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(Before and) After the Flood: A multiproxy approach to past floodplain usage in the middle Wadi el-Hasa, Jordan

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A B S T R A C T

Floodplains are an important feature of arid landscapes, enabling intensive agricultural activity by providing a locale with a consistent and largely predictable water source that is accessible without costly infrastructural modifications. Floodplain agriculture, although likely an important part of ancient agricultural systems in the Near East, is notoriously difficult to detect, as the dynamic environments in which floodplains are situated means that these geomorphic features are rarely preserved. However, recent survey in the Wadi el-Hasa, Jordan has revealed a preserved fragment of floodplain surface indicating past floodplain usage during the 7th–8th century cal AD. A multi-proxy analysis that incorporates geomorphic, geochemical, and paleobotanical analyses of this exposure has revealed a process of floodplain aggradation and incision modified by human activities and anthropogenic deposition. Analysis of the anthropogenic sediments suggests that the Wadi el-Hasa floodplain has not been adequately considered as a component of economic and subsistence activity during the early Islamic period.

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1. Introduction

In arid environments, floodplains provide important locations of biotic productivity and offer the possibility of viable and intensifiable agriculture even without expensive infrastructural investments in irrigation (Doolittle, 2006). They are areas that are relatively reliably and predictably watered, albeit geomorphically unstable on various timescales. As a result, floodplains have significant potential as study sites for research into past land use and human development, but despite this considerable potential as archives of regional and local paleoenvironmental conditions and past human land use, the geomorphic instability of floodplains means that they are relatively rarely accessible for paleoenvironmental and archaeological investigation. Cycles of aggradation and incision can bury or erode ancient floodplain surfaces, making preserved archaeological sites and sediment stratigraphy in such settings scarce.

Nevertheless, recent survey in the middle Wadi el-Hasa in Jordan has documented a preserved fragment of floodplain surface containing archaeological evidence of a 7th–8th century cal AD occupation, providing a rare glimpse into past floodplain usage. The archaeological site documented there testifies to intensive use of this now largely-eroded landscape, shedding light on pre-modern floodplain land use in the southern Levant and providing valuable evidence of the potential importance of such little-preserved landscapes.

Using a multi-proxy investigation of this stratigraphic exposure that incorporates geomorphic, geochemical, and paleobotanical analyses, we investigate the anthropogenic and geomorphic processes operative in the floodplain during this period, and in particular examine the evidence for human exploitation of the Hasa floodplain.

2. A preserved floodplain fragment in the Wadi el-Hasa: HML-Exposure 2

The Wadi el-Hasa, located between the modern cities of Kerak and Tafileh, is a perennial watercourse that dissects the Jordan...
Plateau from east to west, draining eventually into the Dead Sea at as-Safi (see Fig. 1). Environmental conditions vary according to topography throughout the Wadi el-Hasa, with a semi-arid climate characterizing the plateau and upper slopes (ca. 1000 m a.s.l.), and a desert climate characterizing the wadi bottom (ca. 400 m a.s.l.). Modern-day precipitation levels within the Wadi el-Hasa are generally low, ranging from less than 100 mm to 200 mm per annum (Office of Arid Lands Studies, 2006), but flash floods during the winter months are not uncommon.

The south side of the middle and upper Hasa has been extensively archaeologically surveyed (Clark et al., 1985; MacDonald, 1988), revealing a settlement history dating back to the Middle Paleolithic (as early as approximately 300 kya; see Fig. 2 for a summary of regional chronology). Subsequent work has explored long-term settlement and environmental dynamics in the drainage (Hill, 2004, 2006, 2009), and investigations of individual sites continue. Recent archaeological research in the area has focused on excavation-based investigations of individual archaeological sites, particularly those dating to the early Neolithic (e.g., Makarewicz et al., 2006; Peterson, 2004), but there is also substantial evidence for occupation and use of the Hasa later in (pre)history. Nabataean, Roman, Byzantine, and Islamic villages, outposts, temples, and infrastructure are scattered throughout the Middle Hasa, and site density peaked in the Byzantine period (Hill, 2006; MacDonald, 1988).

These studies and other more geomorphically-focused investigations have recognized a long history of incision and aggradation in the drainage (Schuldenrein and Clark, 2001, 2003; Schuldenrein, 2007; Vita-Finzi, 1966; Winer and Rachel, 2010). One of the results of this geomorphology is a paucity of floodplain sites in the valley. The scarcity of these sites, however, reflects their destruction by erosion, or occasionally their burial, rather than research lacunae or (as occasional preserved sites suggest) settlement preference.

This scarcity notwithstanding, field survey associated with the el-Hemmeh Archaeological Project in 2010 revealed a small preserved floodplain site (HML-Exp 02) dating to the early Islamic period (ca. 8th century cal AD). Located approximately 2 km upstream of Tannur Dam, the site is buried in the sediments of a 3 m alluvial terrace, and has been exposed by the downcutting activity of a small side drainage. The site, defined in 2011 by careful cleaning of the exposure, is preserved over an ~17 m stretch of the exposure and consists of anthropogenic sediments as well as a series of small architectural features constructed of river cobbles (see Fig. 3). The extent and depth of the anthropogenic sediments (the architecture is less extensive than and clearly postdates the lower anthropogenic strata), coupled with their low artifact density, strongly suggests that these deposits are not domestic refuse.

The preservation of a floodplain fragment in the middle of the Wadi el-Hasa offers an unusual opportunity to investigate the ways in which inhabitants of this portion of the wadi system were utilizing the floodplain during a period of geomorphic stability. We describe here the results of a multi-proxy investigation of the stratigraphic sequence exposed at HML-Exp 02, focusing in particular on the ways in which contrasts between pre-occupation, occupation, and post-occupation deposits identified in the floodplain fragment can inform us about short-term geomorphic change in the valley, broader vegetation change within the catchment, and direct anthropogenic influence on the floodplain. Specifically, we investigate evidence of soil formation and past vegetative communities in these deposits, and examine anthropogenic influences, including the potential of cultivation activity.

