin et al, 2010, Jones, 2012) and ongoing archaeobotanical analysis, this geomorphological data contributes to our understanding ofwhy this particular locality was selected for settlement and why people returned to the same place on the landscape for c. 1000 years (see also Maher, in press). In addition, this work provides more information for an emerging picture of environmental change within the wider AzraqBasin through the late Quaternary (e.g. Jones and Richter, 2011; Cordova et al., 2013; Ames et al., 2014) that improves our understanding of regional environmental and climatic change throughout the Pleistocene and Holocene.

2. Methodology

2.1 Mapping and sediment logging

The topography of the site and the surrounding area was mappedin high-resolution using a ProMark3 differential GPS system, with survey data fixed to the local site grid. In total, 1076 data points were used to create a local contour map of the site and the immediate surrounding area.Six off-site sections were dug into wadi terraces and were visually described and surveyed into the site grid. In addition, a 9m x1m 'GeoTrench' was dug into the edge of the site itself. Careful surveying of all sections to the site grid allowed these off-site sections to be directly compared to the excavation areas on-site (see Maher et al., this volumefor details of these). Of particular interest to this study are the deep sounding in Areas A (excavation square AS42) and B (R/S2/60) and a deep sounding between the twomain excavation areas (AZ51), all of which were excavated into the archaeologically sterile units underlying the site.

2. 2 Age-estimates

A number of dating methods have been used to try and constrain the age of the stratigraphy, both on- and off-site, at KHIV.The methodologies for both Optically Stimulated Luminescence (OSL) and U-series approaches are outlined here.

OSL samples were taken in opaque tubes, sealed at both ends, from both off- and on-site sediments (detailed sampling locations are detailed later in the manuscipt). On return from the field age estimates were obtained at the University of Gloucestershire Luminescence Dating Laboratory.All samples were opened and prepared under controlled laboratory illumination and to isolate material potentially exposed to daylight during sampling, sediment located within 20 mm of each tube-end was removed.The remaining sample was dried, and then subjected to acid and alkaline digestion to removecarbonate and organic components respectively. Fine silt sized quartz was extracted by sample sedimentation in acetone and feldspars and amorphous silica were then removed from this fraction through acid digestion (Jackson *et al*., 1976; Berger *et al*., 1980). Following addition of 10% HCl to remove acid soluble fluorides, grains degraded to <5 μm as a result of acid treatment were removed by acetone sedimentation. Up to 12 aliquots (ca. 1.5 mg) were then mounted on aluminium discs for Equivalent Dose(D_e) evaluation. D_e values were quantified using a single-aliquot regenerative-dose (SAR) protocol (Murray and Wintle 2000; 2003) measuring the natural signal of a single aliquot and then regenerating that aliquot's signal by using known laboratory doses to enable calibration. For each aliquot, 5 different regenerative doses were administered so as to image dose response. D_e values for each aliquot were then interpolated, and associated counting and fitting errors calculated, by way of exponential plus linear regression. Weighted (geometric) mean D_e values were calculated, given sufficient mass, from 12 aliquots using the central age model outlined by Galbraith *et al*. (1999) and are quoted at 1σ confidence (Table 1). Lithogenic Dose Rate(D_r) values were defined through measurement of U, Th and K radionuclide concentration and conversion ofthese quantities into α, β and γ D_r values (Table 1). Cosmogenic D_r values were calculated on the basis of sample depth, geographical position and matrix density (Prescott and Hutton, 1994). Ages reported in Table 1 provide an estimate of sediment burial period based on mean D_e and $D_r$values and their associated analytical uncertainties.

A U-Series age was also obtained from carbonate nodules (e.g. Rowe & Maher 2000)found near the site (see sedimentary descriptions below for details). U/Th data was produced using a Perkin Elmer ELAN 6000 Inductively Coupled Plasma Mass Spectrometer at the University of Reading (e.g. Black et al. 2011; Rambeau et al. 2011). U/Th dating is based on the measurement of ^{230}Th produced by the radioactive decay of ^{234}U, once the latter was preferentially incorporated into the newly precipitated sediment. The U/Th technique provides accurate dating only if 1) the system remains chemically closed after deposition, and 2) either if no initial Th is present within the system at time of precipitation, or the amount of additional Th (e.g., as brought in by detrital contamination) can be calculated and corrected for.

Collected samples were composed of dense, micritic carbonate and showed no sign of weathering internally, minimising the likelihood of dating problems due to open-system behaviour.As an attempt to correct for detrital contamination (that would add detrital thorium to the sediment dated, leading to calculation of ages that are too old) an isochron age was also calculated (e.g. Candy et al. 2004, 2005). Both individual and isochron ages were calculated using the program ISOPLOT© V.2.49 (Ludwig 2001), which also provides a statistical assessment of the validity of the calculated best-fit isochron age, by evaluating its relationship to the dataset (Mean Square of Weighted Deviates [MSWD], probability of fit). These statistics are crucial in estimating the accuracy of the calculated isochron age (Candy et al. 2004, 2005 and references therein); a high MSWD (value >1) indicates analytical or geological problems and ages that are potentially more complex..

2.3 Sedimentology

A series of standard sedimentary analyses were undertaken on a set of 52 samples to further quantify the visual sedimentary descriptions; 11 samples from Area A, 24 from Area B and 17 off-site samples (including those from the GeoTrench).

Loss on Ignition analysis was undertaken using standard procedures (e.g. Heiri et al., 2001). Volume-specific Magnetic Susceptibility analysis was undertaken using a Bartington MS2B Dual Frequency Magnetic Susceptibility Meter. Sub-samples were ground using a pestle and mortar, to achieve a homogeneous sample, and sieved at 0.25mm to remove any large clasts prior to analysis.X-ray Fluorescence (XRF) was undertaken on ground samples on aPanalytical Epsilon 3-XL at the School of Geography at the University of Nottingham with resulting spectra analysed to give values for the major oxides and elements MgO, Al_2O_3, SiO_2, K_2O, CaO, Ti, Fe_2O_3 and Sr. Particle Size Analysis was undertaken using aCoulter LS 200 Laser Granulometer after samples had been sieved at 1.4mm and disaggregated using a weak sodium hexametaphosphate solution. The GRADISTAT software package (Blott and Pye, 2001) was used to analyse this data.

3. Results

3.1 Sedimentology

The field descriptions of the five off-site sedimentary sections nearest to the site can be found below and their relative locations are shown in Figures 2 and 4. Section 3 was dug into the wadi south of the site and is not described here. In general, there are two major sedimentary units around the site 1) a series of pale colouredfine silts that make up the terrace on which the site sits, and 2) a series of reddish-brown, silts, sands and gravels (with clasts of flint) that are found in the wadi running to the south of the site.

KHIV Section 1 (31 43' 27.1" N; 36 27'05.4" E)

0 – 21 cm Light Red (10YR 7/6) silty sand with occasional roots.At base (16 – 21cm) large (2-5cm) flint clasts, some of which lie flat on the base of the unit.

21 – 26cm Pink (10YR 10/4) sand. Contains carbonate concretions and has secondary ?salt features suggesting soil formation during period of stasis or drying episode. Not laterally continuous over the site – predates an erosional episode prior to or during deposition of unit above.

26 – 30cm Same as the basal 5cm of top unit showing erosional features, rip up clasts into unit below and erosional surface on the upper contact.

30 – 62cm Light greenish grey (Gley 7/5GY) silty clay with very occasional large (>10cm) flint clasts. OSL sample GL11035 was taken from the top of this unit.

