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# Geoarchaeology in an urban context: the uses of space in a Phoenician monumental building at Tel Dor (Israel)

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**Abstract**

Interpretation of past urban societies in the Near East, whose settlements are known mostly as tell sites, is largely based on macro-stratigraphy and on the association of architecture with macroscopic artifacts. Analyses of sediments, common in prehistoric sites, are rare in tell sites. Here we show the results of a detailed geoarchaeological study of the micro-stratigraphy of a sedimentary sequence associated with early Iron Age Phoenician monumental architecture. The study involves mineralogical, micromorphological and phytolith analyses and provides new insights into the stratigraphic sequence and the use of architectural spaces. The sedimentary sequence examined comprises alternating layers of gray 'fill' deposits and white 'floors'. We show that 'floors' made from local calcareous sandstone in the lower part of the sedimentary sequence were heated and are thus in effect 'plaster floors'. A concentration of micro-laminated, trampled fish remains above the most elaborate of these plaster 'floors' indicates activities related to fish processing. Fine white layers in the upper part of the sedimentary sequence that were considered as plaster based on macroscopic examination are in fact composed almost entirely of opaline grass phytoliths. The phytoliths appear in an undulating micro-laminated structure and are associated with dung spherulites and phosphate nodules, thus probably reflecting livestock penning. The formation of 'phytolith floors' involves extensive volume reduction due to the degradation of the organic material and this may result in 'floor' subsidence, a phenomenon that is often observed in archaeological sites. Most 'fill' deposits include macroscopic and microscopic remains of wood ash, bones, phytoliths, charcoal, ceramics, plaster and mollusk shells, reflecting the debris produced from household activities. This study shows how a combination of macro-stratigraphy with microscopic and mineralogical analyses of the sediments within architectural spaces can provide information on the varying ways in which the space was used through time, and also contributes to solving macro-stratigraphic problems.


*Keywords:* Mineralogy; Micromorphology; Phoenician architecture; Phytoliths; Tel Dor; Iron Age; Site formation processes

## 1. Introduction

Urban centers in the Ancient Near East usually exhibit long occupational sequences, resulting in the formation of mounds or tell sites with complex stratigraphies. Interpretations of the habitation sequences, the sociopolitical, economic and ideological aspects

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of these societies are largely based on architectural and artifactual data.

Formation processes in urban tell sites have rarely been addressed, though this subject attracted significant attention in the 1970s and 1980s (e.g., see [29] and references therein). Only a few studies focused on the sediments in Near Eastern archaeological urban sites, mostly on mud-brick composition (e.g., [19,29]). Sedimentological studies of activity areas in tell sites are scant and were based mainly on micromorphology and sieved micro-artifacts [24–26,29]. In prehistoric sites, on the other hand, where permanent structures are rarely preserved, many studies have highlighted the importance of detailed analyses of microscopic finds, as well as the mineral and elemental components of the sediments for the reconstruction of activity areas. For example, Weiner et al. [42], Albert et al. [2] and Schiegl et al. [31] identified degraded hearths and the nature of the fuel used using mineralogical and phytoliths analyses. Shahack-Gross et al. [33] used micromorphology, mineralogy and phytoliths to identify degraded livestock enclosures in sites where no visible structures are preserved. Eidt [14], Terry et al. [38] and Knudson et al. [23] showed that activity areas could be determined based on the elemental composition of soils. It is particularly helpful to perform some of these analyses on-site while the excavation is in progress [41].

We study the sediments of an urban, historical site (Tel Dor) using both on-site and laboratory analyses. We focus on mundane features found in any excavation of this type – those customarily dubbed by archaeologists 'floors' and those designated 'fills'. The analysis was conducted on a sedimentary profile left at the eastern baulk of area D2 at Tel Dor (Fig. 1).

Tel Dor, situated on Israel's Mediterranean coast, is a mound site whose earliest occupation dates to the Middle Bronze Age IIA (ca. 2000–1750 BCE). It was built on an elevated ridge of late Pleistocene calcareous sandstone locally known as 'kurkar'. Several kurkar ridges exist along the Mediterranean coast of Israel, some of them submerged (for details on the paleoenvironment around Tel Dor see [35,36] and references therein). Later occupations also extended to the sandy areas east of this kurkar ridge [37]. This study focuses on a small area that is a part of a large architectural complex in area D2 (Figs. 1 and 2), dated to the early Iron Age (11th–9th centuries BCE).

## 2. Overview of the Early Iron Age at Tel Dor, focusing on area D2

Two decades of excavations at Tel Dor revealed a very detailed sequence of early Iron Age occupations

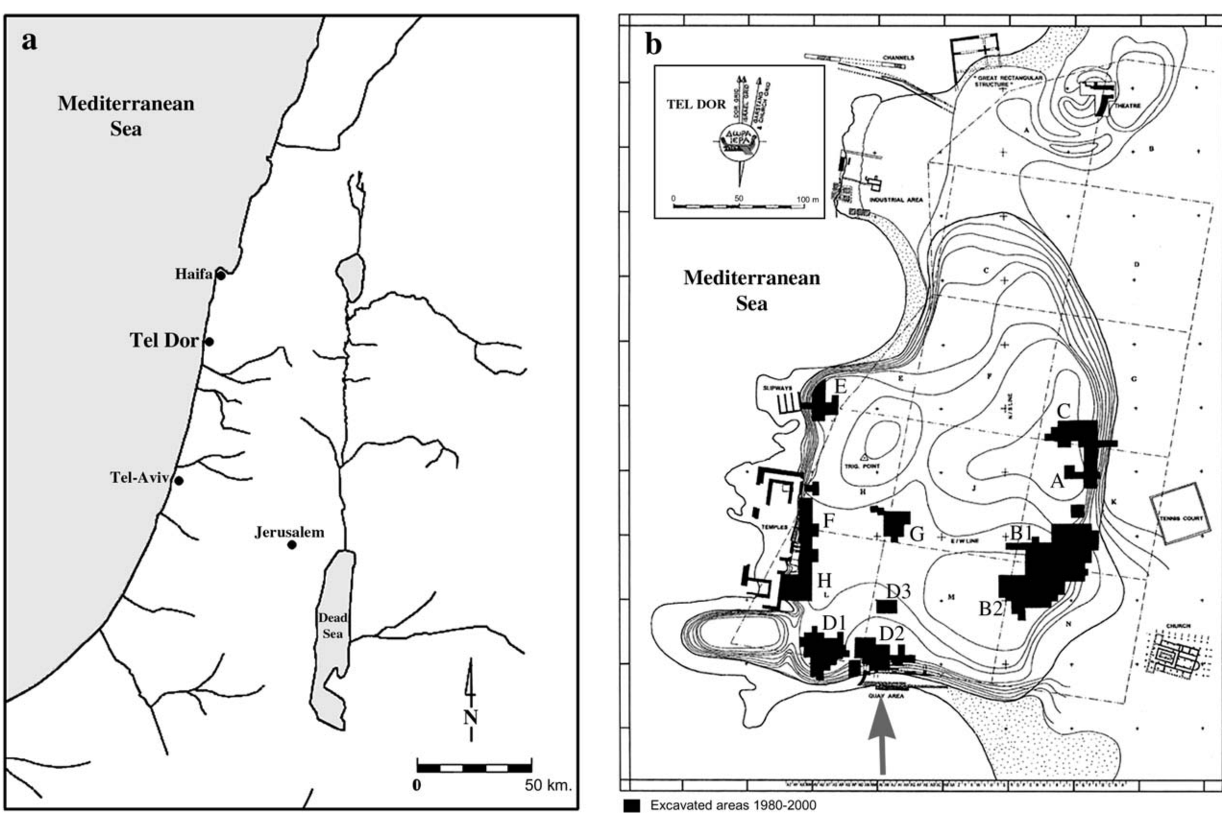


Fig. 1. Maps showing (a) the general location of the site of Tel Dor, and (b) the site itself with the excavation areas in black. Note the location of excavation area D2 (arrow) where the studied sedimentary profile is located.