Fig. 1. Location and topography of the Wadi el-Hasa and the study site.
3. Methods and results

In order to address the issues outlined above, we characterized both vertical (diachronic) and horizontal (synchronic) variability in the HML-Exp 02 deposits through a multi-proxy approach that includes both field- and laboratory-based analyses. Field observations of HML-Exp 02 stratigraphy (see Fig. 4) indicated that the contrast between anthropogenic and alluvial deposits was a product primarily of differences in grain size and charcoal and ash content. Analyses were designed to investigate these contrasts by examining the differences between anthropogenic and alluvial strata, assessing contributions of both soil formation processes and anthropogenic alteration of sediments. Charcoal and phytolith analyses were employed to examine direct evidence of past catchment and potentially in situ floodplain vegetation. The results provide measures of both geomorphic processes in the last two millennia and direct anthropogenic influence during the episode of floodplain stability in the 7–8th century cal AD.

3.1. Site stratigraphy

The architectural features, limited to a single phase of construction, consist of a small wall, approximately 1 m high but partially collapsed, and an associated cobble pavement to the north (Figs. 5 and 6). Two small and informal hearths, apparently resulting from single burn episodes rather than repeated use, are found adjacent to the wall and approximately 2 m to the south. A $^{14}$C determination from wood charcoal recovered from the hearth adjacent to the central wall (HML-021: GrA-53534, 1270 ± 30; see Table 1 and Fig. 6) indicates that the site was occupied during later 7th or 8th century cal AD, during the early Islamic period.

Anthropogenic sediments are visible beneath and adjacent to these features, extending to either side as the architectural features are found only in a section of ~4 m in the center of the exposure. The sediments comprise three to four distinct strata (varying horizontally), and while they contain scattered ceramic fragments, the overall density of material culture is low; fewer than ten ceramic fragments and no bone or lithic material were recovered. Charcoal and ash, however, are abundant throughout these strata, although there is no apparent heat alteration of the sediments. The sediment stratigraphy — see Fig. 4 — demonstrates that these sediments and architectural features were deposited and constructed during a period of floodplain stability, and subsequently rapidly buried by alluvial sediments (see also Fig. 5).

3.2. Grain-size analysis

In order to characterize and quantify the contrasts between strata, samples were subjected to standard grain-size analysis, which quantifies the distribution of grains of varying size classes. After aggregates were manually crushed, samples were sieved...
through a 2 mm sieve. Following the procedures outlined by Blume (2000), organic matter and carbonates in the fine fraction were digested with hydrogen peroxide \( (H_2O_2) \) and acetic acid \( C_2H_4O_2 \) respectively, and then samples were washed with distilled \( H_2O \) and mixed with natrium pyrophosphate \( (Na_4P_2O_7) \) and then analyzed with a Malvern Mastersizer 2000 laser diffractometer.

Grain-size analysis substantiated the macroscopically visible contrasts, demonstrating the high proportion of fine-grained material \(<62.5\ \mu m\) in Strata XVI and VII and the intermediate composition of Strata VI and V (full results are in Table S1). The fine-grained proportion in the anthropogenic strata is twice that of the alluvial strata, and nearly 15% more than the modern alluvial terrace surface (see Fig. 7 and Table 1); inputs of ash are likely responsible for this contrast.

3.3. Loss on ignition

Loss on ignition (LoI) was used to determine organic matter and carbonate content in the samples (Heiri et al., 2001). After samples were dried at 105 °C for 12 hours (subsequent dry weight \( = DW_{105} \)) to volatilize structural water, they were heated in a muffle furnace for 2 hours at 550 °C (subsequent dry weight \( = DW_{550} \)) in order to combust the organic matter. The weight difference between \( DW_{105} \) and \( DW_{550} \) provides the amount of organic matter in the samples (expressed in percent as LoI\(_{550}\)). The remaining sample material was further heated for 2 hours at 950 °C (subsequent dry weight \( = DW_{950} \)) in order to combust inorganic carbon, and carbonate content was calculated from the weight difference between \( DW_{550} \) and \( DW_{950} \) (and expressed in percent as LoI\(_{950}\)).
The results (Table S2) show elevated LoI$_{550}$ in the anthropogenic strata, with some horizontal variability but generally increasing upward within those strata (IV, V, VI, VII, and XVI; see Fig. 7). Aggregated values (Table 1) also demonstrate the distinctiveness of the anthropogenic strata, while highlighting that Group 1 (the basal, pre-occupation strata) have notably higher organic content than the post-occupation alluvial strata, and indeed closely resemble the strata associated with the modern terrace surface.

### 3.4. Magnetic susceptibility

Since all soils and sediments possess magnetic properties to greater or lesser extent, magnetic measurements are useful and frequently-employed tools for investigating past and recent soil formation processes (Jia et al., 2011; Liu et al., 2004). These techniques are also widely accepted in archaeological (e.g., Dalan and Banerjee, 1998; Schmidt, 2007) and (palaeo)environmental research (Maher et al., 2002).

Magnetic susceptibility (MS) measurements were carried out following Dearing (1999): samples were air-dried, gently crushed if necessary and passed through a 2 mm sieve. Plant residues, charcoal pieces, and pebbles were removed. The samples were placed in 10 ml plastic tubes and MS measure were performed on low (470 Hz) and high (4700 Hz) frequencies at room temperature with a Bartington MS2B susceptibility meter linked to a MS2B dual frequency sensor. The values were expressed as mass specific magnetic susceptibility: $\gamma_{LF}$ [$10^{-8}$ m$^3$/kg] – low frequency; $\gamma_{HF}$ [$10^{-8}$ m$^3$/kg] – high frequency. In order to identify neoforming secondary magnetic minerals (derived through chemical and bacterial processes – pedogenesis – or produced during burning) frequency-dependent magnetic susceptibility ($\gamma_{FD}$) was calculated ($\gamma_{FD}$ (%) = $(|\gamma_{LF}-\gamma_{HF}|/\gamma_{LF}) \times 100$) and expressed as percentage. In cases when the original $\gamma_{LF}$ and $\gamma_{HF}$ values were $\leq 25$ ($10^{-8}$ m$^3$/kg) $\gamma_{FD}$ values were not defined due to the high risk of overestimation (Dearing et al., 1996).