KHIV Section 2 (31 43'27.8" N; 36 27'05.6"E)

0 – 30cm Weathering surface and drape

30 – 73cm Pinkish white (10YR 8/2) homogenous silt. OSL sample GL11036 taken from 56cm depth.

KHIV Section 4 (31 43' 22.5" N; 36 27' 13.0" E)

0-12cm Very pale brown (10YR 7/4) silty fine sand containing small (1-3cm) clasts of flint and stone with roots to surface.

12-27cm Brownish yellow (10YR 6/6) fine sand with 2-5cm scale flint clasts. OSL sample GL11037 taken from this unit.

27-82 cm Light yellowish brown (10YR 6/4), but mottled, clayey silt with numerous fine roots and some larger roots.

KHIV Section 5 (31 43'21.6" N; 36 27'21.0" E)

0-10cm	Weathering surface
10-92cm	Very pale brown (10YR 8/2) silt with abundant root holes. OSL samples GL11038 and GL11039 taken from 40cm and 80cm respectively.
92-112cm	Very pale brown (10YR 7/3) sandy silt with occasional small (1-2mm) flint specs.
112-137cm	Very pale brown (10YR 7/4) silts with common small specs (1-2mm) of flint and charred plant remains or charcoal and occasional large (3-5cm) flints.

KHIV Section 6 (31 43' 22.7" N; 36 27' 18.0" E)

0-10cm	Yellow (10YR 7/6) fine sand containing roots to the surface and plant remains. There is a dry crust on the Wadi surface.
10-36cm	Light yellowish brown (10YR 6/4) sandy silt containing root holes and organic remains and occasional small (<1cm) flints.OSL sample GL11040 taken from the base of this section.
36 – 56cm	Very pale brown (10YR 7/3) sand and gravel with large (>10cm) flint clasts.
56-111cm	Yellowish brown (10YR 5/4) silty clay with occasional large flints.

KHIV GeoTrench
Description based on Locus Summary Sheets

0cm	Locus 000 Surface
0-10cm	Locus 001 Disturbed 10cm of slopewash on surface
10 – 25cm	Locus 002 Red/brown Wadi Silt. OSL sample 11041 taken from this locus.
25 – 40cm	Locus 003 Brown Clay – possible palaeosol in lake sediments?
40 – 43cm	Locus 004 Upper White Clay
43 – 53cm	Locus 005 Brown Clay. OSL sample GL11042 taken from this locus.
53 – 55cm	Locus 006 Middle White Clay
55 – 70cm	Locus 007 Brown 'Palaeosol'; looks like level of earliest site occupation given stratigraphy and comparison to sediments in AZ51.
70-72cm	Locus 008 Lower White Clay looks like the white silt seen towards the base of AZ51 and in Sections 2 and 5

The sedimentological analyses (Table 1) show distinct differences between the on-site and off-site sediments particularly in terms of magnetic susceptibility and the amounts of calcium and silica in the sediment. Average matrix grain size (Fig. 5) is slightly coarser on-site, most likely reflecting the anthropogenic origin of some of these sediments.

Given that there is little difference in iron content between the groups of samples it is likely that the substantial differences in magnetic susceptibility values reflect the amount of burning of the sediment onsite (e.g. Morinaga et al., 1999). Analysis of more samples would be required to confirm if the differences between Areas A and B are significant in terms of different intensities of burning throughout these areas, or if certain occupation layers have typically high magnetic susceptibility values. But these preliminary results do suggest this is an area of analysis that may warrant further investigation at the site.

The differences in elemental composition of the sediment, particularly in terms of calcium and silica reflect the visual description of these samples. CaO values from off-site samples are slightly skewed by the carbonate-rich silts of the terrace on which the site sits; samples in sections 1, 2 and 5 have an average of 42.2%. Sieving of these samples for other analyses, and during flotation on-site, reveals that they are rich in ostracod shells and we interpret them as carbonate-enriched wetland sediments, or marl.

3.2 Age-estimates

To provide an absolutechronology for the off-site sediments, where unlike inthe site itself charcoal was not preserved, a series of OSL and U-Series age estimates were obtained (Tables 2 and 3). These, along with the radiocarbon chronology of the site, are summarisedstratigraphically in Figure 4. Due to low amounts of material suitable for analysis in some OSL samples, some of these age estimates have to be treated with caution or as minimum ages. The lack of material in samples GL-11035, 11039, and 11041 restricted the number of aliquots available for D_e estimation. The latter 2 samples also did not have enough material to allow a dose recovery test, nor did samples 11046 and11047. Sample GL11043 had significant feldspar contamination, such that this age is a minimum age estimate.

Analytically this leaves seven secure OSL age estimates. In the pale terrace silts we discount samples GL11044 and GL11045 based on stratigraphic reasons. These samples were taken from archaeologically sterile sediments directly below a well-constrained site age (Richter et al., 2013) and therefore cannot be younger than the site. The three other OSL age estimates, GL-11036, 11038 and 11042give an age of 19 – 23 ka BP for the terrace silts. Although some caution is warranted in the use of this age range as the ‘true’ age of this unit, due to the clearly ‘young’ age estimates of samples GL11044 and GL11045, it is an age that is supported by 4 of the age estimates from samples with limited datable material, and by the stratigraphic overlap of this unit with the site itself (19,830-18,600 cal. years BP; Richter et al., 2013).

From the second major sedimentary unit (the reddish browns silts, sands and gravels) two OSL age estimates (GL 11037 and 11040) place these deposits in the mid to late Holocene, 5 – 3.5 ka BP. There are no analytically insecure age estimates from this unit, and stratigraphically they sit within the present day wadi, overlying the terrace silts in Section 1.

The individual U-Series ages on the carbonate nodules from the terrace surface gave an average age of 22,740 ± 920 years. Individual ages were not corrected for detrital contamination, which $^{230}Th/^{232}Th$ ratios show could be important (Table 3; low detrital contamination is usually indicated by high$^{230}Th/^{232}Th$ >25; Candy et al. 2005). Although the uncorrected ages of all carbonate concretion subsamples seem highly coherent, an isochron age was calculated to try and take into account this contamination. However, the MSWD (120) and probability of fit (0), given by ISOPLOT as statistical assessment of the fit between the isochron and the original dataset, indicate a probable large degree of scatter around the best-fit isochron such that this age-estimate should be treated with great caution. Failure to obtain a statistically-meaningful isochron can be due to the fact that, although belonging to the same layer, the subsamples did not deposit at exactly the same time or contain different generations of carbonates (Candy et al. 2004); and/or there was more than one source of detrital contaminants. The subsamples also have very similar U-series ratios (Table 3), making it difficult to produce a well-defined isochron (e.g. Dean et al., 2015). This is exemplified by the degree of scatter shown on selected activity ratios (AR) plots (Fig. 6). Although the Rosholt plots,$^{230}Th/^{232}Th$ AR versus $^{238}U/^{232}Th$ (Rosholt I plot) and $^{234}U/^{232}Th$ AR versus $^{238}U/^{232}Th$ (Rosholt II plot; Rosholt et al. 1976), emphasise alignment of subsamples, which suggests suitability for the construction of an isochron, the Osmond plots,$^{230}Th/^{238}U$ AR versus $^{232}Th/^{238}U$ (Osmond I plot) and$^{234}U/^{238}U$ AR versus $^{232}Th/^{238}U$ (Osmond II plot; Osmond et al. 1970)highlight the clustering of subsamples due to chemical similarities which render them inappropriate for statistically meaningful isochron calculations.

