


Ge archaeological Investigation of Site Formation and Depositional Environments at the Middle Palaeolithic Open-Air Site of ‘Ein Qashish, Israel

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Abstract ‘Ein Qashish is a Middle Palaeolithic open-air site in the southern Levant, encompassing an excavated area of several hundred square meters and a 4.5-m thick stratigraphic section. Its placement within a fluvial system, combined with the presence of Neanderthal skeletal remains and diverse material culture finds, presents possibilities

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for understanding human behaviour on the open landscape during the late Middle Palaeolithic. The aim of this study is to investigate the depositional and post-depositional processes at 'Ein Qashish, based on the stratigraphic section exposed in the 2013 excavation season. We employed field observations, sedimentology, micromorphology, mineralogy, elemental and isotopic analyses. Our results indicate that the sedimentary sequence, including four archaeological occupation levels, accumulated in a generally low-energy alluvial environment with evidence for syn-depositional localised seasonal water bodies. On-going post-depositional processes related to wetting and drying cycles include shrink-swell and calcite and gypsum pedofeatures. Bone mineral is relatively well preserved. The data suggest limited fluvial and argilliturbation reworking of artefacts, indicating that spatial patterning of lithic and bone assemblages is rather well preserved in some areas. The current analyses do not indicate the presence of combustion features or fire-related residues at the site, although burned lithics occur in low frequencies. The absence of combustion features in the large excavated area and deep stratigraphy contrasts with patterns observed in Middle Palaeolithic cave occupations in the region, adding nuance to a dataset that will enable a better understanding of human activities under sheltered and open-air conditions.

Keywords Open-air sites · Geoarchaeology · Site formation processes · Southern Levant · Middle Palaeolithic · Neanderthals

Introduction

Caves and rock shelters have long been the primary source of archaeological data from the Middle Palaeolithic (250–50 ka) in Eurasia, because they were favoured as locales of group habitation. The visibility of caves and rock shelters on the landscape made them primary targets of prehistoric investigations (Hovers et al. 2014; Sharon et al. 2014), especially since they often provide long and well-preserved sequences relative to open-air sites (Goldberg and Sherwood 2006). Accordingly, geoarchaeological research in the Levant has focused on caves, with several key studies on the reconstruction of human behaviour, depositional and post-depositional processes (e.g. Goldberg and Bar-Yosef 1995; Schiegl et al. 1996; Shahack-Gross et al. 1997, 2004; Karkanas et al. 2007). However, the ethnographic record of mobile hunter-gatherers suggests that in tropical, sub-tropical and sub-temperate climates the majority of activities are carried out in the open landscape (e.g. Yellen 1977; Gould and Saggars 1985; O'Connell 1987; Brooks 1996; David and Kramer 2001). In recent years, a relatively large number of Middle Palaeolithic open-air sites have been discovered and investigated in the Levant (Hovers et al. 2008, 2014; Cordova et al. 2011; Ames et al. 2014; Kalbe et al. 2014; Sharon and Oron, 2014; Zaidner et al. 2014, 2016; and see Hovers, 2017 for summary). Such sites need to be thoroughly investigated to attain a more complete understanding of Middle Palaeolithic decisions regarding settlement patterns, subsistence strategies and technological organisation (Hovers and Belfer-Cohen 2013).

The majority of open-air Lower and Middle Palaeolithic sites that are not raw material quarries are associated with lake or fluvial water bodies. Such environments are dynamic on multiple time scales (seasonal and annual to centennial or millennial; e.g. Brown 1997; Feibel 2001; Malinsky-Buller et al. 2011; Marder et al. 2011), resulting in variable effects on anthropogenic remains such as scattering by fluvial reworking or dissolution by water. As archaeologists, we observe the sum of such

effects. The understanding of site formation processes and an evaluation of their effects on the archaeological record is therefore key to our investigations. Most of the few available geoarchaeological studies on Middle Palaeolithic open-air sites in the Levant (see review in Zaidner et al. 2016) employed a single analytical technique for elucidating such processes. With the excavation of the site of ‘Ein Qashish in northern Israel, we now have an opportunity to conduct a multi-method investigation of an open-air Middle Paleolithic site on a flood plain, addressing in detail aspects of the site’s formation processes and how they impacted the archaeological remains.

‘Ein Qashish

The site complex of ‘Ein Qashish is located on the floodplain of the Qishon stream, 16 km east from the stream’s modern outlet into the Mediterranean Sea at the Haifa Bay and ca. 1 km north from the slopes of Mt. Carmel (Fig. 1a). The site is located just upstream from a narrow gap between the Carmel Mountain and the Tiv’on Hills to the North (Fig. 1b). The lithology of the Carmel Mountain consists of Upper Cretaceous limestone, dolomite, chalk and marl, whereas the Tiv’on Hills are composed of Eocene chalk, chalky limestone and marl. At its upper reaches, the drainage system of the Qishon also includes Upper Cretaceous carbonate rocks and Miocene basalts from the lower Galilee (Greenbaum et al. 2014).

The site was discovered in 2004, first excavated in 2005 (Hovers et al. 2008), and then in the years 2009 to 2011, when an archaeological level containing Middle Palaeolithic lithics and bone remains was uncovered (Ekshtain et al. 2014; Hovers et al. 2014; Malinsky-Buller et al. 2014). During these first excavations, six stratigraphic units were identified and described, of which Unit 2 (composed of dark loamy clay and carbonate gravel dated by OSL to 70,000–60,000 years BP) comprised the main archaeological level (Hovers et al. 2014; Greenbaum et al. 2014). Geological trenching in 2012 suggested a distribution of Middle Palaeolithic finds over an area of a minimally ~ 1400 m² along the Qishon flood plain (Hovers et al. 2014).

In 2013, a large salvage excavation, due to extensive road construction, took place at the site (Barzilai et al. 2015). This excavation is located some 30 m southeast of the 2009–2011 excavation. The 2013 excavation was conducted in six different areas (Fig. 1c) over a total area of 650 m² and to a maximum depth of 4.5 m below surface, extending the previously estimated spatial distribution of the Middle Palaeolithic occupation area. The newly exposed stratigraphy was correlated to that studied by Greenbaum et al. (2014) in the previous excavations. Thus, the stratigraphic section in the 2013 excavation comprises of Units 2–5 (numbered from bottom to top, Fig. 2), which are of Pleistocene age. Units 6–10 were not exposed at the 2013 main excavated area; thus Unit 5b is overlain by Unit 11, which is of Holocene age¹ and does not contain Palaeolithic remains (a contact marking a significant unconformity; Fig. 2). Unit 11 will therefore not be discussed further. Groundwater appeared during excavation at

¹ The stratigraphic scheme reported in Been et al. (2017) was based on observations in the 2013 excavation and referred to layers 1–6. The scheme presented here is based on correlation done across all the excavation areas and trenches studied over the years and will be reported in detail in Ekshtain et al. (in preparation). Following this revision, we use the terminology of ‘units’ instead of ‘layers’. Layer 6 mentioned in Been et al. (2017) is thus equivalent to Unit 11 in this study. Designations of earlier stratigraphic units at the 2013 excavation area (Units 2–5), which include the MP materials, have not changed. Units 7 (late Pleistocene) and Units 9–10 (Holocene) were observed only in Area A of the 2013 excavation.