Elevated values in the anthropogenic strata indicate soil development and/or presence of burned material (full results in Table S3). Aggregate values (Table 1) suggest only limited soil development, not unexpected in this environment due to limited inputs of organic material in such an arid environment and limited exposure times of surfaces during periods of alluvial activity. High correlation between $\gamma_{LF}$ and LoI$_{550}$ suggests soil formation in the pre-occupation strata, albeit weak as visible indicators are not present, while much weaker correlations in subsequent strata, including anthropogenic ones, indicate an absence of soil formation (due in alluvial strata to brevity of near-surface exposure and/or stability, and in anthropogenic strata either to these factors or to disturbance).

### 3.5. Charcoal analysis

Charcoal quantification and identification of taxonomic spectra offer the possibility of examining the changes in floodplain vegetation associated with the periods represented in the sediments (as with any fossil deposits caution is warranted in interpreting the source of the burned material; we consider this issue in the Discussion section below). Analysis of charcoal records extracted from sediment samples was performed in order to 1) assess the patterns of total charcoal content in the various stratigraphic units, and 2) identify the taxonomic spectra of the charcoal assemblages.
Table 1
Summary and mean values by stratigraphic group.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Estimated date rangea</th>
<th>Associated 14C dates</th>
<th>LoI550 Charcoal concentration (g/kg)</th>
<th>Total % &lt;62.5 μm</th>
<th>χ LF [10^-8 m^3/kg]</th>
<th>LoI550 and χ LF correlation (R²)</th>
<th>Charcoal interpretation</th>
<th>Phytolith interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>(XIV - modern alluvial terrace surfaceb)</td>
<td>?– presentc</td>
<td>2.34 0.039</td>
<td>41.430</td>
<td>20.85</td>
<td>0.065</td>
<td>Semi-open Rhamnus/Phillyrea and Juniperus woodland</td>
<td>Abundant and well preserved phytoliths; relatively high proportion of grasses</td>
</tr>
<tr>
<td>3</td>
<td>(VIII – XIII; alluvial)</td>
<td>ca. 800–?? cal AD</td>
<td>1.49 0.313</td>
<td>23.609</td>
<td>18.50</td>
<td>0.007</td>
<td>Little woody vegetation</td>
<td>n.d.</td>
</tr>
<tr>
<td>2</td>
<td>(IV–VII, XVI; anthropogenic)</td>
<td>ca. 600–800 cal AD</td>
<td>4.42 0.815</td>
<td>55.447</td>
<td>67.36</td>
<td>0.219</td>
<td>Diverse shrubby evergreen vegetation, including economically useful species</td>
<td>Abundant and well-preserved phytoliths, including silica skeletons; relatively high proportion of grasses</td>
</tr>
<tr>
<td>1</td>
<td>(I–III; alluvial)</td>
<td>ca. 0–600 cal AD</td>
<td>2.29 0.03</td>
<td>27.986</td>
<td>27.65</td>
<td>0.896</td>
<td>Semi-open Juniperus woodland</td>
<td>Few and poorly preserved phytoliths; relatively low proportion of grasses</td>
</tr>
</tbody>
</table>

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a Date ranges are derived from the 14C dates associated with Phases 1 and 2; the former provides a terminus post quem for Phase 1 (likely providing a date estimate that is at least somewhat too early, as it comes from sediment charcoal and probably includes some built-in age due to old wood and residence time effects) while the latter provides a terminal date for Phase 2. The transition between Phases 1 and 2 is estimated based on the archaeological assessment of a relatively brief occupation at the end of Phase 2 and the relatively limited amount of preceding deposition; the precision of this date is correspondingly low. The date of the transition between Phases 3 and 4 remains unknown, and while in Phase 4 aggradation ceased and incision began; the date of that incision is also unknown.

b Includes HML-094 and 322.

c Remains active until present as an alluvial terrace surface undergoing soil formation; alluvial deposition ceased at some earlier time (datable only as post-Phase 3).

---

Fig. 7. Values of LoI550, χ LF, and percentage of grains <62.5 μm (i.e., silt, clay, and ash). Stratigraphic boundaries are indicated by dotted grey lines, and phase boundaries (per Table 1) are indicated by dotted black lines.
Charcoal was extracted from sediment samples by sieving through a mesh column of 5, 2, 1 mm and 355 μm. Each size class was sorted under a stereo lens (Nikon SMZ1500, ×7.5 to ×112.5) to separate the charcoal content, and dry charcoal weights were subsequently standardized against the dry volume of the sediment samples in order to obtain charcoal concentrations (in g/kg; Carcailliet and Thiron, 1996). Such quantification and standardization of concentrations allows comparison of sediment samples of varying sizes and thus from different areas of the exposure.

For a subset of stratigraphic units taxonomic analysis was performed to determine the type of burnt vegetation. Carbonization preserves taxonomically diagnostic microscopic wood structure (Nelie et al., 2013; Vernet, 2008), at least for those specimens large enough to permit observation of relevant diagnostic anatomical criteria (800 μm/1 mm; Robin et al., 2014). Identifications were performed with a stereo lens (Nikon SMZ1500, ×7.5–×112) and a reflected light microscope (Nikon Eclipse ME600, ×100, ×200, ×500), with reference to standard identification keys and wood anatomy atlases (Fahn et al., 1986; Crivellaro and Schweingruber, 2013), as well as to the modern comparative wood charcoal reference collection maintained by the Palaeoecology Working Group of the Institute for Ecosystem Research at CAU Kiel.