The age of ca. 22,500-23,500 years given by both the individual dates and the isochron date should therefore be considered as a maximum age of the sample (since it cannot be properly corrected for initial detritalTh). This fits with the other chronological and stratigraphic controls on the site, as we presume these nodules formed during, or after the silts in which they sit (e.g. Rowe & Maher 2000) i.e.after c. 19 ka BP.

4. Discussion

The detailed mapping and absolute dating of the sediments surrounding KHIV allows us to reconstruct the environmental changes at the site for various time windows over the last 23,000 years.

The spatial extent, duration and type of water body that deposited the pale terrace clays and silts at KHIV are difficult to establish. The present day extent of the marl terrace is clear from satellite imagery (Fig. 3) but as Garrard et al. (1985) noted there is no clear natural barrier to form a lake in this point on the wadi, and there are no shorelines evident against the limestone bedrock on the northern edge of the wadi. A more recent drainage pattern is now superimposed on the wadi, cutting the marl terrace between the site and section 5, and the main drainage channel of the WadiKharaneh to the north of the site may have eroded any remaining shoreline evidence.

The lack of distinct shoreline and other morphological features of the marl, such as the apparent parallel nature of the sedimentary units to the wadi floor, are similar to those defining ground-water discharge (GWD) deposits (Pigati et al., 2014). The sediments, especially those described in sections 2 and 5 often resemble those described as 'Wetland Marl' by Pigati et al. (2014) i.e. massive to blocky, which they interpretas forming in shallow wetlands, or in marshy areas. Of note at Kharaneh though is the massive nature of some of the marl, particularly in Section 2, suggesting there was little vegetation growing at the site of deposition. This suggests that the Kharanehwetland, at least at times, held substantial amounts of water and may have had open water areas.

Interpretation of this water body as being a GWD deposit is hard to envisage given the main Azraqaquifers today are at least 100m below Kharaneh (e.g. Al-Kharabsheh, 2000). However, in times of more effective precipitation (see further discussion below) it is possible there was a localised, shallow, groundwater source at this location. Surface water recharge of this wetland may also have been possible. The marl terrace and the site sit in a particularly wide section of the main wadi channel, constrained by the limestone bedrock wadi edge to the north and the flint pavement (D in Figure 3) to the south. The full depth of the 'basin' in which the Pleistocene sediments of Kharaneh sit is unknown, but based on current topography this is a section of the wadi where flowing surface water could have slowed down and pooled, particularly in an area already rich in wetland vegetation. The recent digging of a dam near KHIV (clearly visible in Fig. 3) has shown that winter rains draining through WadiKharaneh today can last well into the summer months given sufficient storage capacity. Given the spatial extent of the marl terrace it is likely that the Late Pleistocene wetland that produced these sediments would have been in the order of 50 times larger than this dam, at least at its maximum extent.

The marl terrace, and therefore the wetland which deposited it, dates to between 23 and 19 kaBP,based on the chronological discussion above. Today, there is a slight stratigraphic overlap between the top of sections 2 and 5, and the occupation levels of AZ51 on-site, given the regional topographic gradient (Figure 4). However, it is likely that this terrace was higher in the past. Besancon et al. (1989) describe carbonate concretions at the base of a 30cm silt layer, we observe these nodules(from which the U-Series age estimates were produced) at or near the surface today, suggesting some substantial deflation in the ~30 years between our surveys.

Under the western and northern areas of the site itself (Area A and AZ51), the wetlanddeposits are ostracod-rich, carbonate-concreted greenish marls, similar to thoseseen in sections 2 and 5, and are interstratified with the earliest Early EP occupations. Under the eastern portion of the site (Area B), archaeologically sterile, tan-coloured clays with little visible carbonate form an abrupt boundary (with no visible mixing) with the overlying occupational deposits (Maher et al., this volume). Given the subtle differences in the wetlandfacies observed on and around the site and their stratigraphic overlap with the site itself, andthe microfossils observed during our initial analyses presented here (i.e. ostracods; diatoms are also preserved, K. Mills pers. com.) more detailed analysis of these wetlandsediments are planned to tease out the detail of environmental change recorded here through the late Pleistocene.

Following the marl deposition Besancon et al. (1989) and Garrard et al. (1985) describe a silty loam (with carbonate concretions at the base) which today appears to have largely been deflated.Garrard et al. (1985) suggest these were loess deposits that, given our chronological data, were deposited at some point post-19 ka BPand would suggest substantial drying of the local environment. It's possible that these loess deposits are the same as those found in Locus 2 of the Geotrench (with a cautious age estimate of 15 ± 1 ka BP; GL11041) but we are not able to link them together directly. The next depositional event related to the siteis theHolocene fillidentified in the minor wadis that make up the present day drainage pattern, dating to around 4 ka BP. This points to a substantialerosional phase of the marl terrace at some time between 19ka and 4ka BP.

4.1 A suitable site for occupation?

Given the location of the site, above much of the marl deposition, and also within the southern limits of the proposed maximum extent of the wetland(Fig. 3), it is unlikely that the most extensive Pleistocene water body still existed at Kharaneh at the time of the first site occupation around 20,000 years ago. However, as reported above, it seems likely that water did still exist at the site to some degree when it was first occupied, at least on a seasonal basis. Given the site's environmental history prior to occupation as documented here,Kharaneh IV would likely have appeared anoptimal location within a resource-rich environment in which to set up camp. The sustained occupation of the site suggests, despite limited sedimentary evidence post 19 ka BP, these resources were available for some time, at least 1200 years.

Jones and Richter (2011) show that the centralAzraq oasis was also a well-watered locale at this time and yet there is no large aggregation site apparent there. Archaeological evidence suggests that groups using different sets of lithic technology and with ties to either the west or the southern and northern Levant occupied the Azraq Basin during the Early Epipalaeolithic (Richter et al., 2011; Maher et al., this volume). It is possible that social barriers prevented the establishment of a large basecamp-style aggregation site in the oasis itself at that time. The AzraqOasis may have fallen in between territories of different social groups of hunter-gatherers making the establishment of a large site here socially unacceptable. This idea is supported by the fact that the only other large aggregation site in the Azraq Basin, Jilat 6, is characterised by a very different set of lithic industries compared to KHIV, whereas the lithic assemblages recovered from Ayn Qasiyya, a smaller site,have parellels with both the KHIV and Jilat 6 lithic assemblages. At the same time, it is also possible that the oasis may not have been suitable for long-term aggregated settlement due to other factors, such asthe presence of large predators. Given the long history of archaeological survey in and around the oasis it is unlikely that a site of the magnitude of Jilat 6 or KHIV has been missed.

Unfortunately there is no local sedimentary evidence from which to reconstruct the environment through most of the occupation of KHIV, or to point to reasons for eventual site abandonment. Such environmental information must come from ongoing work from the site itself. The now largely deflated loess deposits described by Garrard et al. (1985) and Besancon et al. (1989) does suggest a drier period following the wetlanddeposits that overlap with the site but there are nostratigraphically secure absolute dates to confirm if these were deposited during the site occupation, or following abandonment.

4.2 Comparison to regional palaeoenvironmental records

High lake levels during the Late Pleistocene are reported from across the wider eastern Mediterranean region, with water bodies substantially larger than those found today, such asLake Lisan (e.g. Torfstein et al., 2013), Lake Van (Çağatay et al., 2014) and in the Konya plain (e.g. Roberts, 1983). A combination of increased precipitationand/or reduced evaporation is likely to have increased the potential (compared to present day conditions) for standing water to remain, where geomorphological conditions allowed. Both Lake Lisan and Konya had significant falls in lake levels ~ 21 ka BP and the deposits at Kharaneh IV would fit this pattern with the maximum extent of water at the site occurring before site occupation around 20 ka BP, and subsequent drying afterwards.