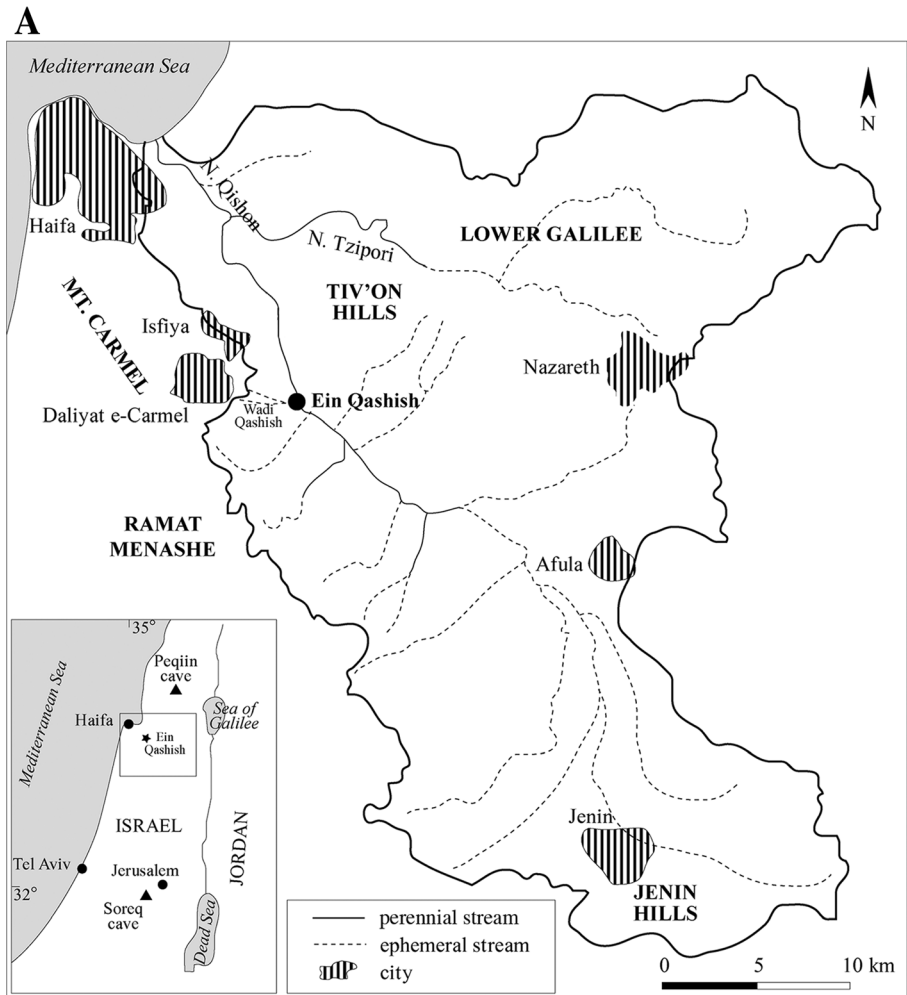


Fig. 1 The site of ‘Ein Qashish. **a** Drainage basin of the Qishon stream (redrawn after Greenbaum et al. 2014, p. 204). **b** Photograph taken from Mt. Carmel looking NEE showing the setting of the site on the floodplain of the Qishon stream. The stream flows northwest and drains into the Mediterranean Sea. Tel Qashish is an urban historic site built on a natural chalk hill. **c** Plan and photos of the excavation areas and trenches at ‘Ein Qashish. Note the high number of trenches dug across the site (trenches annotated TQ were dug during 2009–2011 excavations and trenches annotated T were dug in 2012 by the IAA as part of a large-scale survey). The red arrow indicates the location of the profile depicted in Fig. 2a. Photo of Area A (left) with a view to the west towards Mt. Carmel and of Areas B to F (right) to the southeast

topographic levels corresponding to Unit 3a and limited the extent of fieldwork. Unit 2 was therefore exposed only sparsely and patchily across the excavation areas and was not sampled for this study. The exposures of Units 3–5 observed in the 2013 excavation provide the materials as well as the lateral and stratigraphic scope for the research reported here.

The sediments at the site generally consist of greyish-brown loamy clay. Unit 3 was subdivided into two parts based on sediment colour, with the lower sub-unit 3a being darker. The contact between sub-units 3a and 3b is gradual. Unit 4 was defined in the

B



Fig. 1 (continued)

C



Fig. 1 (continued)

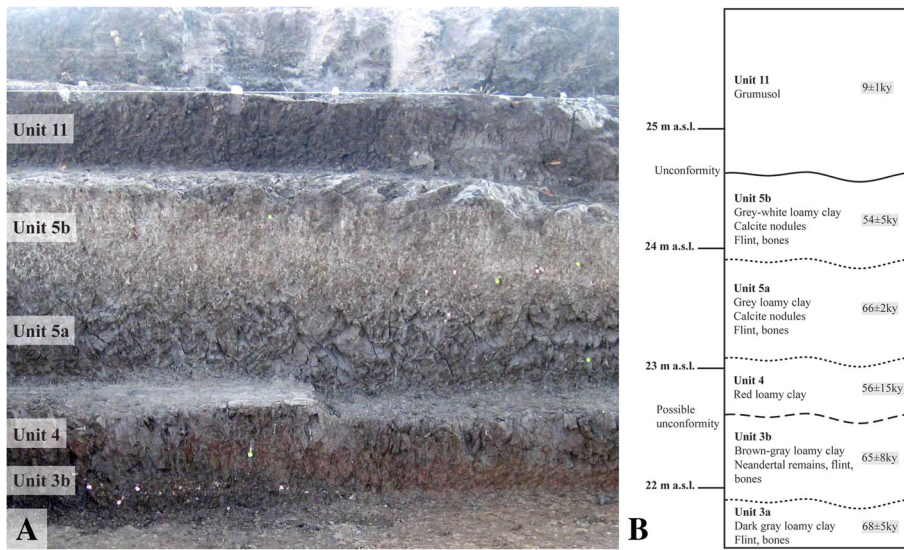


Fig. 2 Sediments and stratigraphy. **a** Photograph showing the sedimentary units 3b, 4, 5a, 5b and 11 as exposed on the north section of Area B. Note the brown colour of Unit 3b, red colour of Unit 4, dark grey colour of Unit 5a and light grey colour of Unit 5b. Unit 3a, below Unit 3b, is not visible in this photograph. **b** Schematic drawing of the general stratigraphic sequence compiled based on the study of sediments and artefacts. OSL ages (after Been et al. 2017) appear in shaded grey boxes

field based on its reddish colour. It is relatively thin (less than 1 m), and its thickness appears to change laterally, with an apparent thin concave shape. It is almost barren of archaeological remains. The unit presents clear (yet not ‘knife-sharp’) contacts with the underlying Unit 3 and overlying Unit 5 (Figs. 2a, b). Unit 5 was defined based on the presence of abundant white nodules. The concentration of white nodules in this unit decreases with depth, hence the separation into the lower sub-unit 5a (low nodule concentration) and upper sub-unit 5b (higher nodule concentration) (Fig. 2a). Archaeological remains in this unit are often covered by white crusts.