A total of approximately 163 g of charcoal (all pieces > 355 μm) from fourteen sediment samples, representing nine different stratigraphic units, were recovered. Of this recovered charcoal, approximately 49 g (318 charcoal pieces; to maxima of 60/sample) have been taxonomically analyzed, resulting in identification to taxa, genus, or species level of 255 charcoal pieces (see Fig. 8 for examples). The remaining 63 charcoal pieces were unidentifiable due to fragmentation or poor preservation that destroyed diagnostic anatomical criteria (e.g., vitrified charcoal; McParland et al., 2010). The results are presented in Table S4; these demonstrate significant diachronic variability in charcoal concentrations and taxa represented.

Although there is notable horizontal (synchronic) variability in charcoal concentrations, higher concentrations of charcoal in the anthropogenic strata are evident (Fig. 9), with the exception of Stratum VI. However, this stratum is under-represented and further sampling would be necessary to assess the deviation of Stratum VI from the larger pattern.

Taxonomic diversity between strata is also variable, but notably higher in the anthropogenic strata, including several taxa (most notably some broadleaf taxa) that have been identified only in the anthropogenic strata (Table S4 and Fig. 9).

3.6. Phytolith analysis

Given the possibility that charcoal in anthropogenic strata may result from human transport of burned or unburned vegetation or wood, we pursued alternative lines of evidence that could address the question of whether the charcoal data was related to local vegetative cover and/or human transportation of material. Pollen and phytoliths are also subject to such anthropogenic influences on formation processes, but given their ubiquity should at least

![Fig. 8. Micro-photographs of a sample of the taxa identified in the charcoal record. A: cf. Acer cross-section (×200); B1: Pistacia cross-section (×100) and B2: radial section (×500); C: Juniperus cross-section (×100); D: Quercus coccifera/calliprinos cross-section (×50); E: Olea cross-section (×50); F1: Tamarix cross-section (×200) and F2: radial section (×200); G: Salix radial section (×200).]
include a local signal, and they also provide complementary information on non-arboreal vegetation. Tests of six samples from various strata indicated that pollen preservation was so poor as to render pollen analysis impossible; screening the pollen samples encountered only few grains belonging to Chenopodiaceae and Cichorieae. Given this poor pollen preservation, exploratory phytother analyses were undertaken in order to a) determine whether preservation in this arid environment was sufficient to use phytoliths to characterize floodplain and/or catchment vegetation, and b) provide evidence of floodplain vegetation complementary to the sediment charcoal analyses.

Eight sediment samples obtained from both alluvial and anthropogenic deposits were processed following the protocol described by Neumann and colleagues (2009). Minima of 200 single-cell phytoliths from identifiable morphotypes were counted from each sediment sample in which phytolith concentration was sufficient to allow analysis (see Fig. 10 for a sample of identified phytoliths). Multicellular siliceous aggregates, and sponge spicules were counted independently. Opaque, darkened phytoliths from grasses (GSCPs and bulliforms), which have been used to indicate grass burning (Cordova et al., 2011; Parr, 2006), were also recorded (full counts are presented in Table S5). Morphotype distinction follows the relevant literature, as specified in Table S6.

Corrosion of phytolith surfaces — pitting and surface erosion — is frequent across all samples. However, some general patterns are visible, and in anthropogenic strata and in the upper alluvial deposits morphotypes are recognizable and study is possible (see Table 2). Most significantly, the phytolith assemblages from alluvial and anthropogenic layers are clearly distinct. The concentration of phytoliths is higher, and their preservation better, in anthropogenic deposits than in alluvial sediments (with exception of sample HML-035, which is comprised of material from the surface of the modern alluvial terrace). In addition, phytoliths are more fragmented in alluvial layers, likely resulting from sediment transport. Such transport is also reflected in two samples from alluvial deposits (HML-047 and HML-029) in which phytolith preservation was too poor for analysis, while a further alluvial sample (HML-054) displayed a low concentration of phytoliths and a relatively high amount of undefined opal silica elements, mostly phytoliths too fragmented to be identifiable.

The majority of the identified phytolith morphotypes correspond to monocotyledons (e.g., grasses and sedges), though some morphotypes representative of dicotyledons (e.g., arboreal plants) are present as well. Among diagnostic morphotypes, grass short cell phytoliths (GSCPs), which are characteristic of the leaves and inflorescences of grasses, have been detected in the anthropogenic strata and near the modern terrace surface, where they are most abundant. GSCPs are notably absent from the alluvial strata, likely as they are prone to deterioration more easily than other grass phytoliths (Cordova et al., 2011). Nevertheless, overall elongate cells from the stem/leaves of grasses and bulliform cells from monocot leaves are the most ubiquitous and abundant morphotypes.

Although the phytolith analyses reported here are from a small number of sediment samples, these data nevertheless provide some insight into the general vegetative composition of the floodplain of the middle Hasa, and demonstrate a clear distinction between the alluvial and anthropogenic components of the overall phytolith assemblage. Relative abundances of monocots, dicots, and other significant subgroups in different strata are shown in Fig. 11. Despite the usual under-representation in sediment samples of phytoliths from woody dicots compared to grass phytoliths, due to low production and high fragility (Strömberg, 2004), in this sequence the highest value for woody dicots is registered in the lowermost sample (HML-054) from the alluvium and dicots as a proportion of the assemblage tend to decrease toward the top of the sequence. In conjunction with the charcoal evidence, this more likely represents increasing abundance of grasses over time than an absolute decrease in woody vegetation.