Evidence from other sites in the AzraqBasin would also suggest that the period of most positive water balance in the basin occurred shortly prior to 20 ka BP.Garrard et al. (1988, 1994) and Garrard and Byrd (2013) interpret the sediments of Uweynid 14 (23.4 – 21.4 kacal BP; Richter et al., 2013) as being deposited during a period of relatively high water table and identify a ‘humid’ phase in the WadiJilat around 23 kacal BP (19,000 uncalibrated radiocarbon years BP). The timing of both these events would fit with the absolute dating of the Kharaneh marls. Organic marsh deposits are well established in the central oasis at Ayn Qasiyya by 24 ka BP as water levels fell from a more extensive open water body, although locally open water conditions there continued until 16 ka BP (Jones and Richter, 2011).

There is a lack of continuous post-Last Glacial Maximum sediments in the wider basin that make reconstructing environmental changes through the last glacial-interglacial transition and the early Holocene here difficult. For example in the central oasis there is a sedimentary hiatus at Ayn Qasiyya between 16 and 10.5 ka BP (Jones and Richter, 2011); we cannot therefore place events such as thethe net erosive period at KHIV between 19 and 4ka BP with any better resolution. Identifying how environments in the Azraq Basin changed through this important transition remains a particular challenge of work in the region.

5. Conclusions

The Kharanehwetlandwas likely a well-known landscape feature for Early Epipalaeolithicoccupants of the Azraq Basin. As elsewhere in the region, a relatively positive hydroclimatic balance existed c. 23ka BP. Water balance has not been as positive in the region since, having already begun to decline by the time of occupation at KHIV. With the central oasis providing persistent water and associated floral and faunal resources throughout this time period, KHIV and Jilat6 additionallysuggest the endof the Pleistocene was a prime time for people to thrive in the AzraqBasin, with a c. 1000 year window of rich environmental resources that were substantially exploited by Early and Middle EP communities.

Acknowledgements

We thank the Department of Antiquities of Jordan and its Director General, our DoA reps for the field seasons at Kharanehand our DoA collaborator Ahmad Lash. We thank all the field crews of 2007-2015, in particular Samantha Allcock, and the community of Azraq for their continued support.This work was funded by grants from theArts and Humanities Research Council of Britain, Council for British Research in the Levant, American Centre for Oriental Research,University of California, Berkeley, the Wenner-Gren Foundation, the University of Nottingham, and the Fragmented Heritage Project at the University of Bradford.Phil Toms is thanked for his advice on the interpretation of the OSL age estimates. This manuscriptwas written while MJ was a visiting Fellow in the School of Geography, Planning and Environmental Management at the University of Queensland. We thank Jason Rech and an anonymous reviewer for comments which improved this manuscript.

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Figure and Table Captions

Figure 1 Extent of the Azraq basin (dashed line) showing major wadis (solid lines) and playa (hashed areas). The major archaeological sites discussed in the text are shown. Shading depicts 250m contour intervals (masl). The sites of Kharaneh IV and Ayn Qassiyya are also shown on the regional map for context.

Figure 2 Detailed topography of the WadiKharaneh around the site of Kharaneh IV (here marked by the thick black line). The locations of the off-site sedimentary sections as described in the text are shown. The dotted line marks the transect described in Figure 4.

Figure 3 Annotated satellite image of the site and surrounding area from Google Earth. The dotted line represents the maximum extent of the Kharaneh wetland, as defined by the bedrock topography and distribution of marl sediments.

Figure 4 Relative distribution of off-site stratigraphy and occupational horizons of Kharaneh IV. All age estimates associated withthese sections are shown (bar one 'rejected' OSL date for the Geo Trench; GL11041); age estimates in bold are used in the final interpretations. The location of OSL samples are marked by circles (see Table 1 for details), the date of the present-day terrace surface was obtained using U-Series techniques (Table 2) and the date for the occupation horizons comes from Bayesian modelling of 13 radiocarbon age estimates (Richter et al., 2013). Note; for clarity the location of Section 4 has been moved, its actual location marked by the dotted outline. A full description of the sub-units of each section can be found in the main text.

Figure 5 Particle size summaries for analysis of sediments taken from on- and off-site sections at KIV.

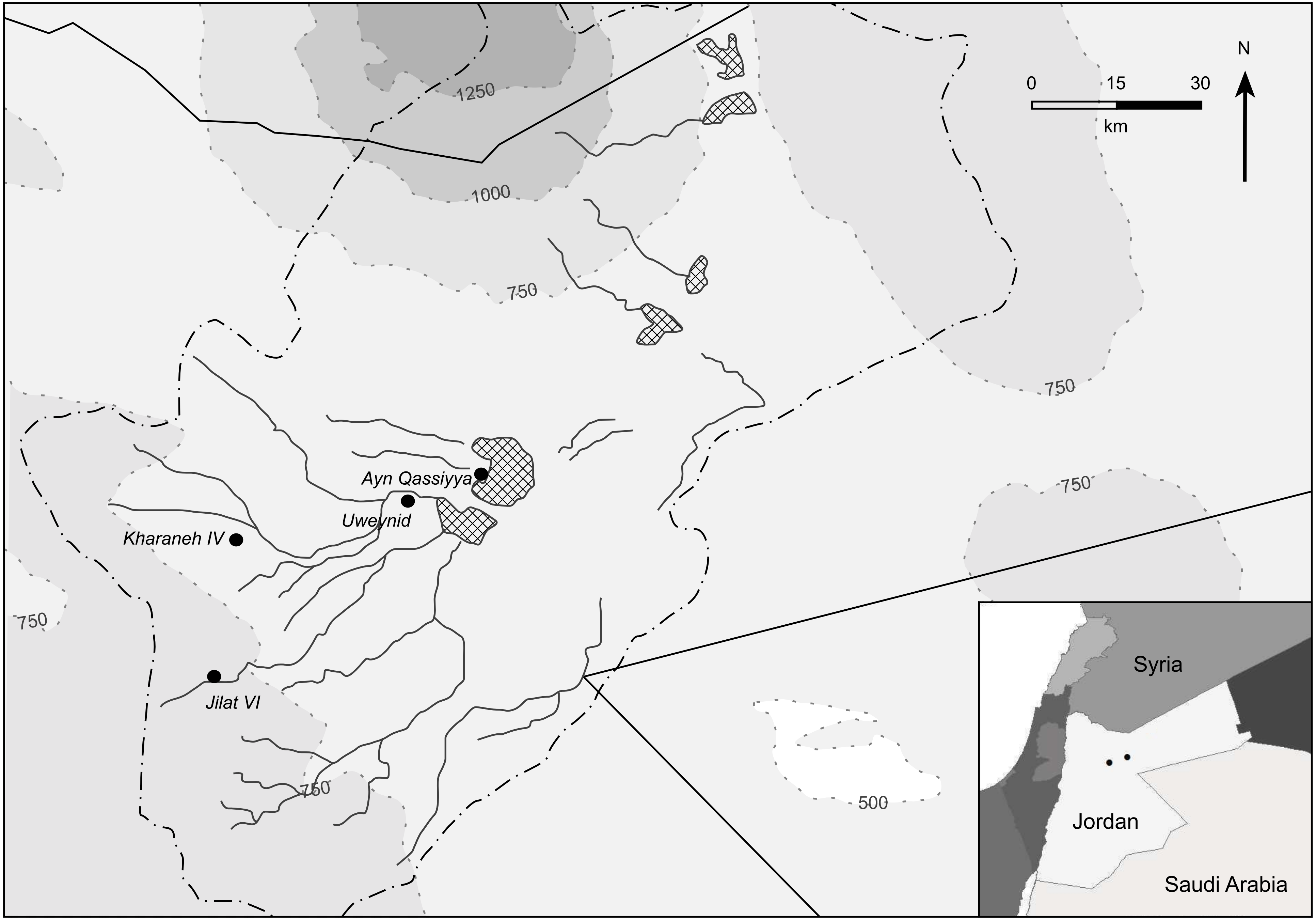
Figure 6 Activity Ratio bi-plots from the U-Series analysis of carbonate nodules from near Kharaneh IV following Rosholt et al. (1976) and Osmond et al. (1970)

Table 1 Data summary from sediment samples from Kharaneh IV and surrounding sediments. Mean values ± 1 standard deviation are shown.