Other characteristics of the sediments in Units 3–5 include slickensides, rhizoliths, gypsum crystals/nodules and gravel lenses. Archaeological materials consist of stone artefacts (knapped flint and limestone and possibly a few anvils), faunal remains (anthropogenically transported and modified) and Neanderthal remains, the latter constituting the first known diagnostic human remains in a Levantine Middle Palaeolithic open-air site (Been et al. 2017). The leg bones (a femur, two tibiae and two fibulae) were found in partial articulation within Unit 3b in Area B of the excavation, in close proximity to Middle Palaeolithic stone tools and animal bones (Been et al. 2017). The occupation levels at the site date to 70,000–55,000 years ago (Been et al. 2017), in agreement with the 2009–2011 dated archaeological levels (Greenbaum et al. 2014).

Studies of site formation (Hovers et al. 2014; Boness and Goren 2016) and paleoenvironments (Greenbaum et al. 2014) at ‘Ein Qashish were initiated in the small-scale 2009–2011 excavations. These studies interpreted the general depositional environment as alternating between marshy wetland and dry areas, with human activities associated with the latter. These studies also identified fluvial reworking as well as wetting and drying cycles as the main natural formation processes that affected

the dispersal of artefacts across the archaeological level. As the excavation area was located at the mouth of a small tributary (Wadi Qashish) running off Mt. Carmel, fluvial reworking was associated mainly with the activity of this channel. Geoarchaeological evidence was not detected for combustion features, hearths or ash rake-out, which are prevalent in Levantine Middle Palaeolithic occupation levels in caves. However, Hovers et al. (2014) and Ekshtain et al. (in preparation) observed the presence of burned lithic artefacts and of burned unmodified flint clasts in the 2009–2011 and 2013 excavations, respectively. ‘Ein Qashish thus resembles many other open-air sites where there is scarce evidence for fire use (but see field evidence for fire reported for Fara II; Gilead and Grigson 1984; Gilead 1988; and macro- and microscopic evidence from Neshar Ramla; Friesem et al. 2014). One possible scenario to explain this scarcity is that post-depositional processes alter and erase the evidence for fire use in open-air settings in contrast to the more sheltered cave sites (e.g. washing away or dissolution of ash by rain). The other possibility is that fire was not used at the site. We address these questions via microscopic techniques applied to the large spatial sample available from the 2013 excavations.

The research presented here aims to provide higher-resolution insights into the formation processes of the site of ‘Ein Qashish, with special reference to its location in an active fluvial environment. To this end, we benefit from the paleo-environmental perspectives offered by the large area of the excavation, mining environmental information embedded in sediments and bones found on-site. Specifically, we focus on three goals: (1) to fine-tune our understanding of the syn- and post-depositional processes that formed the sedimentary units along the stratigraphic sequence; (2) to investigate the state of preservation of bones, the only study of this type to take place at an open-air MP site in the Levant, and (3) to tie depositional environments with human activity and address evidence for on-site combustion. We employ several complementary geoarchaeological techniques (see below) and contextualise all lines of evidence (Goldberg and Berna 2010). This approach allows us to propose high-resolution reconstructions of the depositional history of the site and how it influenced the formation of the archaeological record found in it.

Materials and Methods

In this study, we coupled detailed field observations and sampling with a battery of laboratory analyses. Sediment and bone samples were collected from Units 3–5 across all excavation areas. The mineralogy and elemental composition of sediments were investigated through FTIR, ICP-MS and XRD analyses. Sediment pH and its total organic carbon content were measured as well. The white nodules found in all levels were studied using stable carbon and oxygen isotopic analysis. The preservation state of bones was studied through acid dissolution to determine presence/absence of collagen and the crystallinity of bone mineral was assessed via the infrared indicator known as splitting factor. The elemental composition of bones was tested using SEM-EDS, XRF and ICP-MS analyses. The overall sedimentary processes were evaluated using micromorphology. Each method is described in detail in Online Resource 1 (Materials and Methods) and complete sample lists are provided in Online Resource 2.

Table 1 Bulk mineralogy based on XRD and FTIR analyses. Major minerals 20–50%; minor minerals 5–20%; trace minerals < 5%. Total organic carbon (TOC) values represent the average and standard deviation between two measurements

Unit	Major minerals	Minor/trace minerals ^a	Dominant clay mineralogy ^b	TOC (%)
3a	Clay, quartz	Calcite, plagioclase	Smectite	0.6 ± 0.06
3b	Clay, quartz	K-feldspar, calcite	Smectite	0.2 ± 0.04
4	Clay, quartz	Plagioclase, K-felds.	Illite	0.3 ± 0.02
5a	Quartz, calcite, clay	Plagioclase, K-felds.	Smectite	0.1 ± 0.0
5b	Calcite, clay, quartz	Plagioclase, K-felds.	Smectite	0.3 ± 0.23

^a Other trace minerals include: anatase, aragonite, gypsum, dolomite

^b Kaolinite is found in all samples as a minor mineral

Results

The following presents an overview of the results, starting with sedimentology, followed by carbonate nodule and bone analyses. Analytical data are presented in the [supplementary online material](#).

Sedimentology

Bulk mineralogical analysis via XRD and FTIR showed that the major minerals composing the site's sediments in all stratigraphic units are clay, quartz and calcite (Table 1). Units 3 and 4 are dominated by clay, while Unit 5 shows a more variable mineralogy with higher amounts of calcite. Unit 4 is markedly different in its illitic clay mineralogy relative to the smectitic clay typical of all other units. Total organic carbon in the sediments is highest in Unit 3a ($0.6 \pm 0.06\%$) and rather similar among the other units ranging between 0.1 and 0.3% (Table 1). Despite differences in calcite content, all sedimentary units have similar pH levels, ranging between 7.0 and 7.7.

Macroscopic observations on thin sections representing all units show the colour differences, the fine-grained nature of the groundmass of all units, the gravel inclusions typical of Unit 3a and calcite nodules dominant in Unit 5 (Fig. 3). Micromorphological analysis shows that quartz grains are mostly of silt to fine sand size across all units.

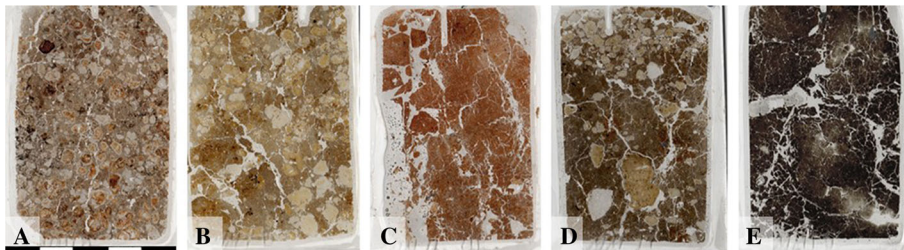


Fig. 3 Scans of thin sections produced from the various stratigraphic units. Scale is 5 cm long. **a** Unit 5b; note the high frequency of rounded whitish and brownish (iron-stained) calcite nodules. **b** Unit 5a; note lower frequency of calcite nodules relative to Unit 5b. **c** Unit 4; note the reddish, fine-grained and homogenous nature of this deposit. **d** Unit 3b; note its brown colour and gravel associated with a fine-grained deposit. **e** Unit 3a; note the dark brown colour and the fine-grained nature of this deposit