4. Discussion

The preserved architecture and extensive anthropogenic sediments occupying a floodplain location, but unmixed with alluvial or overbank sediments, suggest the exploitation of a stable terrace within the floodplain, buried by renewed fluvial activity sometime shortly after the middle of the 8th century cal AD (the occupation layers are directly buried by alluvial sediments). The stone architecture, substantial deposition, and absence of any hiatus in occupation argue that the site preserves the remains of continuous occupation rather than repeated temporary use. This evidence of floodplain use provides a glimpse of the exploitation of a niche rarely observed in the archaeological record of the Wadi el-Hasa.

The multi-proxy approach to a rare floodplain archive described here substantiates the macroscopic contrasts between alluvial and anthropogenic phases on the Hasa floodplain, and allows us to explore some of the drivers of these apparent contrasts.
Fig. 10. Micro-photographs of phytoliths from HML-Exp 02. Scale bar 50 μm for single morphotypes (a–k) and 100 μm for multicellular aggregates (l–m): (a) bilobates from HML-45, (b) trapeziform sinuate from HML-48, (c) parallelepipedal bulliform from HML-46, (d) saddle from HML-35, (e) trapeziform polylobate from HML-35, (f) cuneiform bulliform from HML-49, (g) burnt cuneiform bulliform from HML-48, (h) elongate dendritic long cell from HML-35, (i) elongate faceted from HML-45, (j) globular echinate from HML-35, (k) stellate parenchyma from HML-49, (l) silica skeleton with cuneiform bulliforms (double focus) from HML-48, (m) silica skeleton with elongate long cells and bilobates from HML-48.

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Sample</th>
<th>Context</th>
<th>Preservation</th>
<th>Abundance</th>
<th>Silica skeletons</th>
</tr>
</thead>
<tbody>
<tr>
<td>XIV</td>
<td>HML 035</td>
<td>ALLUVIAL</td>
<td>Good but with fragmentation</td>
<td>Rich</td>
<td>No</td>
</tr>
<tr>
<td>XVI</td>
<td>HML 048</td>
<td>ARCH.</td>
<td>Quite good, some corrosion with pitting and darkening</td>
<td>Rich</td>
<td>Many, especially with bulliforms phytoliths (Poaceae leaves)</td>
</tr>
<tr>
<td>XVI</td>
<td>HML 045</td>
<td>ARCH.</td>
<td>Good, little corrosion</td>
<td>Rich</td>
<td>Many, small aggregates with rounded edges</td>
</tr>
<tr>
<td>VI</td>
<td>HML 049</td>
<td>ARCH.</td>
<td>Good</td>
<td>Rich</td>
<td>Some</td>
</tr>
<tr>
<td>VI</td>
<td>HML 046</td>
<td>ARCH.</td>
<td>Good</td>
<td>Rich</td>
<td>Some</td>
</tr>
<tr>
<td>IV</td>
<td>HML 047</td>
<td>ALLUVIAL/ARCH.</td>
<td>Very poor (study not possible)</td>
<td>Very low</td>
<td>No</td>
</tr>
<tr>
<td>IV</td>
<td>HML 029</td>
<td>ALLUVIAL/ARCH.</td>
<td>Very poor (study not possible)</td>
<td>Very low</td>
<td>No</td>
</tr>
<tr>
<td>III</td>
<td>HML 054</td>
<td>ALLUVIAL</td>
<td>Poor, rounded edges</td>
<td>Low</td>
<td>No</td>
</tr>
</tbody>
</table>
Aggregating the strata into four groups (see Table 1) – pre-occupation alluvial (1), occupation (2), post-occupation alluvial (3), and modern alluvial terrace surface (4) – allows characterization of this span of floodplain history.

4.1. Stabilization of the floodplain (Phase 1)

The first phase, characterized by alluvial sediments with some evidence of weak soil formation, was apparently one of a stabilizing floodplain, but one still prone to episodic activity, as evidenced for instance by the alluvial gravels of Stratum III (see Fig. 4). In spite of these alluvial sands and gravels, mean organic content in the Phase I sediments is notably higher than in the post-occupation alluvial phase, and indeed comparable to the modern terrace surface (see Table 1). In addition, organic content correlates tightly with moderately elevated \( \gamma \) LF values, suggesting weak (non-visible) soil formation. Low quantities and concentrations of charcoal suggest that this elevated organic content is derived from local unburned vegetation rather than charcoal inputs, with catchment fire frequency low; arboreal species represented in the charcoal record suggest a semi-open woodland of scattered \textit{Juniperus} (juniper). The presence of phytoliths produced by woody dicots is consistent with the charcoal evidence in suggesting an area of open woodland consisting of scattered shrubs and/or trees, but some grasses and sedges were already present, suggesting, together with the presence of sponge spicules, that this generally open landscape was one in which moist environments were locally available at least seasonally. A \(^{14}C\) determination from sediment charcoal in Stratum II (HML-313; see Table 1 and Fig. 6) returned a date whose calibrated 95% range is 40 cal BC – 125 cal AD (calibrated with OxCal 4.2 using IntCal13), placing Phase 1 in approximately the first century cal AD.

4.2. Human use of a stable floodplain (Phase 2)

As the floodplain stabilized it apparently became an attractive locale for human activity. Stratum IV is evidence of this transition, representing a stable floodplain with some soil formation that was altered by human activity (in contrast with subsequent strata from Phase 2 – V, VI, VII, and XVI – which seem entirely anthropogenically derived). The charcoal and phytolith records suggest that the stabilized floodplain (Phase 2) featured more abundant and diverse vegetation than the open woodland present in Phase 1, including increased abundance of grasses and sedges. Stratum IV is characterized by evergreen bush vegetation dominated by \textit{Pistacia} – \textit{Tamarix} (pistachio and tamarisk), while subsequent anthropogenic strata also present important quantities of \textit{Tamarix}, \textit{Pistacia} (pistachio), \textit{Rhamnus}/\textit{Phillyrea} (buckthorn or phillyrea). \textit{Olea}, \textit{cf. Acer}, and \textit{Prunus} (olive, maple, and \textit{Prunus}, the genus including the stone fruits and almond) are found exclusively in the anthropogenic strata (Fig. 9), and \textit{Quercus coccifera}/\textit{calliprinos} (evergreen oak) appears as well. Although a stable floodplain likely would have featured expanded floristic diversity independently of human influence, the increase in taxa useful for food, fuel, construction, or other products is suggestive.