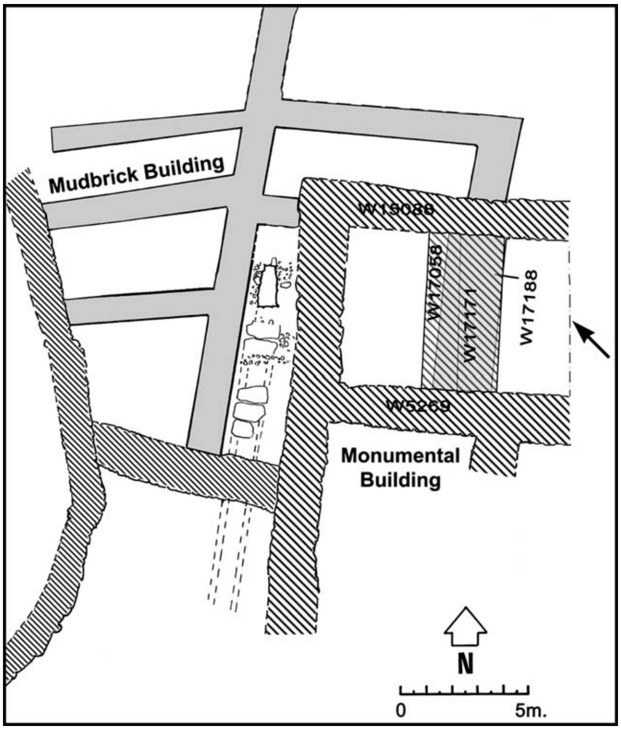


Fig. 2. Schematic drawing showing Phases 10-9 of area D2 in plan view. Note two construction methods: mud bricks (gray) and stone (diagonal lines). The studied baulk is located on the eastern edge of the excavation (arrow). The studied 'floors' and 'fills' were confined to the area between the baulk in the east, wall W15088 in the north, wall W5269 in the south that is an internal partitioning of the Monumental Building, and a succession of walls in the west. The latter include an earlier mud-brick wall W17188, and later two, probably contemporaneous, stone walls W17058 and W17171.

datable to the 12th–9th centuries BCE (for overviews, see mainly [18,34,37]). Area D2 is one of the main areas in which this sequence was uncovered. It overlooks the southern lagoon of Dor, where the ancient harbor may have been situated (Fig. 1b). One important aspect of the Early Iron Age sequence in area D2 is its succession of monumental constructions, apparently of public nature. Dor is one of the few sites in which public edifices related to the early Phoenician Iron Age were thus far uncovered. These are of prime importance for studying issues such as the nature of the Late Bronze/Iron Age transition in Phoenicia, modes of early Phoenician mercantilism, and so forth (see [17]). Thus, elucidating the functions of the spaces within and around buildings in area D2 in Tel Dor is of importance.

The architectural elements in area D2 and their stratigraphic relations are presented in Gilboa and Sharon [18] and Sharon and Gilboa [34]. In general, the stratigraphy of the west and north quadrants of area D2 is more detailed, and comprises three major constructional clusters. The first, an early Iron Age stone building on bedrock is earlier than the sequence discussed here and will not be referred to (phases D2/13-12, [34]). The second (phase D2/11, [34]) is a badly-preserved and ill-defined occupation post-dating the destruction of the previous building. The third (phases D2/10-9, [34]) is a complex of massive constructions dating to the late Iron Age I (11th century BCE by the 'conventional' or 'high' Levantine Iron Age chronology or 10th century BCE by the 'low' chronology and by Tel Dor radiocarbon dates – see [18] for discussion and further bibliography). The massive constructions during these phases include a very large mud-brick storage facility and a drainage channel (Fig. 2). In the Iron Age I/II transition and early Iron Age II (phase D2/8, – 9th century BCE based on Tel Dor 'low' chronology [18,34]), these structures go out of use and are partly overlain by another stone building (in the north) and partly by an open courtyard (in the south).

The Monumental Building which occupies the southeast quadrant of area D2 (Fig. 2) is an exceptionally large structure; one of the largest edifices of the early Iron Age, not only in Phoenicia but in the entire eastern Mediterranean Basin. It is built mainly of large limestone boulders, but its one preserved corner is constructed of massive kurkar ashlars. The building may have two major systems of superimposed inner partition walls, the lower one constructed of mud bricks, and the upper one of un-hewn stones. The upper, stone system abuts the external walls of the building, while the relation of the lower, mud-brick system is yet unclear. It either belongs to the building, or may have been cut by it (see below for details). This uncertainty in the macro-stratigraphy of the building raises two possibilities for the date of its construction. It may have been constructed either during the middle Iron Age I (i.e., phase D2/10; with a later renovation in phase D2/8 [34]) or during the transition to Iron Age II (phase D2/8 and the mud-brick wall system belongs to an earlier construction [34]). While the smaller structures west and north of the Monumental Building had artifact assemblages in primary deposition, the floors of the Monumental Building were practically bare of artifacts.

Overall, after excavation of several rooms of one of the largest monuments of the early Iron Age in the Levant, it was impossible to reach definitive conclusions about its function, precise stratigraphy, date of construction, and even architectural plan. It could only be conjectured that it was a public structure, possibly fulfilling some administrative role associated with the activities in the harbor it overlooks.

This study will concentrate on one space within this building, defined by wall W15088 on the north, wall W5269 on the south, and the sequence of walls W17058 ≥ W17171 > W17188 on the west (Fig. 2). The baulk forming the eastern boundary of this excavated space is the object of this study (Figs. 2 and 3a). We studied a 70-cm thick section that contains 10 depositional units, here termed layers, exposed in the lower part of the eastern baulk (Fig. 3). These layers represent the transition from the late Iron Age I to the early Iron Age II (phases D2/10-8b, [34]), based on the ceramic assemblages [17]. Originally, these layers were excavated in several sections over two seasons and each comprises several different locus numbers. Table 1 shows all locus numbers and highlights the main number that is routinely used. For brevity, the layers are numbered sequentially from bottom to top by capital letters, from A to J (see also Fig. 3b) and these designations are used throughout the text. The stratigraphic relations between the inner and outer walls of the building and the excavated 'floors' inside it are also summarized in Table 1 (see also Fig. 3a). The upper part of this sequence, layers E–J, relates to the upper system of internal stone walls and thus certainly belongs to the building. The lower part (layers A–D) relates to the problematic mud-brick system and thus either also relates to the building, or alternatively, to a massive mud-brick building cut by it. In addition, note that all the layers studied here end ca. 20 cm before the northern wall of the Monumental Building (W15088), giving the impression that these layers were cut by a foundation trench for the building. On the other hand, all layers reach the wall in the south (W5269), indicating that the building and the sedimentary profile within it are coeval. These relations emphasize the macro-stratigraphic problems associated with the time of construction of the Monumental Building described above.

We first determined the material sources of each layer through mineralogical and phytolith analyses, and then examined the detailed structures and relations within and between the various layers, mainly through micromorphological analyses.