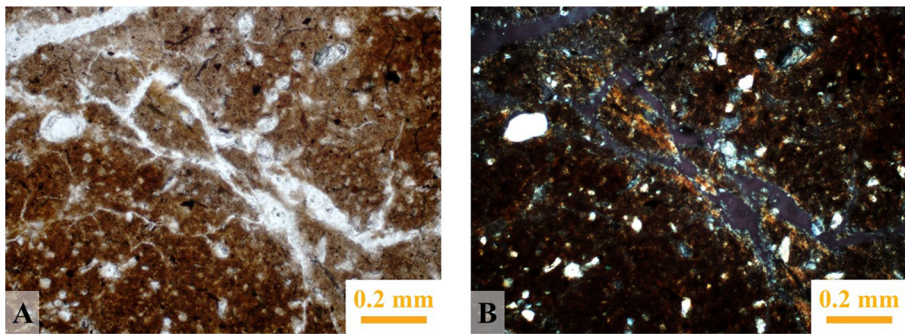


Fig. 4 Microphotographs from Unit 3a. **a** Prismatic microstructure showing fissures with accommodating planes indicating shrink-swell processes. Plane-polarised light (PPL). **b** Same as **a** in cross-polarised light (XPL). Note the bright streaks along the fissures indicating orientation of the clay particles as the result of shrinking and swelling processes

Gravel sized particles include rounded chalk, shells (mollusc), bones and flint where sediments are associated with an archaeological occupation level. The clay exhibits a weakly poro- and granostratified fabric indicative of shrink-swell cycles. Secondary (pedo-) features include rhizoliths, calcite nodules and gypsum crystallizations, as well as iron-manganese (Fe-Mn) oxide staining, coatings and concretions (see more details in Online Resource 3). The overall microstructure is prismatic, with accommodating planes and slickensides (Fig. 4). Variations in the amount of microscopic Fe-Mn oxides (nodules, coatings and matrix), the quantity of white calcite nodules and dark amorphous organic matter are the main factors causing the macroscopic colour differences among the units. Unit 3a is uniquely darker than the other units (Fig. 3e), including concentric nodules composed of alternating layers of clay and amorphous iron hydroxide, possibly pisolites, reflecting the saturated, reducing, nature of this unit.

In thin section, the transition from Unit 3a to 3b is gradual and hard to detect. Unit 3b includes gravel lenses composed of calcite nodules, rounded chalk (Fig. 5a), limestone and volcanic rock fragments and rare occurrence of mollusc shell fragments, bone (Fig. 5b), angular flint, plant organic residues (resembling modern root intrusions) and charophytes. Unlike 3a, Unit 3b includes calcareous hypocoatings, while micritic calcite

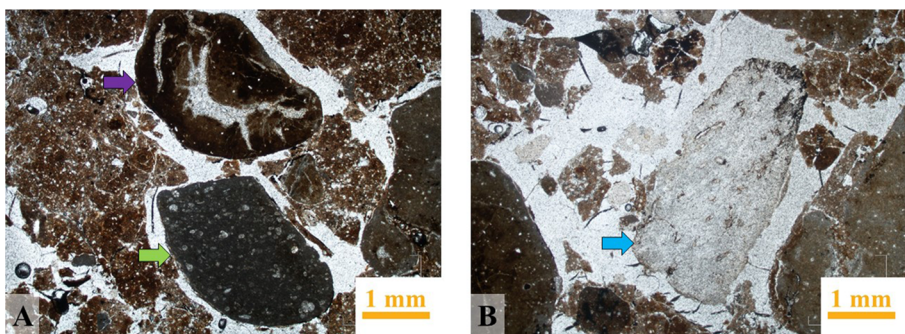


Fig. 5 Microphotographs from a gravel lens in Unit 3b. **a** A calcite nodule (purple arrow) and chalk (green arrow). Note the strong, homogenous iron impregnation of the calcite nodule and that its sparry centre is not iron-impregnated, which indicates later sparry recrystallization and that the nodules are pedogenic. PPL. **b** Bone fragment (blue arrow). PPL

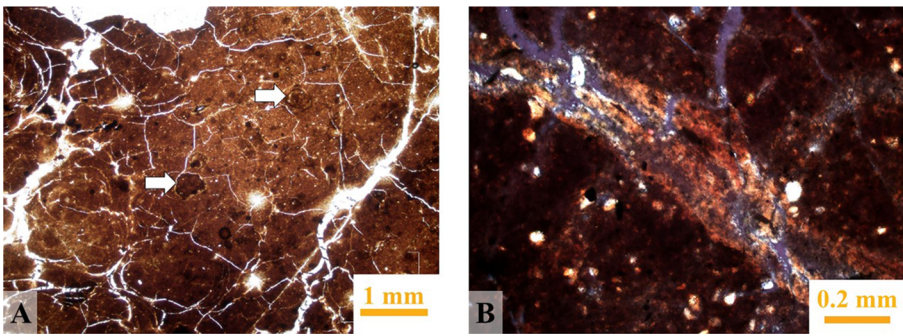


Fig. 6 Microphotographs from Unit 4. **a** Homogenous red (iron oxide-stained) fine-grained sediment having prismatic and spheroidal microstructures. Note the Fe/Mn nodules (white arrows). PPL. **b** Slickensides resulting from shrinking and swelling processes, here in thin section EQ 13 MM9. XPL

nodules are commonly iron impregnated, with sparry (non-Fe-impregnated) domains (Fig. 5a). Calcite nodules show the same properties in all stratigraphic units (see Fig. 3 and more below).

The transition from Unit 3b to 4 is clear in the field but gradual in thin section. Macroscopically (and microscopically), this unit differs from all others at the site by its reddish colour (Fig. 3c). Microscopically, it differs from the other units by its prismatic to spheroidal microstructure and a groundmass heavily impregnated by massive, amorphous, oxidised iron (Fig. 6). Some irregular and regular Fe-Mn oxide nodules are also present (Fig. 6). Few calcite nodules and hypocoatings are present.

The transition from Unit 4 to 5a is clear in the field but gradual in thin section. Calcite nodules are common in Unit 5a and their frequency increases upwards (Figs. 3a, b), evident also in the occurrence of domains of calcitic crystallitic b-fabric. Calcite nodules are disorthic (i.e., with sharp boundaries) and rounded (Fig. 7a), features that are common in vertisols, resulting from argilliturbation (Blokhuis et al. 1969; Kovda and Mermut 2010). They are commonly iron-impregnated (except for sparry domains). Irregular Fe-Mn nodules and hypocoatings are rare. An example of gypsum intergrowth associated with a calcite nodule has been observed (Fig. 7b).

The transition from Unit 5a to 5b is gradual in the field as well as in thin section. Unit 5b shows an almost ‘nodule-supported’ microstructure (Figs. 3a and 8a), reflecting the

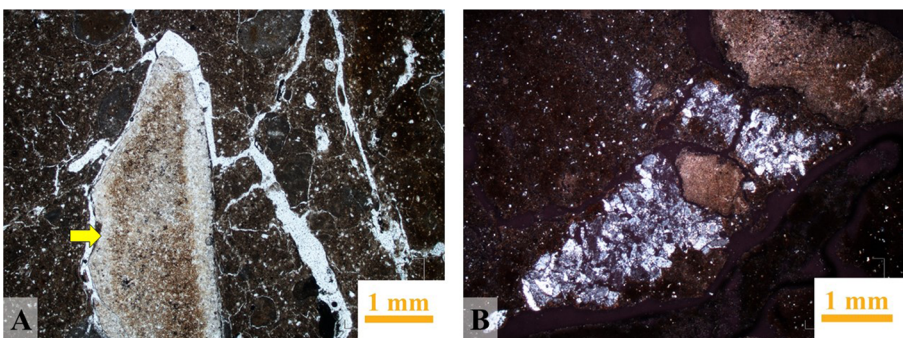


Fig. 7 Microphotographs from Unit 5a. **a** Vertically oriented flint fragment (yellow arrow). Note the accommodating planes indicating shrink-swell processes. PPL. **b** A gypsum pedofeature. Note the calcite nodule appearing among the gypsum crystals indicating complex timing of pedofeature formations. XPL