The exact provenience of the charcoal fragments that testify to the vegetation spectrum cannot be determined (i.e., they may represent vegetation burned \textit{in situ} and/or material transported by humans to the floodplain in the form of either wood or charcoal), but the spectrum of flora identified exclusively in the anthropogenic strata clearly distinguishes these strata from the previous and subsequent alluvial sediments. As those strata provide samples of both a relatively stable floodplain (Phase 1) and a dynamic one (Phase 3), it is likely that the vegetation spectrum from Phase 2 represents not simply a change resulting from the stabilization of the floodplain, but also active human influence on the composition of floodplain flora. As noted above, the charcoal spectrum of the anthropogenic strata still indicates shrubby evergreen vegetation, but richer in taxa than previously.

These notably high charcoal and ash contents may represent deliberate soil amendments, though at the same time no evidence of soil formation is apparent in these strata. This may be the result of the magnitude of the anthropogenic impact in the upper portion...
of Phase 2 (Strata VII and XVI), or evidence that the period of exposure before burial by renewed alluvial activity was too short to allow soil development.

Anthropogenic influence is also evident in an increase in abundance of grass or sedge leaves and culms and their burning, demonstrated by the presence of opaque monocot phytoliths as well as sedimentary evidence of charcoal and ash and elevated $\chi$ LF values (see Table 1). In Strata IV and XVI, low values of phytoliths from grass inflorescences are also attested. Such relative paucity of evidence of inflorescences and the marked abundance of phytoliths from monocot leaves and culms (see Fig. 12) can result from the first stages of crop processing (i.e., the selective removal of grain and spikelets after threshing; Harvey and Fuller, 2005), and also can be an indicator of herbivorous livestock dung because of the frequent use of cereal by-products as fodder (especially in arid environments; Lanciotti and Madella, 2012; Shahack-Gross, 2011). Remains of dung burnt as fuel, another practice attested ethnographically in arid environments and recognized in archaeological samples (Jenkins et al., 2011; Shahack-Gross, 2011) may be also spread on fields as manure, and could, in conjunction with the potential burning of crop remnants, account for abundant ash and burnt plant remains. The presence of hygrophilous plants, evidenced by the presence of sponge spicules and phytoliths associated with palms, suggests that habitats with high humidity were available in the catchment, at least seasonally.

In the latter part of Phase 2 the floodplain became a location of intensive human use; in conjunction with the deposition of ash- and charcoal-rich strata (VII and XVI), the stone architectural features described above were constructed. The $^{14}$C date from the small hearth adjacent to the cobble wall (HML-021; see Table 1 and Fig. 6) places the end of this occupation between 665 and 780 cal AD (~92% of rounded range, with <2% of the probability falling later; calibrated with OxCal 4.2 using IntCal13).

4.3. A return to floodplain dynamism (Phase 3)

This stable and partly anthropogenic floodplain, including stone construction, was abruptly buried by alluvial sediment (Stratum VIII) in the latter part of the 8th century cal AD, signaling a period of renewed floodplain dynamism (Phase 3). Continued alluvial activity and rapid sediment burial apparently prevented the establishment of vegetation and soil development; multiple alluvial strata indicate episodic fluvial activity. The charcoal record displays dramatically reduced abundance and diversity in Phase 3, suggesting little local woody vegetation, and the charcoal present, entrained in alluvial sediments, likely represents catchment as well as local floodplain vegetation.

4.4. Modern terrace surface (Phase 4)

Strata XIV and XV, near the modern alluvial terrace surface, contrast with the Phase 3 alluvial sediments in that they display evidence of soil formation (higher $\chi$ LF, %C, and clay fraction compared to preceding alluvial strata). This soil formation may be the product of a stabilizing floodplain in the period of deposition, or may result from soil formation processes that postdate the incision of the drainage, which left these strata as the surface of an alluvial terrace. In either case, the floristic diversity remained lower than in Phase 2; the charcoal evidence from Phase 4 suggests a semi-open woodland of Rhumus/Phillyrea and Juniperus comparable to Phase 1. The phytolith record from Stratum XIV display a high relative abundance of phytoliths from grass inflorescences and low abundance of phytoliths from grass leaves (see Fig. 12), contrasting with the anthropogenic assemblage from Phase 2. The Phase 4 assemblage apparently represents unaltered floodplain vegetation, while the accumulation of phytoliths from grass leaves in Phase 2 was the result of human practices. The indicators of wet environment and of dicotyledons decrease as well, despite the presence of some palm phytoliths.

4.5. Implications

The contrast between Phase 4 and Phase 2 suggests that the stability of the alluvial terrace present in Phase 4 was not sufficient to prompt the establishment of the floristic diversity evident in Phase 2 (although the anthropogenic nature of the Phase 2 deposits raises the possibility that these result from transported material rather than in situ vegetation, none of the species are implausible as locally grown, and Pinus, abundant on the plateau, is conspicuous by its absence). Similarly, comparison of the phytolith assemblages

Fig. 12. Anatomical origin of phytoliths from HML-Exp 02. Some morphotypes (e.g. elongate psilate/sinuate long cells) included here have multiple attributions in the literature, but considering the phytolith assemblage as a whole, as well as the charcoal data, modern plant distributions, and the arid environment, we attribute them to monocots, i.e. grasses (the main producers) and sedges. The morphotypes associated with monocot leaves/culms are bulbiform cuneiform and parallelepipedal cells, elongate psilate and sinuate long cells; the morphotype associated with grass inflorescences is elongate dendritic long cells; the morphotype associated with sedge roots is stellate parenchyma. Grass short cell phytoliths have not been used here because they can occur in both grass leaves and grass inflorescences.
from the modern terrace surface and the anthropogenic strata suggests an occupied 8th century floodplain distinct from the modern environment, whereas the earlier anthropogenic Stratum VI is notably similar to the modern alluvial terrace.