## 3. Materials and methods

The sedimentary profile examined here was exposed during the 1995–1996 excavation seasons. The profile was cleaned and straightened several times in 2002

Table 1
Field descriptions and stratigraphic relations of the loci and 'floors', here termed layers (see Fig. 3b), in the studied sedimentary profile (from top to bottom)

| Layer | Loci and 'floor' numbers | Matrix and comments as recorded in the field | Relations of 'floors' to walls | | | |
|---|---|---|---|---|---|---|
| | | | W15088 (N) | W5269 (S) | W17171 (W) | W17188 (W) |
| Above J | Fill 17138 (17112, 17141) | Orange material with *kurkar* bits, possibly constructional fill, over 40 cm thick, sloping eastward. | + | + | ? | – |
| J | Fill 17088 (17113, 17119, 17142, 17149) | Soft gray material with ash, charcoal, burnt mud-brick material and vitrified nodules, sloping eastward. Bones, varied artifacts and pottery, possibly in primary deposition. | | | | |
| I | Floor 17088 | White plaster floor, four more resurfacings below it, sloping eastward. | – | + | ? | – |
| H | Fill 17158 (17156, 17159) | Gray ashy fill with some mud-brick material, *tabun* fragments, sloping eastward. Bone, including fish bones, potsherds and various artifacts. | | | | |
| G | Floor 17158 | White floor, sloping eastward. | – | + | + | – |
| F | Fill 17165 (17166) | Gray fill, some sand, some mud-brick material, bones, including fish bones, potsherds and various artifacts. | | | | |
| E | Floor 17165 | Kurkar floor with mollusk shells in lower part. | – | + | + | – |
| *Transition from inner mud-brick to inner stone system, from late Iron Age I to Iron Age I/II – Iron Age IIA* | | | | | | |
| D | Fill 17174 (17177, 17178) | Brown-gray, composed of shells, mud-brick material and contains *tabun* pieces, charcoal bits, potsherds, some purple substance, bones, including many fish bones. | | | | |
| C | Floor 17174 | Kurkar floor with shells. In northern part there is plaster above the kurkar. | – | + | – | Probably |
| B | Fill 17179 (17189) | Brown and gray fill. | | | | |
| A | Floor 17179 | Crushed kurkar and plaster floor, sloping eastward. Pottery in primary deposition, bones are present. | – | + | – | Probably |

The associations of 'floors' with surrounding walls are also indicated in order to relate the studied layers to the macro-stratigraphy in area D2. Wall W15088 is the northern wall (N); wall W5269 is the southern wall (S); wall W17188 is the lower (mud-brick) wall on the west (W) and wall W17171 is the upper (stone) wall on the west (W): (–) means 'floor' does not reach the wall, (+) 'floor' abuts wall, and (?) unclear relation to wall. Note that we included the relation to the walls of the 'fill' above layer J in order to show that in contrast to all of the studied layers, this layer *does* abut wall W15088 on the north.

through 2004, and over 100 bulk (loose) sediment samples were collected based on texture and color differences. These samples were analyzed on-site by both a portable Fourier Transform Infrared (FTIR) Spectrometer (MIDAC Corp., Costa Mesa, CA, USA) and a petrographic microscope (Nikon, Labophot2-pol).

The bulk sediment samples were collected and placed in plastic vials. These samples weighed on average a few to tens of grams each. For FTIR measurements, each sample was prepared by mixing about 0.1 mg of powdered sample with about 80 mg of KBr. FTIR spectra were collected at 4 $cm^{-1}$ resolution. For phytolith analyses, the bulk sediment samples were gently homogenized using a mortar and pestle. Quantitative phytolith analyses were carried out based on the methods developed by Albert et al. [3]. Phytoliths were morphologically identified using a polarizing light microscope (Nikon Labophot2-pol) at 400× magnification. Morphological identification was based on standard literature [7,27,28,39]. When possible, the terms describing phytolith morphologies follow anatomical terminology, and otherwise they describe the geometrical characteristics of the phytoliths [4].

In addition to the bulk samples, 13 undisturbed sediment blocks were carved out of the profile for micromorphological analysis. The samples were taken diagonally along the profile with slight overlap between consecutive samples in order to have a full, uninterrupted sequence. This was repeated in two localities along the profile, close to the northern wall (W15088) and about 2 m north of the southern wall (W5269) (Figs. 3a and 4). Additional blocks were taken as well (Fig. 4). Due to the sandy nature of the sediments, the carved blocks were coated with plaster of Paris prior to their detachment from the profile. The blocks were transported to the laboratory where they were impregnated with a polystyrene mixture, cut using a rock saw and sent for thin section preparation to Spectrum Petrographics Inc. (Oregon, USA). Thin sections (standard 30 μm thickness) were observed using a polarizing light microscope (Nikon Labophot2-pol) and described following Bullock et al. [8] and Courty et al. [12]. In addition, one embedded block was polished, carbon coated and analyzed with a scanning electron microscope (Jeol 6400) with an EDS link (Oxford Instruments) operating system. Elemental analyses were performed in order to identify the various minerals based on stoichiometry (thus differentiating, for example, between phytoliths and calcite grains) and in order to determine the relationships between the mineral grains. Images were recorded in the back-scattered electron (BSE) mode.

An on-site burning experiment was conducted in the 2004 season in order to quantify the change in the volume of domestic livestock dung with degradation (i.e., from dry dung pellets to mineral, mostly phytolith, powder). Dung pellets of free ranging cattle and sheep/goat were collected in locales in northern Israel. An aliquot of each dung type was weighed (g) and its volume recorded (ml). The aliquot was placed in a metal pot and burned. Burning temperature was recorded using a portable digital thermometer (Yokogawa model 2455, Singapore). The ash was weighed and its volume measured. The calcitic portion of the ash was then dissolved in 1 N HCl. The acid insoluble fraction was weighed after washing in water and drying, and its volume measured, and compared to the volumes of the same sample before burning and acid treatment. The mineralogical composition of these samples was determined using FTIR spectroscopy and grain mounts were prepared for microscopic examination.

## 4. Results

We first present the stratigraphic data obtained during the excavation of the Iron Age layers that are now exposed on the eastern baulk of area D2. The analytical results are then reported based on depositional categories, i.e., ‘floor’ and ‘fill’ deposits. For each category, the results of bulk analyses obtained through FTIR spectroscopy and phytolith analyses are shown first. These analyses provide information on the material composition of the sediments, i.e., the material sources. Micromorphological observations are then presented, highlighting the structure of the sediments, i.e., the manner in which the sediments were deposited and the role of post-depositional changes.