Table 2 Dose rate (D_r), Equivalent Dose (D_e) and Age data from Kharaneh IV OSL samples. Further discussion of the samples listed as having limited datable material or significant feldspar contamination can be found in the main text.

Table 3 Uranium/Thorium age for sample KAL-IV. The isochron age is calculated using a series of subsamples (1-5). Uncorrected U/Th ages for each subsample are given in italics. Average uncertainties (SDs) on U and Th concentrations are calculated from all data measured during the same batch and are 0.45% and 0.67% respectively.

Figure 1



1250
1000
750
750
750
750
750
750
500
0
15
30
km
N
Ayn Qassiyya
Uweynid
Kharaneh IV
Jilat VI
Syria
Jordan
Saudi Arabia

Figure 2

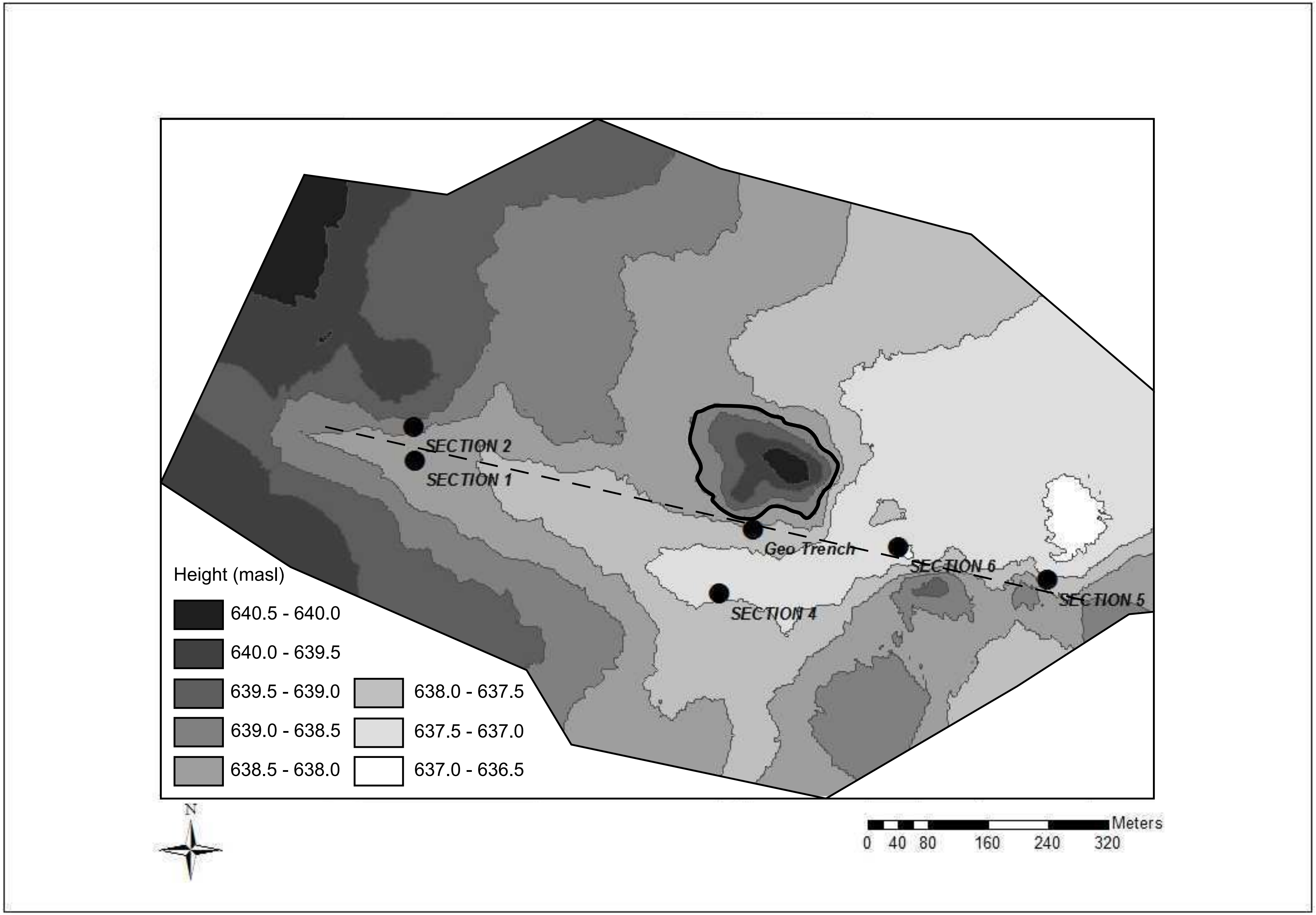

SECTION 2
SECTION 1
Geo Trench
SECTION 6
SECTION 4
SECTION 5
Height (masl)
640.5 - 640.0
640.0 - 639.5
639.5 - 639.0
639.0 - 638.5
638.5 - 638.0
638.0 - 637.5
637.5 - 637.0
637.0 - 636.5
N
Meters
0 40 80 160 240 320