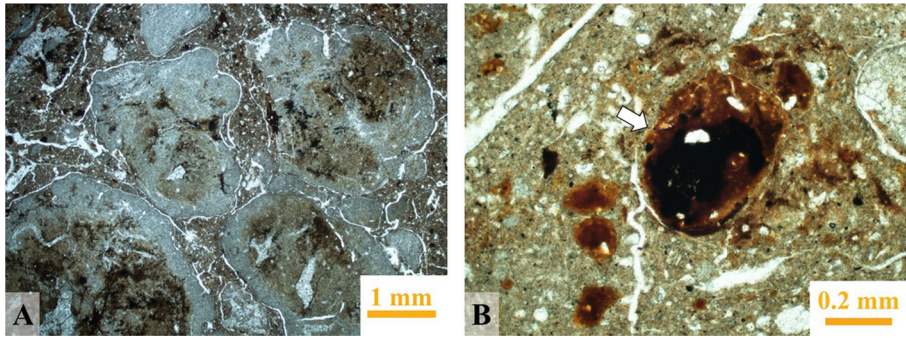


Fig. 8 Microphotographs from Unit 5b. **a** A ‘nodule-supported’ microstructure illustrating the abundance of calcite nodules in this stratigraphic unit. PPL. Note the complexity of the nodule formation illustrated here. Nodules seem to be composed of several parts, possibly pressed together by argilliturbation, which then continued to grow and shape as one nodule. **b** An anorthic Fe/Mn nodule (white arrow). PPL

dominance of calcite nodules in this unit. Irregular Fe-Mn nodules (Fig. 8b) and hypocoatings decrease upwards.

In summary, the sedimentological attributes of the studied stratigraphic sequence indicate that it is uniformly composed of clay with silt to fine sand quartz, suggesting one fluvial source of sediment transport. Gradual increase with depth in the frequency of Fe-Mn nodules and hypocoatings correlates with proximity to ground water level (i.e. hydromorphic conditions). On the other hand, the frequency of calcite nodules decreases with depth. As micromorphology ruled out the possibility that calcite nodules are allochthonous rolled chalk fragments from the Tiv’on Hills, the question of interest becomes whether the pattern of decreasing frequency of calcite nodules with depth formed through deposition from rising (thus evaporating) groundwater or downward percolation typical of pedogenic processes. This is addressed in the next section.

Oxygen and Carbon Isotopic Composition of Calcite Nodules

To address and test the two possible pathways of calcite nodule formation, the oxygen and carbon isotopic compositions of 16 nodules, from Units 3b, 4, 5a and 5b, have been analysed. $\delta^{13}\text{C}$ values plotted against $\delta^{18}\text{O}$ values of these 16 calcite nodules are presented in Fig. 9. The results show that the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values of the nodules from Unit 3b (-12.4 to -8.3‰ and -5.6 to -3.5‰ , respectively) considerably differ from those measured from Unit 4 (-8.9 to -7.4‰ and -3.4 to -0.9‰ , respectively) and Unit 5 (-9.2 to -6.0‰ and -4.3 to -2.2‰ , respectively), with the isotopic values of the nodules from Units 4 and 5 occurring within a similar range.

In order to gain further information on paleo-environment and site occupation, we studied the mineralogy and chemistry of bones.

Bones

Field appearance of the bones varied stratigraphically, with bone surfaces from Unit 3 being mostly orange and/or dark-coloured and bones from Unit 5 often coated by thick white crusts. FTIR analysis clarified that the white crusts on bones from Unit 5 are calcite (Nir 2016; Online Resource 4) while XRF analysis showed that the dark

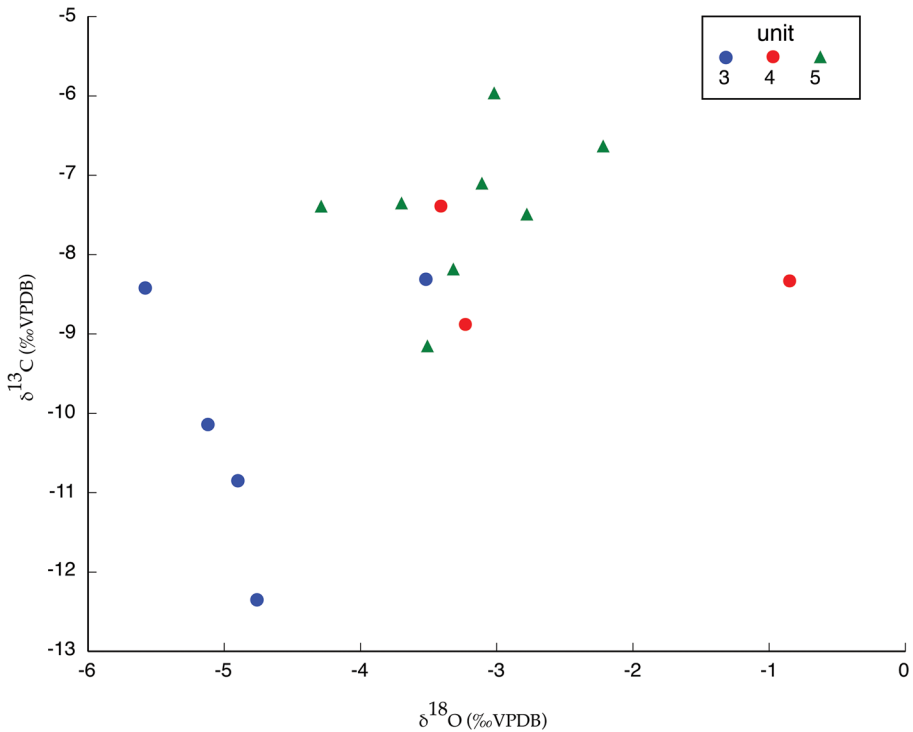


Fig. 9 A plot of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values of 16 calcite nodules from stratigraphic Units 3b (blue circles), 4 (red circles) and 5 (green triangles; Units 5a and 5b). Note the low values of both oxygen and carbon isotopic compositions in nodules from Unit 3b, relative to the higher and overlapping values of nodules from Units 4 and 5, suggesting that Unit 3 was deposited under wetter and most likely cooler conditions

colouration on bones from Unit 3, as well as the rare bones from Unit 4, is from Fe-Mn oxyhydroxides (Nir 2016; Online Resource 5).

After dissolution of bones and analysis of the remaining insoluble fraction using FTIR spectroscopy, it became evident that bones in ‘Ein Qashish did not contain either collagen or pyrolyzed collagen (cf. Shahack-Gross et al. 1997) and that the insoluble fraction was composed of detrital clay and quartz. The prevalence of Fe-Mn oxides and absence of pyrolyzed collagen in dark-coloured bones indicate that bone colouration is due to post-depositional staining rather than burning (Nir 2016). Calculated values of the infrared bone crystallinity index (IRSF; Weiner and Bar-Yosef 1990) were plotted in reference to the full width at half maximum of the hydroxylapatite main absorbance band at 1030 cm^{-1} , following Asscher et al. (2011) (Fig. 10). The results show that bone mineral crystallinity is typical of archaeological bones and is similar across the site regardless of excavation areas or stratigraphic units.