### 4.1. Stratigraphy of the sedimentary profile

The sedimentary profile examined (Fig. 3a, lower part) is composed of alternating dark and light layers, conventionally interpreted as ‘fill’ deposits (the dark-colored layers) and ‘floors’ (the light-colored layers). All layers slope in a northeasterly direction. Note the convexity of the layers in the southern part of the profile (Fig. 3a). Table 1 summarizes the sequence of deposits exposed on the studied sedimentary profile. Table 1 also presents the relations between the ‘floors’ and the surrounding walls (these can be partially observed in Fig. 3a), and the macroscopic description of the layers, as recorded during the excavation. The sequence includes five ‘floors’ and five ‘fill’ deposits. The excavators determined that the three lower ‘floors’ (layers A, C and E) are composed of crushed kurkar, while the two upper ones (layers G and I) are composed of lime plaster. Note that the composition of all ‘fill’ deposits was not determined, and that the excavators noted a large concentration of fish bones and relatively small amounts of pottery in the ‘fill’ deposit of layer D. In fact, several almost complete skeletons of small fish

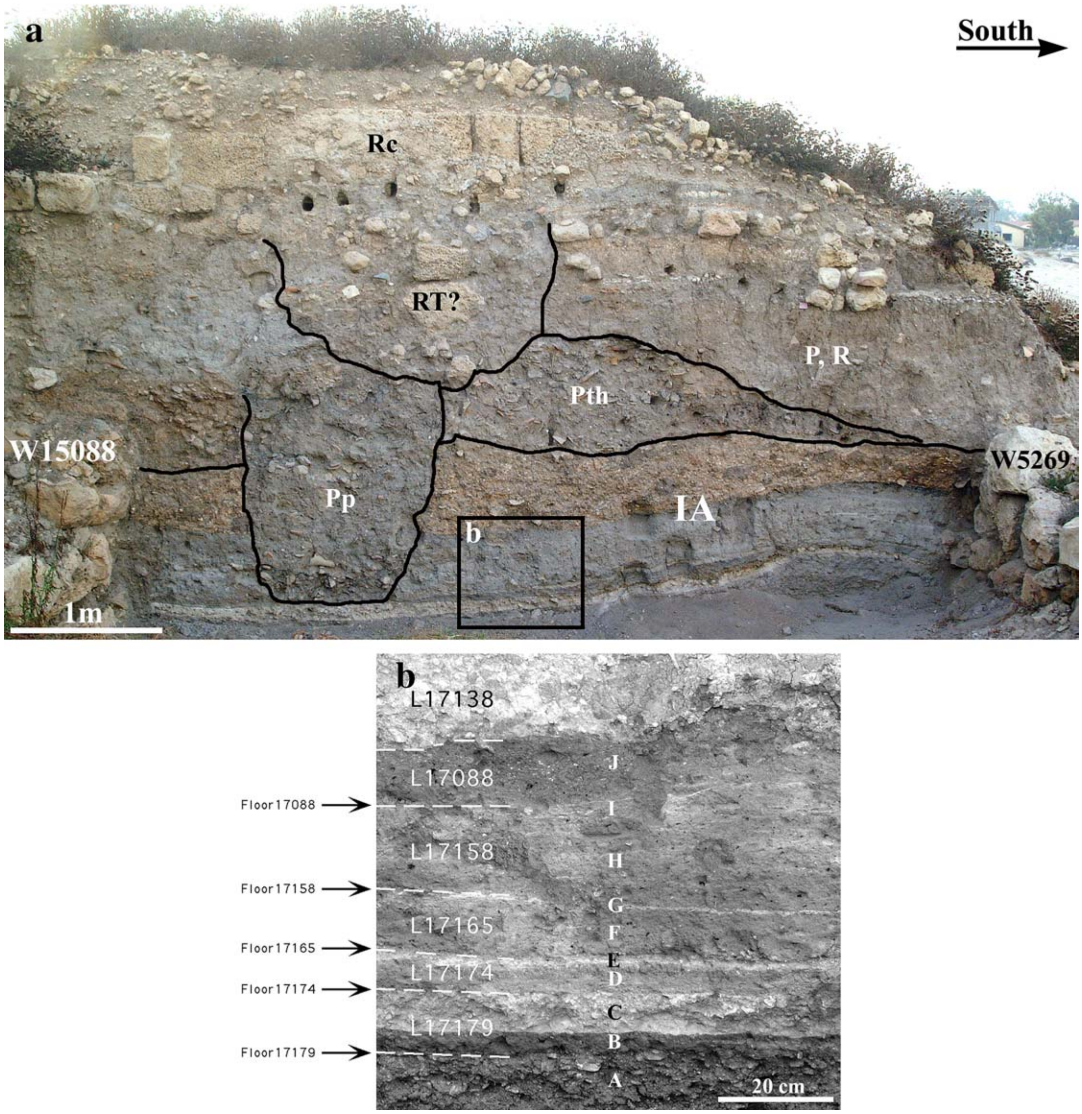


Fig. 3. Photographs of the studied sedimentary profile in area D2 in Tel Dor. (a) General view of the profile showing the north and south walls of the Monumental Building, and the sediments from the Iron Age (IA), Persian period and Roman stratified sediments (P, R), Persian trash heap (Pth), a possible robbers' trench (RT?), and Roman construction (Rc). Note that the sediments from the Iron Age period are stratified and cut by a large pit dated to the Persian period (Pp). (b) Close-up view of the gray stratified sediments examined here from the Iron Age showing loci and 'floor' numbers. Each layer is designated by a capital letter (A–J).

(ca. 5 cm long) were uncovered in layer D. The uppermost 'fill' deposit (layer J) included charcoal and burned mollusk shells. Layer J seemed to have been cut horizontally and was covered by a thick orange-colored layer composed of kurkar and clay (L17138, not examined in this study). Based on ceramic analysis the pottery assemblages from the lowermost loci (L17181 and L17179, i.e., layers A and B) date to the late Iron Age I period. The pottery assemblages from the other loci (layers C through J) are either from the Iron Age I/II transition or early Iron Age II (see [17]). All the ceramic assemblages, however, seem to be very close in age which led the excavators to assume that the stratified sequence represents a continuous occupation.

### 4.2. Floors

Mineralogical analyses of layers A, C and E confirm the excavators' descriptions of these floors being composed of the local carbonaceous sandstone, kurkar. The mineralogical compositions of these floors are all mainly quartz, calcite and aragonite (Fig. 5a). The latter mineral originates from mollusk shells. Overall, this composition does reflect the structure of kurkar, i.e., quartz sand grains and aragonitic shells cemented by relatively large crystals of calcite (ca. 10–20 μm, Fig. 6a). Micromorphological observations, however, show that most of the kurkar in layers A, C and E is altered. It is composed of quartz grains in a groundmass

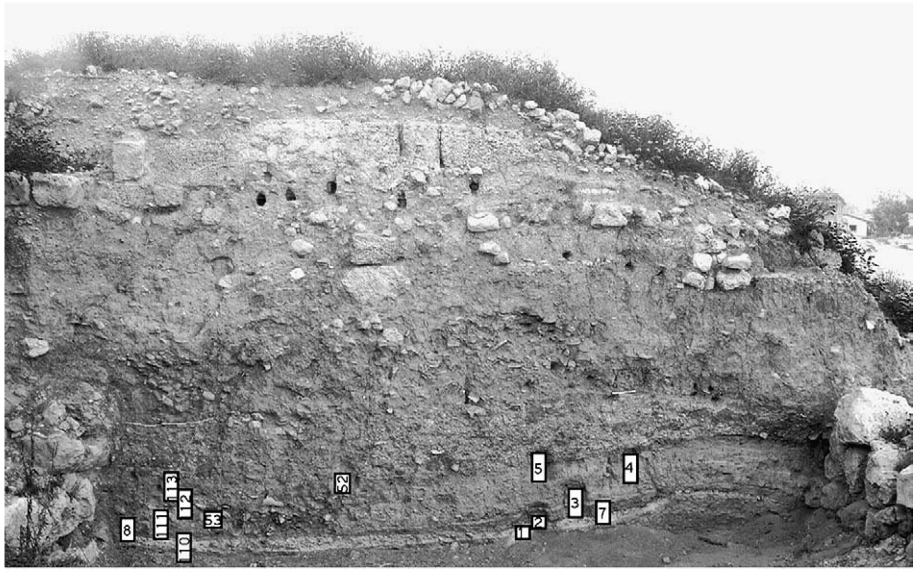

Fig. 4. Photograph of the studied sedimentary profile in area D2 in Tel Dor showing the locations of block samples obtained for micromorphological examination.