Figure 3

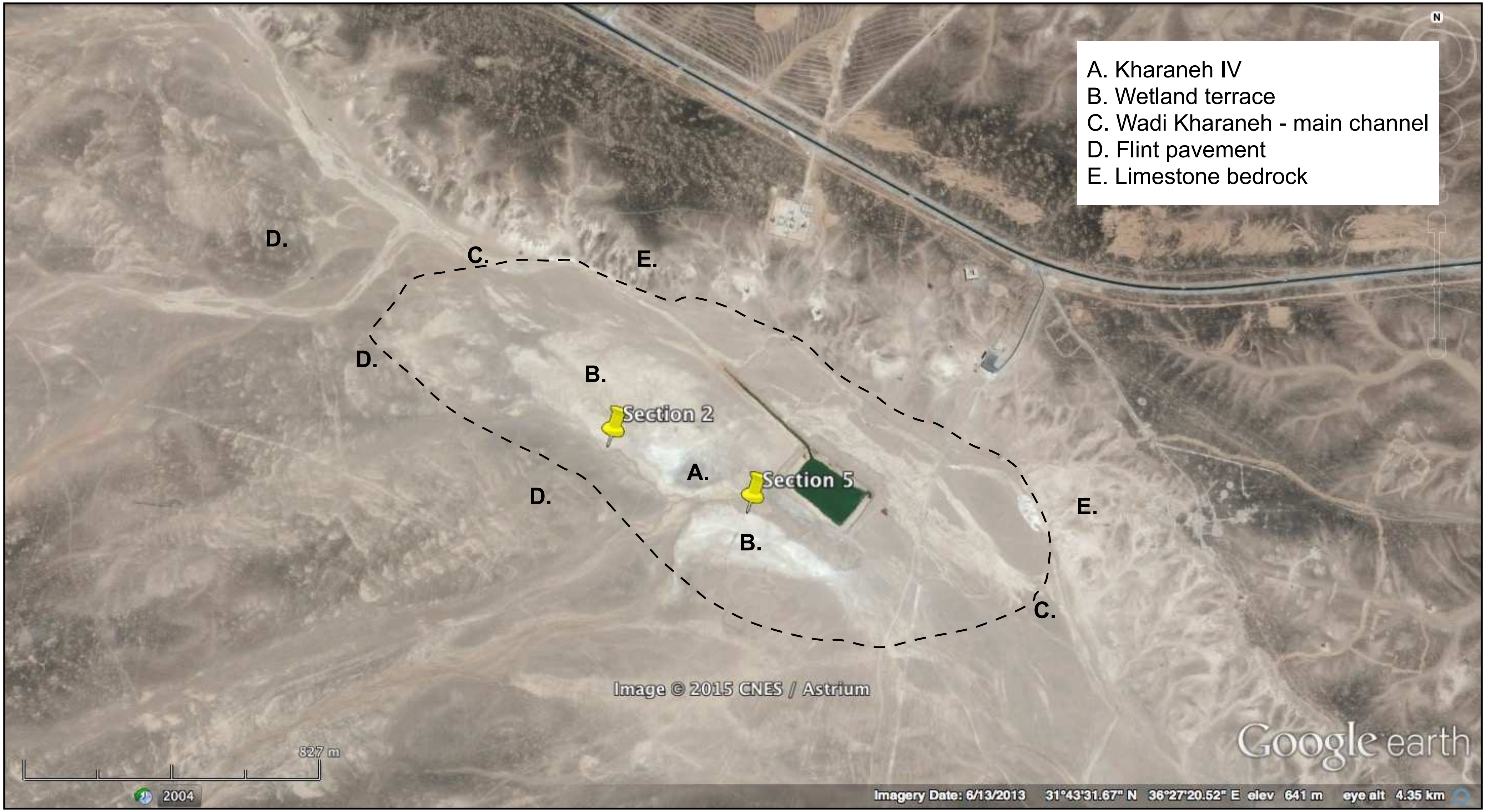
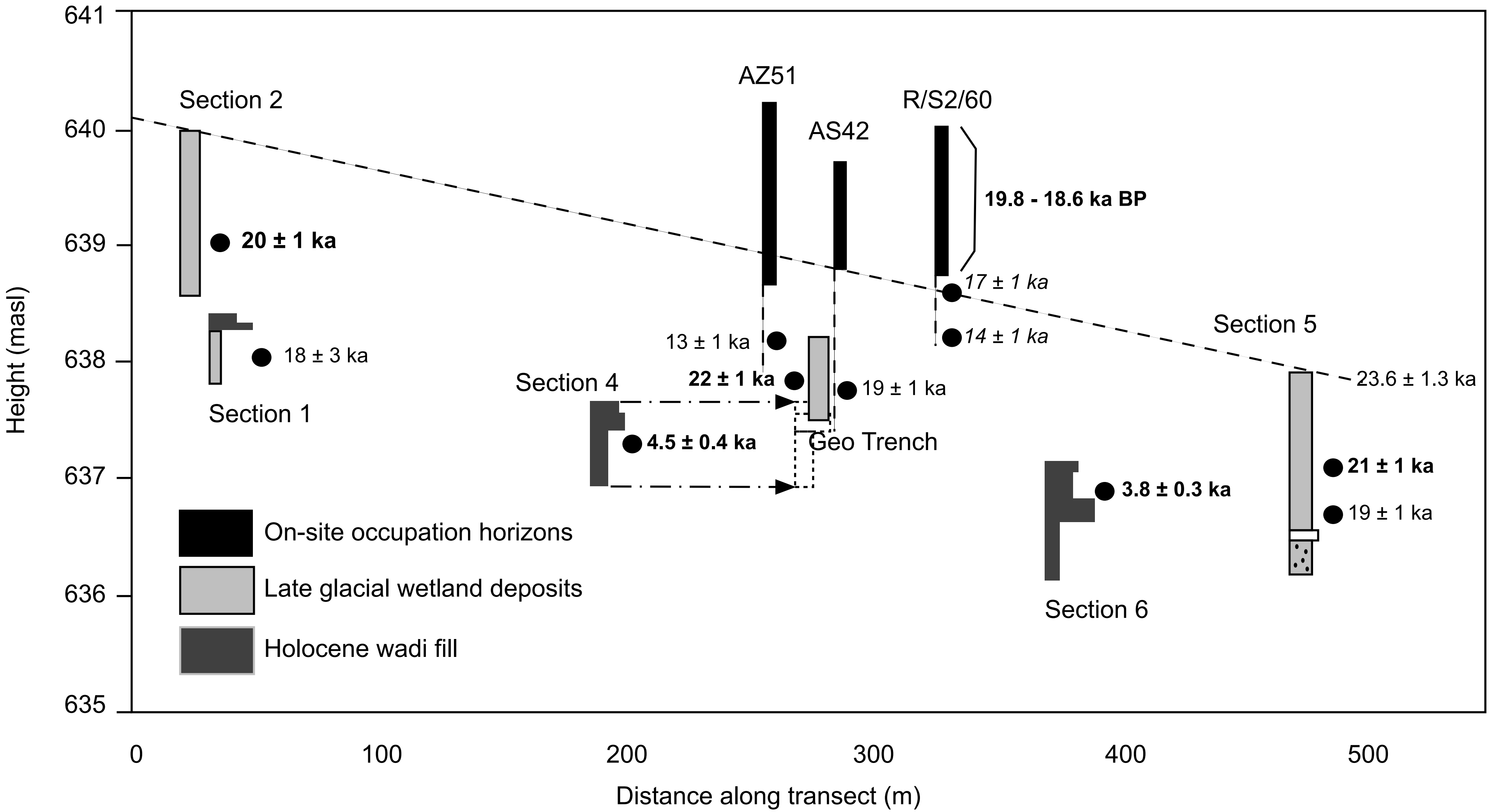
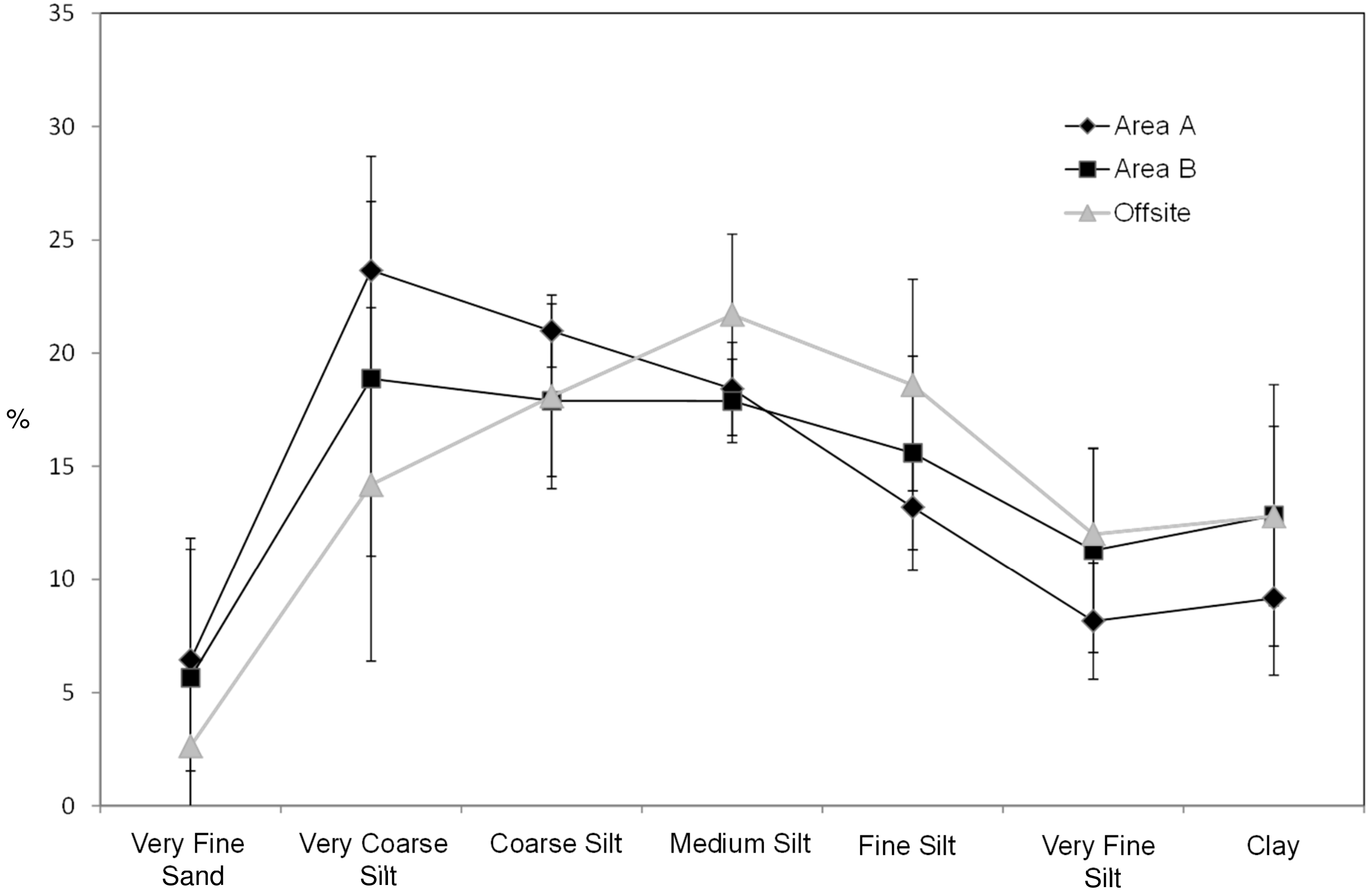