Elemental analyses were carried out primarily on material scraped from the external surfaces of bones to identify environmentally informative elements. Chlorine and barium were found in high concentrations in bones from Unit 4 compared to bones from the other units (Online Resource 6). Rare earth elements (REE) are abundant, with cerium reaching as much as 0.7% by weight of a bone

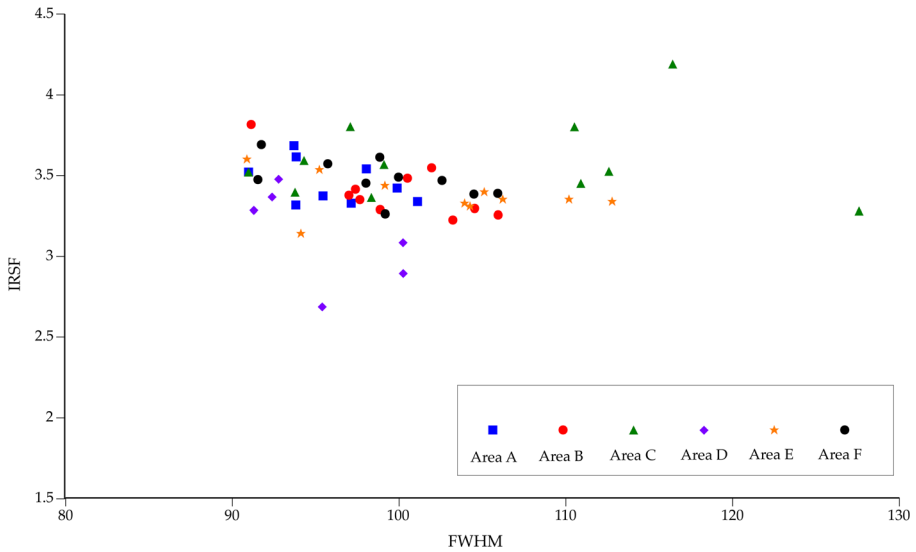


Fig. 10 A plot showing the relationship between bone crystallinity index as calculated from infrared spectra (IRSF; Infrared Splitting Factor) in relation to the full width at half maximum (FWHM; in wavenumber units, following Asscher et al. 2011) of the main phosphate absorbance which reflects both crystallinity and aggregate size (an effect of sample grinding; see explanation in Online Resource 1). Values from all excavation areas and all stratigraphic units cluster together, indicating that bone mineral across the site underwent similar diagenetic processes

surface sample (Online Resource 7). Cerium anomaly, a geochemical marker for shifts between oxidising and reducing conditions in sedimentary contexts (De Baar et al. 1983), has been identified in bones from Unit 4 only, with a negative cerium anomaly indicating a shift from reducing to oxidising conditions in the past burial environment of Unit 4 (Fig. 11). The relationship between La/Sm and La/Yb

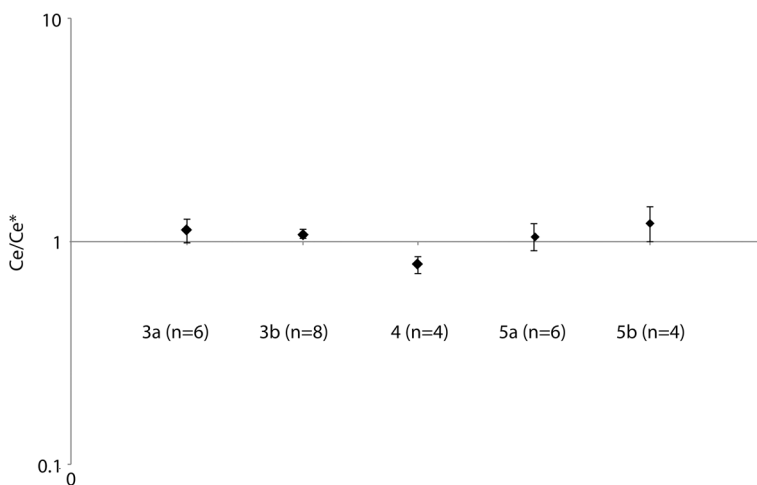


Fig. 11 A plot showing a log diagram of normalised cerium values (Ce/Ce^* ; see more in Online Resource 1) from bones from stratigraphic Units 3a, 3b, 4, 5a and 5b. Note the slight negative anomaly in bones from Unit 4, indicating a change from reducing to oxidising conditions in the paleo pore-waters of Unit 4 sediments

representing light and heavy REE, respectively, serves as a geochemical marker for general depositional environments (Trueman et al. 2006), placing ‘Ein Qashish in an environment that is between marine/coastal to fluvial/terrestrial (Online Resource 8).

Discussion

The battery of field and laboratory analyses of sediments and bones from ‘Ein Qashish enabled the reconstruction of the depositional and post-depositional processes at the part of the site exposed in 2013.

Depositional Processes and Environments

The sediments from all stratigraphic units in all excavation areas studied here were formed by the deposition of clay loam in an alluvial floodplain setting, in agreement with Greenbaum et al. (2014). The dominance of clay, together with the silt to fine sand sizes of quartz grains, indicates a general low-energy depositional environment, most plausibly overbank deposits. We did not observe bedding, probably due to post-depositional obliteration by argilli- and bioturbation. However, localised accumulations of gravels may indicate episodes of higher depositional energy in these contexts. The composition of the gravel (basalt, chalk and limestone) represents the lithology of the drainage system of the paleo-Qishon stream, including gravel from Wadi Qashish. The regularity in size and shape of the quartz grains is similar to characteristics found in aeolian deposits and soils in the region (Singer 2007). We therefore assume that the fine sediments and gravel originate primarily from reworked soils and rock outcrops transported by the Qishon stream. All units include rhizoliths indicating that these sediments supported live vegetation in the past, which implies episodes of unknown duration of surface stabilisation (i.e., no significant sediment movement, allowing onset of vegetation and soil formation). Sedimentary characteristics of semi-permanent water saturation include a prismatic structure, slickensides and redoximorphic features (mottling, Fe-Mn coatings, hypocoatings and nodules). These are more frequent in the deeper units (3a and 3b) due to their proximity to the groundwater table (Kovda and Mermut 2010; Lindbo et al. 2010). The higher organic carbon content in Unit 3a may relate to its more permanent saturation conditions relative to the other sedimentary units. Repeated changes in water saturation caused shrink-swell cycles that resulted in small-scale spatial disruption along slickenside surfaces and grano- and poro-striated birefringence fabrics.

Overall, the macroscopic and microscopic observations conducted during and following the 2009–2011 (Greenbaum et al. 2014; Boness and Goren 2016) and 2013 (current study) excavations point to a variety of depositional settings in the paleo-Qishon alluvial system. These include deposition primarily under low-energy conditions (further supported here by the micromorphological identification of charophyte remains that flourish in low-energy water bodies), the presence of gravel lenses transported in high-energy fluvial channels and alternating wetting and drying episodes. The deposits do not include preserved vegetal matter (i.e. no peat formation), indicating

that low-energy sedimentary environments, such as marshes, were generally oxidising, probably undergoing seasonal flooding (i.e. short-term reducing conditions) and recurrent evaporation (i.e. transition to oxidising conditions).