of very small calcite crystals. The small size of the crystals gives the groundmass a grayish appearance in plain polarized light (PPL). In addition, a few kurkar particles seem to be partially altered, containing large and small calcite crystals and showing shrinkage cracks (Fig. 6b). All these features indicate that the kurkar rock was heated prior to its deposition as a floor (see e.g., [1,5,15,20–22]). In this respect, layers A, C and E are in fact lime plaster floors and this is, to our knowledge, the first time that this rock is demonstrated to have been used as raw material for lime preparation. Micromorphological observations further confirmed the field observation of the excavators that the floor material of layer C was covered by a thin film (ca. 3 mm thick) of lime plaster in the northern part of the profile. The micromorphological observations are further supported by the mineralogical composition of the kurkar floors, having only traces of aragonite (Fig. 5b) relative to unaltered kurkar (c.f., Fig. 5a). Aragonite readily transforms into calcite at high temperatures [43]. We determined the transformation temperature of aragonite into calcite (in kurkar samples heated in a furnace oven in the laboratory) to be in the range of 450–500 °C. Taken together, it seems that floor A is composed of a relatively small amount of heat-altered kurkar fragments, that floor C is composed of more heat-altered kurkar fragments (especially in its upper 5 cm) and that floor E is composed almost entirely of heat-altered kurkar fragments. It may be thus concluded that most of the kurkar used for floor construction was heated to temperatures of at least 500 °C prior to its deposition. Phytoliths are not expected to be found in a rock such as kurkar. The small amounts of phytoliths present in layers A, C and E (Fig. 7) result from mixing of kurkar with 'fill' deposits, especially in the case of layer A that contains kurkar and 'fill' deposits in a 1:1 ratio.

The 'floor' materials (i.e., 'floor' make-up) of layers G and I were thought by the excavators to be composed of lime plaster due to their white color and fine-grained texture. The FTIR analyses show that the mineralogical composition of these 'floors' comprises mainly opal with varying amounts of calcite, quartz and clay (Fig. 5c). A grain mount observed under the petrographic microscope showed that the opal originates primarily from plant phytoliths. It is thus demonstrated that 'floors' previously termed "plaster" are actually composed mainly of opaline phytoliths. Moreover, this composition questions whether these layers truly represent floors. The concentration of phytoliths in 1 g of bulk sediment from these 'floors' is in the order of tens of millions of phytoliths compared to soils surrounding the tell, where the phytolith concentrations are in the order of less than 1 million phytoliths in 1 g of bulk sediment (Fig. 7). In addition, we have never observed phytolith layers in natural soil profiles. This clearly indicates that phytolith layers do not accumulate naturally but originate from anthropogenic activities.

The phytolith morphologies observed in both 'floors' (i.e., layers G and I) show that over 90% of the phytoliths originate from monocotyledonous plants, mostly C3 type grasses. The grass phytoliths were then re-divided into three broader categories, namely grass leaves/stems, grass inflorescence and grass short cells. The latter is common in both the leaves/stems and the inflorescence of grasses, and its presence in such abundance attests to the fact the major grass types from which almost all the phytoliths were derived, are C3 type grasses (Fig. 8). Inflorescence phytoliths

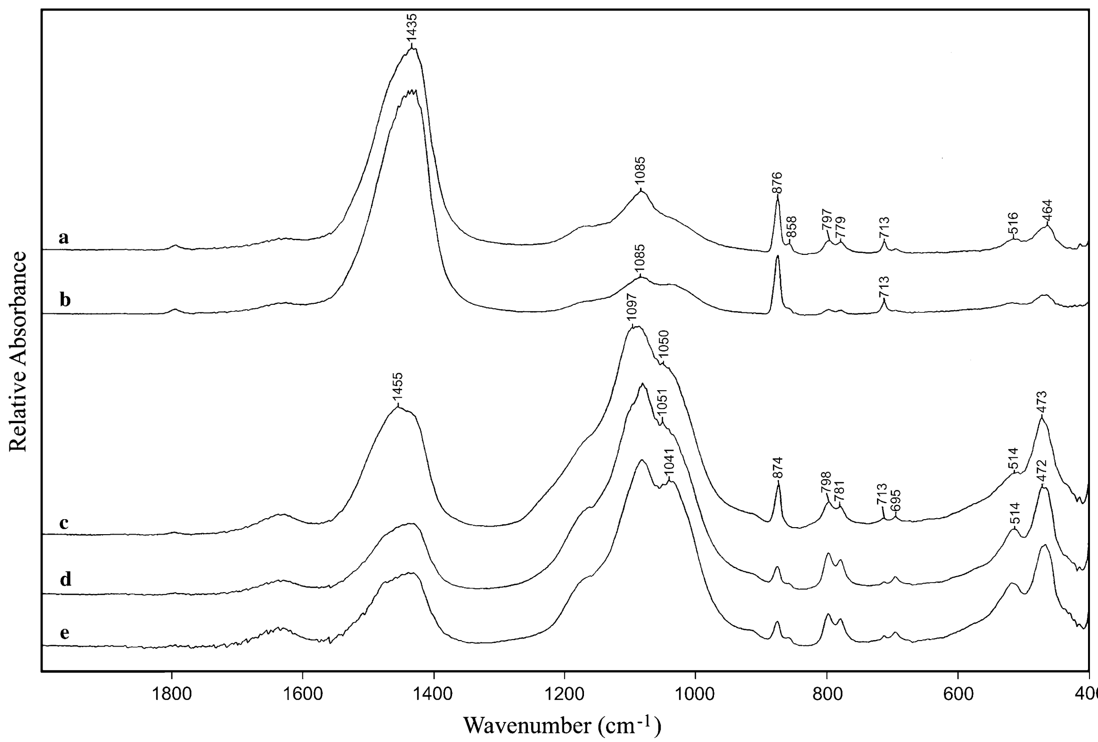


Fig. 5. Fourier Transform Infrared (FTIR) spectra of representative materials identified in the studied sediments. (a) Spectrum of fresh (unmodified) kurkar rock collected near the tell. The absorptions at 1435, 876 and 713 $cm^{-1}$ are from calcite. The absorptions at 1085, the doublet around 780 and 464 $cm^{-1}$ (and other weak absorptions in this spectrum) are from quartz. The absorption at 858 $cm^{-1}$ together with absorptions at 1435 and 713 $cm^{-1}$ are from aragonite. This mineralogical composition reflects the structure of kurkar rocks, composed of quartz sand grains and aragonitic mollusk shells cemented by calcite. (b) Spectrum of kurkar from layer E. Note the similarity to the fresh kurkar except for the negligible absorption at 858 $cm^{-1}$ relative to fresh kurkar. This spectrum reflects the transformation of aragonite to calcite. (c) Spectrum of bulk sediment sample from layer G. The absorptions at 1097, weak doublet around 790 and at 473 $cm^{-1}$ are from opal, the mineral component of siliceous plant phytoliths. The other absorptions are from minor amounts of calcite, clay (main absorption at 1035 $cm^{-1}$ but shifted to 1040–1050 $cm^{-1}$ due to small amounts of the phosphate mineral dahllite, almost not detected in the spectrum) and quartz. (d) Spectrum of bulk sediment sample from layer H. The main absorptions are from quartz, clay and calcite. (e) Spectrum of bulk sediment sample from layer D. Note that this layer is richer in clay compared to other 'fill' deposits (c.f., Fig. 5d).