The precise nature of the floodplain usage evident in Strata IV-VII and XVI remains somewhat unclear, and the absence of clear evidence for soil formation may argue against floodplain cultivation. However, the short duration of use and potential tilling may have limited soil formation, and in the absence of clear infrastructure (as seen in the Negev; Ashkenazi et al., 2012) fields generally have low archaeological visibility (Miller and Gleason, 1994). Moreover, the inputs of wood charcoal and ash derived from burnt grass leaves and culms without evidence of local burning would be consistent with a strategy of soil amendment and/or in situ burning of crop remnants. If there is no “smoking gun” for floodplain cultivation, nonetheless this evidence, coupled with the increase in economically productive taxa in the charcoal record and the construction of infrastructure on the floodplain make it clear that this floodplain environment was a significant component of wadi occupation and exploitation; it was built upon and its vegetative communities altered and perhaps cultivated. This floodplain usage came to an abrupt halt, and was not re-initiated, with the rapidity of dynamism and alluvial deposition of the late 8th century cal AD.

The site is also testament to the geomorphology of the middle Hasa during the last two millennia, demonstrating that that period witnessed aggradation, stability, and incision, with both deposition and erosion on the order of 3 m. Imprecise chronologies make relating the last two millennia of Wadi el-Hasa geomorphic activity as recorded in HML-Exp 02 to regional climatic records inevitably provisional. The process relationships are similarly complex: the varying flow energetics may be responsive to both/either inter- and intra-annual changes in precipitation, as well as provision of material from the valley slopes. The latter — as well as quantity and rapidity of runoff — is likely to have been significantly affected by human activity throughout the period in question. While by the Nabatean/Roman Period when Phase 1 deposition began the entire drainage was already a legacy environment, certainly continued agricultural and pastoral activity and changing population densities and production intensities played their part in de-vegetation and erosion — which might have contributed to either aggradation or incision in the trunk stream depending (primarily) on the amount of available slope sediment.

The different facies evident in HML-Exp 02 record variability in alluvial deposition that was likely responsive to both local and regional conditions, including both climatic and anthropogenic activities. The increase in fluvial activity that marks the transition from Phase 2 to Phase 3 at approximately 800 cal AD might be correlated with the peak in precipitation documented in the Soreq Cave speleothems — but must also account for the contemporary lowstand of the Dead Sea (Bar-Matthews et al., 1998; Bar-Matthews and Ayalon, 2004; Bookman et al., 2004; Frumkin and Elitzur, 2002; see Ackermann et al., 2014:Fig. 11 for a juxtaposition of these datasets). Similarly, the Phase 1–Phase 2 transition, representing a stabilization of the floodplain roughly estimated as occurring at approximately 600 cal AD, might be associated with the post-400 cal AD drying evident in the Dead Sea record, or either the post-450 cal AD or post-570 cal AD drying episodes evident in the Soreq record. Moreover, although no archaeological remains are preserved to suggest this, channel manipulation (e.g., indirectly through upstream water diversion or directly through stream canalization) was certainly within the technical capacity of the inhabitants of the Hasa and direct anthropogenic influences on sedimentation should not be entirely discounted.

The shift from aggradation to incision in Phase 4 (at some point post-800 cal AD; given the amount of Phase 3 and Phase 4 deposition a date as late as the 20th century might be reasonable, but no dates for the beginning of incision are available) may represent a response to either/both inter- and intra-annual changes in precipitation, as well as shifts in base level. The modern situation is telling: although precipitation levels are quite low (~200 mm/year, a level that would be characterized as quite arid in paleoclimate proxies), intense winter rainfall still drives significant channel activity.

In any case, this Late Holocene fill dating to the last two millennia suggests some of the complexity resident within what studies of longer-term processes have glossed as Fill IV (according to Copeland and Vita-Finzi, 1978) or the final phases of Fill III (according to Schuldenrein, 2007). HML-Exp 02 demonstrates that the last two millennia have witnessed at least 3 m of deposition, followed by incision through that deposit; where Schuldenrein (2007) suggested that drainage-wide incision began in the early Islamic Period, HML-Exp 02 testifies to first floodplain stability and then renewed aggradation at that time. The sequence that Hill (2006:82–84) posits — two incision episodes, dating to 100 cal BC–200 cal AD and pre-16th century cal AD — is clearly at odds with the HML-Exp 02 chronology, and Schuldenrein’s (2007:579) proposed first millennium cal AD incision is likewise incompatible with the HML-Exp 02 evidence. Apparently, either the chronologies are inaccurate or processes that have been understood to be drainage-wide and synchronous are either more local or time-transgressive. The geomorphic history of the Late Holocene in the Wadi el-Hasa appears to be more complicated than has previously been appreciated; improved chronologies and further research into local alluvial sequences as well as local and regional paleoclimate proxies are needed to resolve relationships between these complementary datasets.

5. Synthesis: land and floodplain use in the Wadi el-Hasa

Land-use and subsistence in the Wadi el-Hasa during the time period in which HML-Exp 02 was occupied (ca. 600–800 cal AD) varied topographically, with the plateau (ca. 1100 m a.s.l.) generally used for mixed agro-pastoralism, including rain-fed agriculture, and the wadi bottom (ca. 400 m a.s.l.) used for irrigated agriculture (Hill, 2004, 2006). Archaeological survey (MacDonald, 1988) indicates shifting settlement patterns on various timescales over millennia in the Wadi el-Hasa, with site abandonment common. Various scholars have argued that this regular site abandonment was due to the rapid degradation of fragile soils (by plowing, de-vegetation, and trampling) and subsequent erosion, which could make sustained land-use untenable (Hill, 2000, 2006, 2009; Schuldenrein, 2007).