Human activity (evident from lithics and bones) took place across space within this changing alluvial environment. Certain localities appear to have been buried shortly after human occupation, preserving *in situ* activity evidenced by articulated faunal and human skeletal parts and tightly-spaced refitted lithics. In other areas, slight displacement of artefacts occurred (Hovers et al. 2014; Been et al. 2017). Nevertheless, the episodes of human occupation must have taken place on relatively dry surfaces. Greenbaum et al. (2014) and Boness and Goren (2016) raised the option that human activity was conducted next to a permanent water body such as a swamp. This study revealed direct evidence for the presence of a shallow water body, as discussed in the next section.

Syn- and Post-Depositional Processes

Syn- and post-depositional processes were revealed through field observations, the chemical composition of bones and stable isotope compositions of calcite nodules. Stratigraphic Unit 4 stood out as an exceptional deposit due to its reddish colour, thin basin shape and scarcity of lithic and bone remains. Micromorphology showed that the red colour is due to extensive staining by oxidised iron and that the contact between Units 3b and 4 that appeared sharp in the field was in fact gradual, showing continuation of the same type of sediment. The few bones obtained from this unit include, in addition to iron and manganese that are present in bones from all stratigraphic units, the elements chlorine and barium in significantly higher concentrations than found in bones from Units 3 and 5. Both elements are highly soluble in water and may originate from sea spray, which can travel hundreds of kilometres inland (e.g. Bondy et al. 2017), a suggestion that may be supported by the pattern obtained from the light and heavy rare earth element (REE) composition (Online Resource 8). The high concentrations of chlorine and barium on bone surfaces indicates that these elements have been present in soluble form in the vicinity of bones during deposition of Unit 4, for a sufficiently long time to allow adsorption on bone surfaces. Moreover, while bones from all stratigraphic units include a variety of adsorbed rare earth elements (REEs), only bones from Unit 4 show a negative cerium anomaly, suggesting that the depositional environment in Unit 4 changed from reducing to oxidising (Bau and Koschinsky 2009). Another observation that discriminates Unit 4 as unique is the dominance of illitic clay rather than the smectitic clay typical to Units 3 and 5. Taking all these observations together we propose a ‘seasonal water body hypothesis’ as follows:

Sediment transported by the paleo-Qishon stream accumulated at the study area forming Unit 3, concomitant with human activity. Seasonal water accumulation may have occurred in a natural shallow depression, possibly as the result of overbank flooding (an analogous process can be observed at present after rainy winters). The standing water induced reducing conditions along with intensive formation of iron and manganese oxihydroxides. The water included dissolved REEs from the drainage system as well as chlorine and barium from sea spray. Human activity took place around this seasonal water body, a suggestion that is consistent with the scarcity of bones and lithics in Unit 4 deposits. The few bones found in Unit 4 may have been either

tossed or have rolled naturally into this water body, where they adsorbed chlorine, barium and REEs. Upon complete rotting of vegetal matter and/or drying up of the water body, oxidising conditions occurred whereby cerium was scavenged from bone surfaces and a negative cerium anomaly was created. The strong oxidation resulted in the deep red iron oxide staining of the sediments along with diagenetic transformation of the smectitic clay into illite (see e.g. Sandler 2013). Assuming that the red-coloured sediment indicates the bottom of the water body, the exposures of Unit 4 in Areas B, F and E as well as in the sections west of Area F (Fig. 1c) indicate that its extent should be minimally $\sim 30 \times 20$ m.

The ‘seasonal water body hypothesis’ presents our understanding of non-anthropogenic depositional processes that occurred partly in parallel with human activities during the deposition of Units 3 and 4. Other frequent features in the ‘Ein Qashish deposits, including calcite and gypsum nodules, are often regarded as post-depositional and are related to changes in the groundwater table, pedogenesis and evaporation (Durand et al. 2010; Poch et al. 2010).

Calcite nodules and hypocoatings are prominent secondary pedofeatures in Unit 5. Their frequency diminishes with depth through Units 4 and 3. The calcite nodules at ‘Ein Qashish show a mixed pattern of crystal sizes, dominantly micritic with sparry domains. Micritic crystals are characteristic of a formation above the saturated zone (i.e. pedogenic) whereas sparry crystals form in the saturated zone (Durand et al. 2010). The pattern of iron impregnation—only affecting the micritic part and not the sparry domains—suggests that the micritic pattern is the original formation structure and that the sparry domains formed by later recrystallization, which is common in pedogenic calcite nodules (Wieder and Yaalon 1974). The analysis of stable carbon and oxygen isotopes of calcite nodules from Units 3, 4 and 5 helps us to better evaluate the two possible scenarios.

The results (Fig. 9) show a considerable difference in the isotopic values of calcite nodules along the stratigraphic section, indicating they formed by pedogenic processes (see rationale in Online Resource 1). The coupling of low $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values which characterises the nodules of Unit 3b indicates that they formed under wetter and most likely cooler conditions associated with dominance of C3 vegetation, compared to the conditions that prevailed during the deposition of Units 4 and 5 (Ayalon et al. 2017). The exact time of pedogenic nodule deposition in any of the units cannot be determined by either radiocarbon or U-Th methods, since they constitute an open system and include detrital Th, respectively. As the nodules represent post-depositional precipitation, we cannot determine with certainty whether or not an unconformity in sedimentation occurs between Units 3b and 4, even though the considerable difference in isotopic values of nodules from Unit 3b vs. Units 4–5 may support such a scenario.

Notably, there are no significant differences between the OSL ages obtained for the various units from the silicate component (quartz; see Been et al. 2017), showing that sediments of Units 3, 4 and 5 were deposited at the time interval between about 70 and 55 ka ago. This time interval is characterised by climatic oscillations represented by variations of isotopic values on the order of 1‰ (Bar-Matthews et al. 2003). Considering the characteristic features of the $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values, it is reasonable to assume that the pedogenic nodules in Unit 3b and those from Units 4–5 were formed under different climatic regimes, i.e. different time periods.

Apart from calcite, gypsum also appears as a secondary component, either as nodules or as single (often large) crystals. Because gypsum would dissolve in sediments saturated by fresh water, its presence is consistent with the scenario of repeated cycles of dissolution and re-precipitation. The interwoven process of calcite and gypsum secondary formations is exemplified by the presence of both, a gypsum intergrowth and a calcite nodule, in the same void (Fig. 7b).

The last syn- and post-depositional process observed at the site relates to displacements due to various turbation processes. The shrinking and swelling of the clay component results in argilliturbation, reflected in the formation of slickensides, contributing to the formation of sharp boundaries and roundness of calcite nodules (Blokhuis et al. 1969; Kovda and Mermut 2010). Argilliturbation can lead to an upward movement of the nodules in the profile (Blokhuis et al. 1969; Wood and Johnson 1978). Bioturbation by plants is also evident in the form of rhizoliths; modern plant turbation is seen in the form of organic roots and rootlets. Faunal turbation is evident by the presence of microscopic chambers and passage features.

Implications for Archaeological Interpretation

Four Middle Palaeolithic occupation levels were identified at ‘Ein Qashish during the 2013 excavation: in Units 5a and 5b (in Areas C and A), in Unit 3b (Areas B, E) and in Unit 3a (Area F). The geoarchaeological study bears on our understanding of artefact presence/absence and spatial distributions and on reconstructions of human activities on the open landscape during the Late Middle Palaeolithic in the Levant.