dominate in both layers. Micromorphological observations of these 'floors' show that the phytoliths are arranged as long arrays in an undulating micro-laminated structure (Fig. 6c). This was also clearly observed using the Scanning Electron Microscope (Fig. 6d). Layer I is composed of four depositional suites, each including a lower sub-unit of densely packed, long phytolith arrays and an upper sub-unit composed of 'fill' deposits (see below). Dung spherulites (calcareous spheres measuring 5–15 μm in diameter that form in the guts of animals and are excreted in their dung [9–11]) are present in both 'floor' layers but are more concentrated on top of layer G. In addition, microscopic masses of authigenic, i.e., in situ formed, phosphate mineral nodules were detected in thin sections. It may thus be concluded that layers G and I were produced from large amounts of grass that included a high proportion of the flowering parts. The presence of authigenic phosphate minerals indicates that large amounts of organic matter degraded in situ, releasing phosphate into the soil solution. The phosphate presumably reacted with calcium carbonate present in the sediment to form the phosphate mineral dahllite (carbonated apatite). This, together with the presence of dung spherulites, some of which were also phosphatized, indicates that these 'floors' were composed, at least in part, of livestock dung [6,9,13,33].

### 4.3. 'Fill' deposits

All gray-colored sediments and the topmost orange-colored sediment layer (locus 17138) were designated by the excavators as 'fill' deposits. They were unable to determine, however, whether these were 'constructional fills', i.e., sediments brought to the area in order to serve as a substrate for the construction of a new floor, or 'accumulated fills' i.e., deposits built up in situ as a result of daily activities. The FTIR spectra of all gray-colored 'fill' deposits show that their major mineral components are quartz, calcite and clay in varying amounts (Fig. 5d). They sometimes also include two weak absorptions around 567 and 603 $cm^{-1}$ indicative of the phosphate

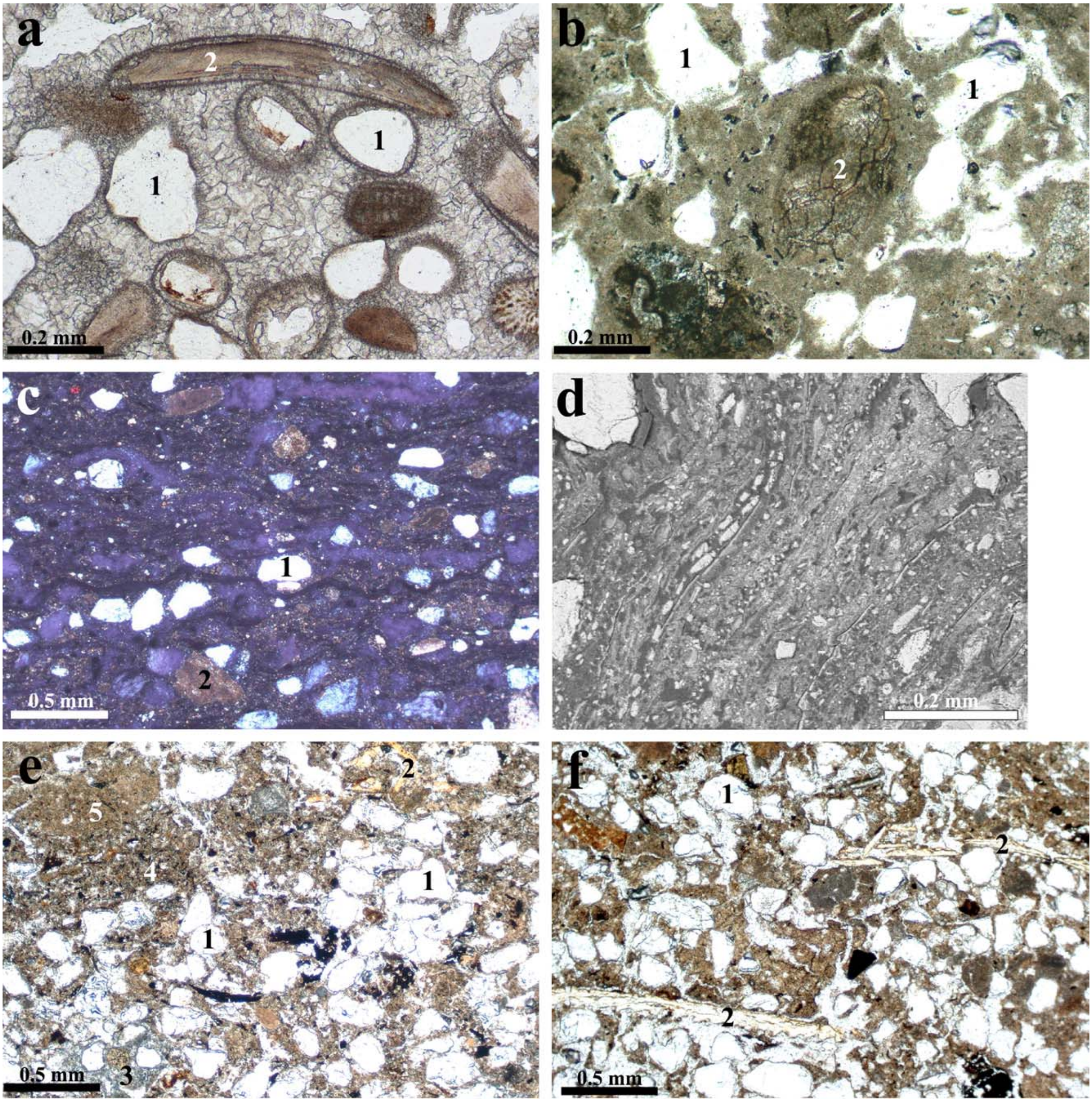


Fig. 6. Photomicrographs of representative materials and microstructures identified in the studied sediments. (a) Fresh kurkar rock in plane polarized light (PPL). Note the presence of quartz sand grains (1), fragments of mollusk shells (2) and calcitic cement (light groundmass). The calcite crystals are large and their boundaries are clearly observed (i.e., crystal sizes are at least 10–20 μm). (b) Kurkar from layer C that has been altered at high temperatures (PPL). Quartz grains (1) and mollusk shell fragments (2) are present. Note the unresolved crystal size of the calcitic groundmass (crystal sizes are below 1 μm) and that the shell fragment (2) in the center of the frame includes larger calcite crystals in its center than along its edge, and contains shrinkage cracks. These two features are typical of lime plaster products, showing that the kurkar was heated. (c) Phytolith arrays (black lineaments) in layer G under crossed polarized light (XPL). Note that these arrays persist for fairly long distances. The material between the lineaments includes quartz grains (1) and a groundmass of calcite and clay (2). (d) Scanning Electron Microscope image of the phytolith arrays in layer G. Note that the width of each lineament is composed of only one or two phytoliths. (e) 'Fill' deposit from layer H. Note the abundance of remains attributed to daily household activities in the sandy (1) groundmass, including bone (2), charcoal (black fragments), kurkar fragments and probable lime plaster fragment (3), short phytolith arrays (4) and clay masses (5). (f) 'Fill' deposit from layer D. Note the quartz sand grains (1) and that the groundmass is composed mainly of calcitic clay. Fish bones (2) are arranged in a sub-parallel manner forming a micro-laminated structure. Note the in situ fragmentation of the upper fish bone, probably due to trampling.