A. Kharaneh IV
B. Wetland terrace
C. Wadi Kharaneh - main channel
D. Flint pavement
E. Limestone bedrock
D.
C.
E.
D.
B.
Section 2
A.
Section 5
D.
E.
B.
C.
Image © 2015 CNES / Astrium
827 m
2004
Imagery Date: 6/13/2013 31°43'31.67" N 36°27'20.52" E elev 641 m eye alt 4.35 km
Google earth

Figure 4



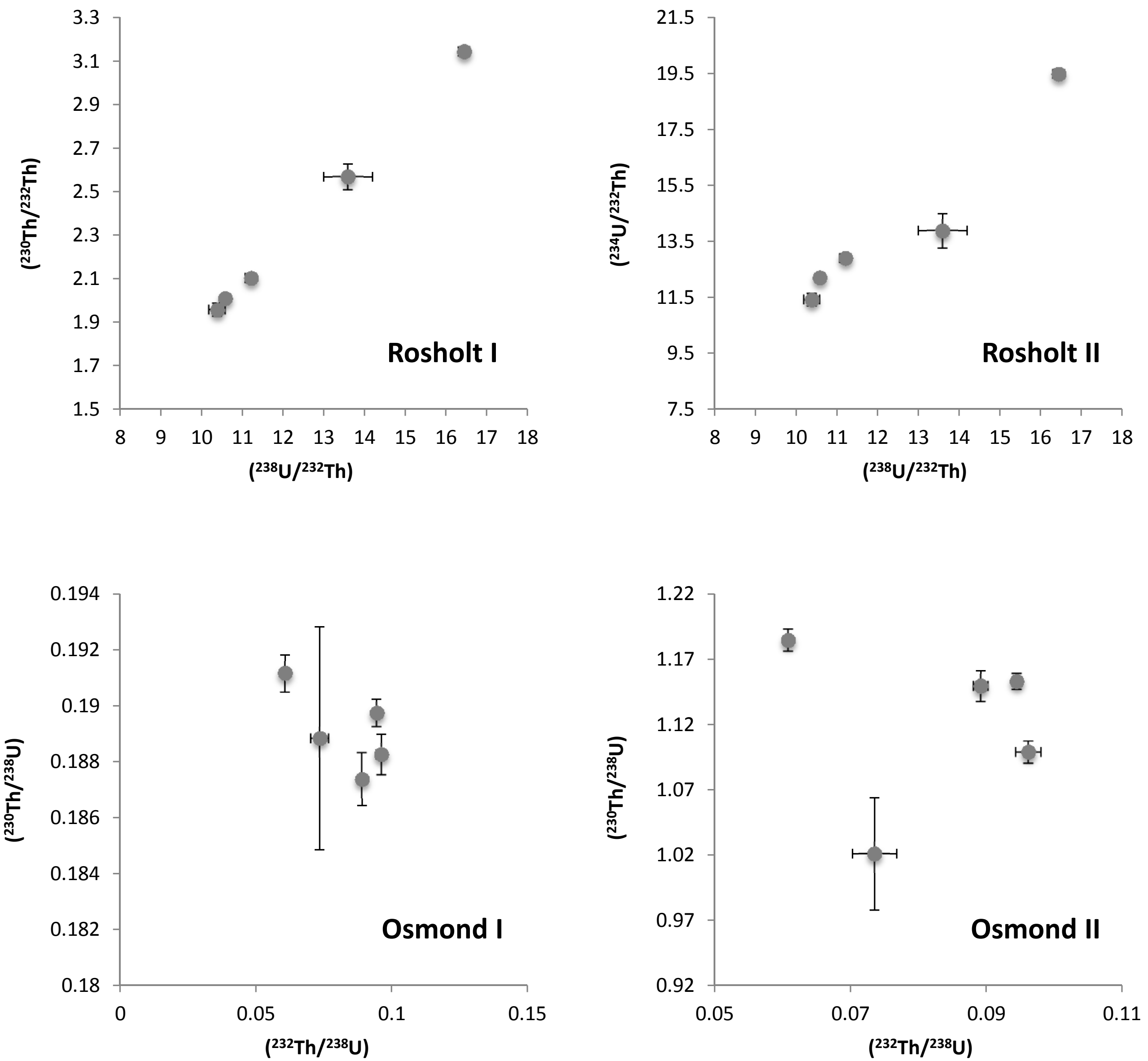
641
640
639
638
637
636
635
Height (masl)
0
100
200
300
400
500
Distance along transect (m)
Section 2
20 ± 1 ka
Section 1
18 ± 3 ka
AZ51
AS42
R/S2/60
19.8 - 18.6 ka BP
17 ± 1 ka
14 ± 1 ka
13 ± 1 ka
22 ± 1 ka
19 ± 1 ka
Section 4
4.5 ± 0.4 ka
Geo Trench
Section 6
3.8 ± 0.3 ka
Section 5
23.6 ± 1.3 ka
21 ± 1 ka
19 ± 1 ka
On-site occupation horizons
Late glacial wetland deposits
Holocene wadi fill

Figure 5



35
30
25
20
15
10
5
0
%
Area A
Area B
Offsite
Very Fine Sand
Very Coarse Silt
Coarse Silt
Medium Silt
Fine Silt
Very Fine Silt
Clay

Figure 6



Rosholt I
Rosholt II
Osmond I
Osmond II
(230Th/232Th)
(238U/232Th)
(234U/232Th)
(230Th/238U)
(232Th/238U)
3.3
3.1
2.9
2.7
2.5
2.3
2.1
1.9
1.7
1.5
8 9 10 11 12 13 14 15 16 17 18
21.5
19.5
17.5
15.5
13.5
11.5
9.5
7.5
0.194
0.192
0.19
0.188
0.186
0.184
0.182
0.18
0 0.05 0.1 0.15
1.22
1.17
1.12
1.07
1.02
0.97
0.92
0.05 0.07 0.09 0.11

Table 1

Table 1 Data summary from sediment samples from Kharaneh IV and surrounding sediments. Mean values ± 1 standard deviation are shown.