Open-air sites often tend to present lower artefact densities compared to those in cave sites. ‘Ein Qashish conforms to this general pattern in terms of the number of artefacts observed in the field (Ekshtain et al. [in preparation](#)), as well as the low frequency of microartefacts in thin sections. This difference between the two types of sites can be attributed to the lateral spreading of activities at open-air sites, which are not as spatially constrained as caves and rock shelters (Sharon et al. 2014). Another contributing factor in the case of ‘Ein Qashish is the active fluvial environment in which the rate and volume of natural deposition surpasses that of anthropogenic deposition. While sedimentary accumulation processes seem to result in an overall preservation of the original locations of human activities, argilli- and bioturbation probably led to lateral as well as vertical displacement of bones and lithics (see also Hovers et al. 2014 and references therein). Judging from the length of slickensides observed in the field, displacement would not exceed a few decimetres.

Our reconstruction of human presence at ‘Ein Qashish suggests that Neanderthal occupations occurred during phases of drying out accompanied by surface stabilisation by vegetation on most parts of the alluvial plain environment, which was probably dotted with seasonal water bodies and occasionally intersected by channels of the paleo-Qishon stream and/or flash floods off Mount Carmel. The general low-energy setting reflected in the sediments suggests limited transport distances of archaeological materials. This is evidenced by the presence of refitted artefacts in the 2013 excavation areas, with short (on the order of cm to dm) lateral and vertical distances between pieces (Ekshtain et al. [in preparation](#); Been et al. 2017) and the preservation of some articulated faunal (Hovers et al. 2014) and human (Been et al. 2017) skeletal elements. In some

areas of the 2013 excavation, pristine knapping areas were identified (N. Mitki, pers. comm.). In other parts of the excavation, limited post-depositional argilli- and bioturbation may have caused vertical artefact movement and resulted in inflated thickness of the archaeological deposits (e.g. 2009–2011 excavation; Hovers et al. 2014).

Apart from physical movement and fragmentation of lithic artefacts and bones due to argilliturbation, chemical diagenesis must also be considered before spatial patterns can be safely interpreted (e.g. Stiner et al. 1995). Bone mineral crystallinity, represented by the values of the splitting factor (IRSF), is a useful proxy of bone preservation (Weiner and Bar-Yosef 1990). The IRSF values of fresh bone are between 2.5 and 2.9, whereas higher values indicate post-depositional increase in bone crystallinity. At ‘Ein Qashish bone crystallinity values are similar across space and along the stratigraphic sequence, which suggests that bones from all areas of the site underwent similar processes of diagenesis. IRSF values for the site range between 3 and 4, as is typical for many archaeological bones that are considered to be well preserved (e.g. at Kebara and Hayonim caves; Weiner et al. 1993, 2002). Based on the lack of authigenic phosphate minerals typical of bone dissolution, such as montgomeryite (Weiner 2010) and absence of micromorphological signs for localised bone dissolution, bone diagenesis seems to have taken place in neutral to alkaline sedimentary conditions. The syn- and post-depositional formation of calcitic nodules and hypocoatings, prevalent around and within bones from Unit 5, further supports this assertion. These observations in turn indicate that the spatial distribution of bones across the site is not biased diagenetically. Nir (2016) noted that the concentration of faunal remains is significantly lower in Unit 4 relative to the other stratigraphic units at ‘Ein Qashish. Given the similarity in bone crystallinity across the site, this cannot be related to differential diagenesis. The parsimonious interpretation for this observation is lack of anthropogenically deposited bone within this stratigraphic unit, which is consistent with the ‘seasonal water body’ hypothesis (see “[Syn- and Post-Depositional Processes](#)”).

In summary, the spatial distribution of bones at ‘Ein Qashish can be used cautiously for assessing site organisation and use of space. As flint does not undergo dissolution under the neutral to alkaline sediment conditions prevalent at the site, the distribution of lithic artefacts can also be used for spatial analysis. For both types of finds, argilli- and bioturbation of the alluvial plain sediments must be taken into account. Under such preservation conditions, the optimal resolution of spatial analysis is probably at the decimetre scale.

Lastly, we address the absence of evidence for combustion across a large excavated area of the site and four occupation levels. Combustion features and their products (e.g. ash, charcoal, burned bones, heated clay, phytoliths) have not been encountered either macroscopically or microscopically. Nevertheless, lithics that were exposed to heat after knapping have been identified (macroscopically) in low frequencies (<10% of ~7300 items larger than 20 mm; details to appear in Ekshtain et al. [in preparation](#)). Burned, unmodified flint clasts were also found. In the main excavation area, specifically in Area B, densities of burned items vary spatially in accordance with those of all the lithic items.

Based on the pH of the sediments (neutral to slightly alkaline), the precipitation of calcite and the good state of bone mineral preservation, there is no reason to assume that (calcitic) ash, charcoal or phytoliths were fully dissolved (Schiegl et al. 1996 for ash; Cohen-Ofri et al. 2006 for charcoal; Cabanes and Shahack-Gross 2015 for phytoliths). We are unable to discern whether ash first dissolved and later precipitated in the form of the many calcite nodules and hypocrotings found at the site, or if ash was present but completely washed away. Regardless, such a post-depositional scenario cannot explain the absence of charcoal and phytoliths. Moreover, we show in this study that dark-coloured bones in the site are stained by Fe-Mn oxides and do not include pyrolyzed collagen (see also Nir 2016). Given the results of our analysis, we cautiously propose that the absence of evidence for direct use of fire at the excavated portion of the site is not due to the effects of post-depositional disintegration or dissolution. Future research will address the conundrum regarding evidence for fire in the form of heated lithics (Ekshtain et al. in preparation) vs. absence of evidence for combustion and burned bones as presented in this study.

Conclusion

The multi-analytical investigation presented here furthered the understanding of the formation of the site of 'Ein Qashish. We identified a small, probably seasonal, water body associated with severe oxidation as a landscape and environmental parameter that affected the Neanderthal occupation at the site in addition to previously suggested fluvial and anthropogenic processes (Greenbaum et al. 2014; Hovers et al. 2014). We provide evidence showing that presence/absence of artefacts across the site and the various occupation levels reflects rather reliably the original material input into the site. Physical movement of artefacts is generally interpreted to be only over distances in the order of decimetres, dictating the scale of valid spatial analysis and inferences (active MP channels, if present, may be the exceptions). These insights bear on the context of the human skeletal remains from the site. While the partial representation of the EQH-3 skeletal remains and their immediate context did not allow their identification as a burial (Been et al. 2017), the current study supports the assertion in Been et al. (2017) that the remains of EQH-3 are at their original place of deposition or very close to it and are directly associated with the archaeological material in its vicinity. This, in turn, provides additional support for Neanderthals as the creators of the archaeological record at 'Ein Qashish and, by extension, of their presence in the open landscape.

Although many prehistoric sites are known from fluvial settings, only a few have undergone the type of multi-proxy geoarchaeological investigations we present here, combining visual and microscopic analyses. This study exemplifies the complexity of formation processes in a flood plain setting, a dynamic environment that presents a mosaic of processes before, during and after hominin occupations. This research demonstrates that a multi-analytical approach is necessary to parse the timeline and the effects of such formation processes on the archaeological remains. Our results also indicate that due to the variability of formation processes in space as well as in time, large excavations are necessary to adequately sample the various contexts and to

understand hominin settlement and behavioural decisions. The large spatial scale of the excavation thus renders ‘Ein Qashish an important case study for an open-air site in a constantly changing landscape.

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