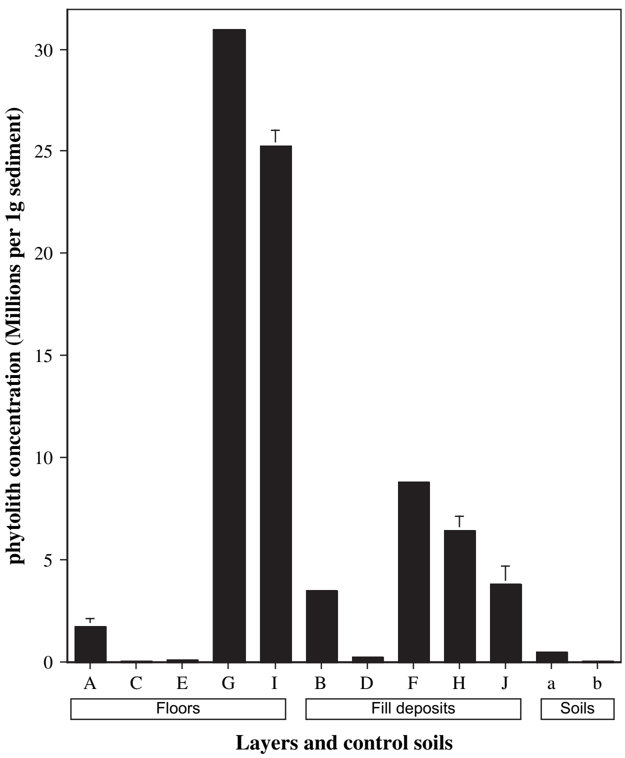


Fig. 7. Phytolith concentrations in 'floor' materials, 'fill' deposits and control soils from around the site (shown as layer notations based on Fig. 3b). Note the low concentrations of phytoliths in the three kurkar 'floors' compared to the phytolith 'floors'. Note also the relatively high concentrations of phytoliths in 'fill' deposits and the exceptionally low concentration of phytoliths in the 'fill' deposit of layer D.

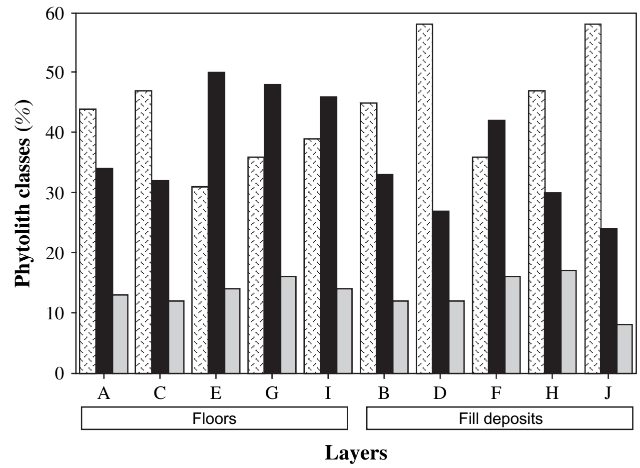


Fig. 8. Phytolith morphologies in 'floor' materials and 'fill' deposits (shown as layer notations based on Fig. 3b). The diagram shows only the grass phytoliths that were identified in each layer. The phytolith assemblages in all layers are composed of ca. 90% grass phytoliths. The three grass phytolith morphological groups shown are from leaves/stems (diagonal lines), inflorescence (black) and short cells (dots) which may originate in either leaves/stems or inflorescences of grasses. Note the abundance of inflorescence phytoliths, indicating springtime use of the grasses.

mineral dahllite. This mineral may be derived from either fragmented bones or authigenic phosphate nodules. After treatment of the 'fill' sediments with 1 N HCl, the main absorption of clay was clearly observed with no interference due to the presence of the main peak of the dahllite. Based on the position of the main clay absorption around 1035 $cm^{-1}$ and a relatively prominent absorption at 535 $cm^{-1}$ it can be concluded that the clay minerals in most layers are not altered due to exposure to high temperatures. The exception is layer J, where a mixture of burned and un-burned clay was detected by infrared spectroscopy (unpublished results).

Phytolith analyses show that the gray 'fill' layers contain a few millions of phytoliths per 1 g of sediment (Fig. 7). 'Fill' layer D (c.f., Fig. 2b) is exceptional as it has low concentrations of phytoliths relative to other 'fill' deposits (0.2 million vs. 1.4–8.8 million phytoliths in 1 g of bulk sediment). In all of the gray-colored 'fill' layers over 90% of the phytoliths are from grasses with abundant inflorescence and leaf/stem phytoliths of C3 type grasses (Fig. 8). This is similar to the 'floor' layers.

Micromorphologically, all gray-colored 'fill' layers are composed of clay, calcite, and quartz grains of fine sand and silt sizes (Fig. 6e). They often include wood ash crystals (identified as rhombohedral calcite crystals resembling the original shape and size of calcium oxalate crystals found in fresh wood [40]), phytoliths, charcoal and occasional bones, small ceramic fragments, kurkar, shell, and probable lime plaster fragments. The large amount of microscopic debris of materials that result from anthropogenic activities, as well as macro-remains of ceramics, bones and charcoal, and the high phytolith concentrations in the 'fill' deposits implies that these sediments represent material accumulation resulting from daily activities.

Several notable micromorphological features were observed in the 'fill' deposits. A general observation is that the upper parts of 'floors' (especially kurkar floors) include small amounts of 'fill' sediment that either infiltrated from above or was trampled into the 'floors'. Similarly, fragments of 'floor' materials were incorporated into the 'fill' deposits above the 'floors' (for similar observations, see Matthews et al. [25]). This is especially evident in the case of the four consecutive phytolith 'floors' that comprise 'floor' layer I. This 'floor' thins from south to north. In the southern part it is composed of four depositional suites, each including a lower level of 2–5 mm thick layer of densely packed, long, micro-laminated phytolith arrays mixed with calcite, a small amount of quartz, and many phosphate nodules. The upper level of each suite is composed of typical 'fill' deposits of daily household debris (i.e., bones, shells, charcoal, phytoliths and possible lime plaster fragments). The phytoliths found in these layers are probably derived from the phytolith 'floor' below because they appear as loosely packed and short micro-laminated phytolith arrays.

The uppermost gray 'fill' deposit (layer J) seems to have been burned in situ because it includes kurkar fragments in a "bubbly" appearance, indicating the loss of calcite at very high temperatures (calcite disintegrates above 750 °C). This is supported by the presence of heat-altered clay (based on its infrared spectrum).

The 'fill' deposit in layer D is of special interest as it lies above the most elaborate floor (i.e., layer C) in the studied profile. The floor is relatively thick (ca. 10 cm), made of kurkar plaster, and, as noted, the remains of true lime plaster were detected on its surface in the northern part of the studied profile. All along the profile (from north to south) this floor is covered by a thin film of about 2 mm of pure quartz grains (i.e., beach sand). This sandy film is covered by brown sediment that includes clay, calcite, charcoal and small kurkar fragments. About 2 cm above the sandy film a unique layer ca. 2 mm thick was observed all along the profile, that includes many fish bones lying sub-parallel to the surface, forming a micro-laminated structure (Fig. 6f). Note that many fish bones were reported in layers D, F and H by the excavators (Table 1), but only in layer D were these bones arranged in a micro-laminated structure. A few bones seem to be broken but still in articulation, probably indicating trampling over them (Fig. 6f). The micro-laminated fish bone layer is covered by a gray 'fill' sediment. Note also that this 'fill' layer (layer D) has an exceptionally low concentration of phytoliths, similar to that in local control soils (Fig. 7).