Occupation of HML-Exp 02 during the early Islamic period locates the site in a timespan during which rural settlement is still very incompletely understood. Settlement patterns have been interpreted as indicating abandonment of many sites at the beginning of the Islamic period (beginning in earnest with the founding of the Umayyad Dynasty in the mid 7th century), suggested as related to regional decline in industry and trade as well as land degradation due to soil erosion (Hill, 2006; Kouki, 2012; MacDonald, 1988). However, more recent regional synthesis (Walmsley, 2007) suggests that claims of regional decline are exaggerated and mask great variability, with increased settlement and production in river valleys more than offsetting population declines in the highlands.

Renewed productivity in river valleys during the Islamic period was perhaps due at least in part to the impact of the “Arab Agricultural Revolution” (Watson, 1974), in which a new suite of crops,
more intensive cropping techniques, and new irrigation technology accompanied the spread of Islam. Although more recent research suggests that this “Revolution” was more of a gradual process less directly linked to Islamic expansion (Decker, 2009; Hoppé, 1999), nevertheless such evolution in agricultural strategies and technologies, while requiring more labor, also provided more output, contributing to population and settlement expansion in the region.

The process — and the complex nature of the evidence — is visible at the local as well as regional level. Using archaeobotanical evidence from the village of Khirbet Faris on the Kerak Plateau (immediately north of the Wadi el-Hasa), for example, Hoppé (1999) argues for agricultural continuity in the region from the Byzantine through to the early Ottoman periods, rather than rapid changes during the early Islamic period. This is not to deny innovation; for example durum wheat was a new introduced crop, but cultivated in Jordan beginning in the Byzantine period rather than as part of an Islamic agricultural revolution (Hoppé, 1999). Other innovations were Islamic in origin, but not synchronous with the Arab expansion; Hoppé (1999) argues, for instance, that the Islamic period did bring new irrigation technology to the floodplain (and a suite of exotic tropical crops necessitating the irrigation), but not until the 13th century cal AD.

In the final analysis, both the drier and the most degraded environments of the southern Levant, including the Jordanian wadi systems (Newsom et al., 2007; Ramsay and Smith, 2013; Walmsley, 1997, 2007:351) and the Negev desert (Ashkenazi et al., 2012; Haiman, 2012), were brought into production beginning in the Late Roman/Byzantine period. Floodplain use in the Wadi el-Hasa could form part of such an expansion of agricultural production, and equally, renewed use of stable and fertile floodplains may have been a necessary land-use decision, enabled by new farming techniques and responding to the effects of millennia of land-use and soil erosion.

In any case, early Islamic use of the Hasa floodplain occurred in a legacy landscape, with millennia of occupation dating back to the Paleolithic. Most immediately, the Wadi el-Hasa’s Nabataean, Roman, and Byzantine period inhabitants actively engineered the landscape; water and soil management techniques developed in the Nabataean period (e.g., check dams and terraces for water and sediment impoundment and runoff irrigation, as well as irrigation systems) remained in use in the southern Hasa through the Byzantine period and beyond. The development of these techniques was not isolated from politico-economic changes: recent work from Petra’s hinterlands (Kouki, 2009, 2012) argues that population increase in the arid deserts of Jordan during the Late Roman and Byzantine period, driven by Roman military expansion, encouraged a shift from locally intensive land–use practices to extensive land–use practices. Hill (2004) suggests that while economic and political stability remained relatively high through the Roman and Byzantine periods, allowing a settlement and population expansion in the Hasa, this expansion may have led to a peak in soil erosion. The peak in soil erosion would have been followed by a shift in agricultural production and settlement from highly eroded upland hillslopes to areas of greater surface stability — namely the early Islamic period floodplain.

While this pulse of erosion remains hypothetical, the evidence we report here of floodplain exploitation is consistent with such a scenario. Perhaps more importantly, this evidence serves to emphasize the potential significance of a type of site that is marginal in three senses: floodplain sites are often discounted due to the rarity of their preservation, hinterland sites are neglected relative to villages and towns due to the relative difficulty of locating them and their perceived peripheral roles, and the early Islamic period in Jordan has been the focus of only limited research. If the scarcity of sites like HML-Exp 02 can be ascribed to their generally rare preservation and a relative lack of interest in looking for them, then the site suggests that a significant component of economy and society in the early Islamic Wadi el-Hasa remains largely unexplored.

The 7th–8th century cal AD floodplain occupation represents a confluence of opportunity — floodplain stability — and cultural interest in exploiting that environmental niche. This begs the question — examination of which is complicated by the landscape taphonomy vis-à-vis settlement survey — of whether the Hasa floodplain was a niche consistently exploited over time, one exploited only in this instance (due to either push or pull factors; e.g., degradation of slope soils [push], stabilization of the floodplain [pull], or external politico-economic demands of the Byzantine or Ummayad political economies [both push and pull]). What is clear, however, is the telling reminder that HML-Exp 02 offers: floodplain environments, in spite of the particular taphonomic challenges they represent, need to be taken into account in considerations of past occupation and exploitation of arid environments like the Wadi el-Hasa. In the context of the middle Hasa, this may have particular ramifications for examinations of early Neolithic occupation. Although preserved sites (MacDonald, 1988) are confined to the valley slopes, topographic reconstruction suggests a more expansive floodplain in the Early Holocene (Contreras and Makarewicz, 2013). HML-Exp 02 demonstrates that consideration of which sites may be missing, and what role those sites may have played, may be vital to investigations of past land use in Jordanian wadi systems generally.

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Appendix A. Supplementary material

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References