Samples locations	Carbon content % weight loss at 550°C	Carbonate content % weight loss at 925°C	Magnetic Susceptibility	MgO %	Al_2O_3 %	SiO_2 %	K_2O %	CaO %	Ti %	Fe_2O_3 %	Sr %
Area A (n=11)	9.0 ± 3.5	10.7 ± 2.6	440.7 ± 100.8	6.2 ± 1.4	9.6 ± 1.0	46.8 ± 3.4	1.2 ± 0.1	26.0 ± 3.7	0.7 ± 0.1	7.3 ± 1.0	0.3 ± 0.1
Area B (n=24)	8.5 ± 2.3	11.3 ± 2.8	224.4 ± 157.6	5.1 ± 0.7	10.7 ± 1.2	46.0 ± 6.0	1.4 ± 0.3	26.2 ± 7.4	0.8 ± 0.1	9.2 ± 1.3	0.2 ±0.1
Off-site (n=17)	7.8 ± 2.3	13.7 ± 5.3	74.5 ± 15.9	3.8 ± 0.4	9.8 ± 1.5	39.9 ± 5.5	1.0 ± 0.4	35.8 ± 8.3	0.7 ± 0.1	8.2 ± 1.1	0.3 ± 0.2

Table 2

Table 2 Dose rate (D_r), Equivalent Dose (D_e) and Age data from Kharaneh IV OSL samples. Further discussion of the samples listed as having limited datable material or significant feldspar contamination can be found in the main text.

Field code	Lab code	K %	Th %	U %	α D_r Gy.ka^{-1}	β D_r Gy.ka^{-1}	γ D_r Gy.ka^{-1}	Cosmic D_r Gy.ka^{-1}	Total D_r Gy.ka^{-1}	D_e Gy	Age (ka)	Comment
Section 1	GL11035	0.83 ± 0.04	5.42 ± 0.42	1.85 ± 0.1	0.35 ±0.02	1.02 ±0.05	0.64 ±0.03	0.21 ±0.02	2.23 ±0.07	39.4 ±7.2	18 ± 3	Limited datable material
Section 2	GL11036	1.07 ± 0.05	6.22 ± 0.44	2.02 ± 0.11	0.39 ±0.03	1.25 ±0.06	0.76 ±0.04	0.19 ±0.02	2.59 ±0.08	51.4 ±2.7	**20 ± 1**	
Section 4	GL11037	0.71 ± 0.04	4.44 ± 0.40	2.67 ± 0.13	0.41 ±0.03	1.03 ±0.05	0.67 ±0.03	0.22 ±0.03	2.33 ±0.07	10.5 ±0.8	**4.5 ± 0.4**	
Section 5 40cm	GL11038	0.84 ± 0.04	5.25 ± 0.38	1.75 ± 0.10	0.33 ±0.02	1.00 ±0.05	0.62 ±0.03	0.16 ±0.02	2.13 ±0.07	44.8 ±2.7	**21 ± 1**	
Section 5 80cm	GL11039	0.69 ± 0.04	3.83 ± 0.36	1.49 ± 0.09	0.27 ±0.02	0.84 ±0.04	0.51 ±0.03	0.17 ±0.02	1.78 ±0.06	34.6 ±2.3	19 ± 1	Limited datable material
Section 6	GL11040	0.97 ± 0.05	6.76 ± 0.52	2.23 ± 0.11	0.42 ±0.03	1.21 ±0.06	0.77 ±0.04	0.22 ±0.02	2.62 ±0.08	10.0 ±0.7	**3.8 ± 0.3**	
Geo B OSL 1	GL11041	0.96 ± 0.05	6.06 ± 0.44	2.10 ± 0.11	0.38 ± 0.03	1.15 ±0.06	0.72 ±0.04	0.22 ±0.02	2.47 ±0.08	37.5 ±1.5	15 ± 1	Limited datable material
GEO B OSL 2	GL11042	1.14 ± 0.06	6.81 ± 0.46	2.19 ± 0.11	0.42 ± 0.03	1.33 ±0.07	0.81 ±0.04	0.21 ±0.02	2.77 ±0.09	61.1 ±3.4	**22 ± 1**	
AZ51 OSL	GL11043	0.88 ±0.05	5.79 ± 0.43	1.97 ± 0.10	0.37 ±0.02	1.08 ±0.06	0.68 ±0.03	0.18 ±0.02	2.32 ±0.07	30.6 ±1.5	13 ± 1	Significant feldspar contamination
R/S2/60	GL11044	1.12 ± 0.05	6.46 ± 0.45	1.91 ± 0.10	0.38 ±0.03	1.27 ±0.07	0.76 ±0.04	0.18 ±0.02	2.59 ±0.08	36.6 ±2.0	**14 ± 1**	
R/S2/60	GL11045	1.02 ± 0.05	5.49 ± 0.42	1.92 ± 0.10	0.36 ±0.02	1.19 ±0.06	0.71 ±0.03	0.19 ±0.02	2.45 ±0.08	41.5 ±2.2	**17 ± 1**	
BS58 OSL 2	GL11046	0.84 ± 0.05	5.04 ± 0.39	1.83 ± 0.10	0.32 ±0.02	0.99 ±0.06	0.61 ±0.03	0.18 ±0.02	2.11 ±0.07	44.6 ±2.1	21 ± 1	Limited datable material
As42 OSL 4	GL11047	0.67 0.04	4.24 ± 0.4	2.07 ± 0.11	0.34 ±0.02	0.90 ±0.05	0.57 ±0.03	0.17 ±0.02	1.99 ±0.06	38.4 ±1.5	19 ± 1	Limited datable material

Table 3

Table 3 Uranium/Thorium age for sample KAL-IV. The isochron age is calculated using a series of subsamples (1-5). Uncorrected U/Th ages for each subsample are given in italics. Average uncertainties (SDs) on U and Th concentrations are calculated from all data measured during the same batch and are 0.45% and 0.67% respectively.

Sub-sample	**U (µg/kg)**	**Th (µg/kg)**	**$^{234}U/^{238}U$**	**$^{230}Th/^{238}U$**	**$^{230}Th/^{232}Th$**	**Age (y.BP)**
KAL-IV-1	8820	2412	1.150 ± 0.011	0.187 ± 0.001	2.100 ± 0.015	*22509 ± 910*
KAL-IV-2	9832	2848	1.153 ± 0.006	0.190 ± 0.000	2.008 ± 0.007	*22827 ± 922*
KAL-IV-3	12102	2256	1.185 ± 0.008	0.191 ± 0.001	3.144 ± 0.015	*23016 ± 930*
KAL-IV-4	10018	2955	1.099 ± 0.008	0.188 ± 0.001	1.956 ± 0.030	*22628 ± 914*
KAL-IV-5	7839	1768	1.021 ± 0.043	0.189 ± 0.004	2.567 ± 0.059	*22705 ± 918*
					Isochron Age (yrs B.P.)	**23560 ± 1247**