### 4.4. On-site burning experiment

The results of the on-site burning experiment are presented in Table 2. The volume change related to dung degradation by burning is between 94.5 and 98% with the average being 97 ± 1.7% ($n = 4$). This implies that if a 100-cm thick layer of dung accumulated, after an average volume reduction of 97%, only a 3-cm thick layer of phytoliths will remain. These measurements can be used to roughly calculate back the thickness of dung that accumulated in a certain location based on the thickness of the phytolith-rich layer. Note that this will most likely be an overestimate as the dung probably degrades continuously once deposited, and in addition, the thickness of phytolith layers reflects not only the opal phytoliths, but also quartz and calcite.

## 5. Discussion

This study shows that detailed microscopic and mineralogical analyses of the matrix of 'floor' and 'fill' deposits may reveal important information that is often missed in excavations of 'historical' tell sites. Below we address issues of material identification and micromorphological relationships, and their role in interpretation of 'floor' materials and 'fill' deposits in terms of activities taking place in space and time in (at least one part of) the public space in area D2 at Tel Dor.

Table 2
Volume and weight changes associated with cattle and caprine dung (i.e., condensed grass material) degradation

| Sample | Volume reduction (%) | Weight reduction (%) |
|---|---|---|
| Cattle dung 1 | 94 | 91 |
| Cattle dung 2 | 98 | 95 |
| Sheep/goat dung 1 | 98 | 96 |
| Sheep/goat dung 2 | 97 | 98 |
| Average | 96.8 | 95.0 |
| Standard deviation | 1.9 | 2.9 |

Cattle 1 and sheep/goat 1 were collected in Kefar HaHoresh, Galilee, Israel. Cattle 2 was collected near Amirim, Galilee, Israel. Sheep/goat 2 was collected near Misliya, Mount Carmel, Israel.

### 5.1. Floor materials

The kurkar floors exposed on the eastern baulk of area D2 at Tel Dor were in part heated, forming de facto plaster floors. Evidence for kurkar quarrying is widespread in the immediate vicinity of Tel Dor. Prior to its heating, kurkar was either crushed from large quarried 'blocks' or may reflect a by-product of stone hewing. Thick kurkar floors such as those discussed here are an unusual phenomenon in Iron Age Dor. Of the three areas with extensive Iron Age exposures, several were indeed found in area D2, but not a single one is recorded in area G – a large residential/industrial area in the center of the mound, nor in area B1 – an area of fortifications and houses along the eastern edge of the tell (with possibly one exception). It thus seems that in Iron Age Tel Dor kurkar floors may be correlated with 'public' architecture. We would also argue that the fact that the Monumental Building had (at least one, and probably more) massive corner(s) constructed of kurkar ashlars indicates that 'crushed kurkar' floors in this building represent recycling of stone-hewing debitage. This hypothesis seems to be supported by the marked increase in both ashlar architecture and 'crushed kurkar' floors in the following periods (Persian and Hellenistic), when both these features appear in private as well as public architecture. Based on the above, we also suggest a possible scenario for the stratigraphic dilemma presented above. Such an association may indicate that the kurkar floors alongside the lower, mud-brick system of inner walls they abut, may be contemporaneous with the construction of the Monumental Building, and are not earlier, despite the fact that these floors fail to reach its northern wall.

This study also shows that in this section the macroscopically defined 'plaster floors' are not made of lime plaster but are layers of almost pure opaline phytoliths. These ‘floors’ could be derived from the remains of matting, grain storage, thatch roofing, stabling and dung-plastered floors. Morphological analysis of the phytoliths and other microscopic evidence enabled us to distinguish between these options. The option of matting is excluded based on the absence of palm and/or reed and/or sedge phytoliths and the presence of abundant inflorescence phytoliths. It also rules out the option of grain storage because in this case mostly inflorescence phytoliths of wheat and/or barley are expected to be present. The following observations are consistent with sediments that originated from livestock dung. The phytoliths derive from wild flowering grasses, appearing in an undulating micro-laminated structure, together with microscopic dung spherulites and authigenic phosphate nodules. Furthermore, the phytolith composition indicates that the animal fodder was composed of flowering grasses based on the abundance of inflorescence phytoliths, thus reflecting springtime utilization of the grasses. The option of dung-plastered floors is ruled out based on modern examples of dung plaster, from South Africa and India. These plasters indeed have a micro-laminated structure, however, the ratio of dung to soil is low. Therefore, after degradation these samples will probably remain micro-laminated but will not form enriched phytolith layers. On the other hand, dung plaster prepared by Maasai in southern Kenya, in which the ratio of dung to wood ash is high (about 80% dung and 20% ash by volume) and therefore will potentially form enriched phytolith layers, does not have a micro-laminated structure (probably because it is kneaded while being prepared) (R.S.-G. personal observations). The combination of a micro-laminated structure associated with high concentrations of phytoliths was observed in abandoned Maasai livestock enclosures in southern Kenya [33]. We therefore conclude that the phytolith layers in the Monumental Building originated from in situ primary livestock dung deposition. The option of roofing is unlikely, but cannot be ruled out.

Considering the thickness of the two phytolith layers identified in the studied profile (layers G and I), it may be calculated, using Table 2, that layer G, with an average thickness of ca. 1.5 cm, originated from about half a meter thick accumulation of dung. Layer G thickens to the north, becoming about 10 cm thick close to wall W15088. Such a thick layer of phytoliths would theoretically have originated from more than 3 m of dung. As the phytolith layers also include sand grains, calcite and phosphate nodules, this is an overestimate. Furthermore, as dung breaks down fairly rapidly by microbial action, it is doubtful that such a thick dung accumulation ever existed. Layer I is composed of 4 phytolith-rich sub-layers. These sub-layers must each have originated from about 6–15 cm of dung. The volume of dung that formed layer I, as well as the layer’s internal arrangement, may indicate four episodes of relatively short-term intermittent stabling.

The phenomenon of ‘phytolith floors’ is not unique to the studied profile at Tel Dor, as other such ‘floors’ were identified in areas D1 and G in the 2004 season. We also know of an occurrence of such surfaces in the Iron Age sediments in a domestic area (area K) at Tel Megiddo (R.S.-G., personal observation and examination). Patches of phytolith-rich layers have also been identified in the Neolithic settlement of Catalhöyük (Arlene Rosen, personal communication). It therefore seems to be a potentially widespread phenomenon in tell sites, and should be investigated further.

### 5.2. ‘Fill’ deposits

The gray ‘fill’ deposits are rich in components that probably derive from daily human activities. One exceptional ‘fill’ deposit is layer D. It contains less debris derived from daily anthropogenic activities (especially less ceramics and phytoliths) than the other ‘fill’ layers, and it contains more clay than the other ‘fill’ deposits. It also contains large amounts of fish remains, arranged in a micro-laminated structure, some of them trampled. The reason for finding a layer of fish remains, some of them in articulation (i.e., whole fish) is unclear. Possibilities are that as the studied area is located close to the waterfront the fish remains represent the waste of a fish processing area. This may also represent a fish storage area because it is located in a public, possibly commercial, area, or possibly a fish refuse disposal site. Systematic sieving in excavated tell sites would most probably produce large numbers of smaller bones and other microscopic remains. This would certainly contribute to a better functional understanding of features such as layer D.

A question that often arises when discussing ostensible ‘fill’ deposits is whether they are constructional (i.e., represent a single depositional episode) or accumulated through continuous in situ habitation (i.e., they are in reality superimposed living horizons). This is one of the most basic questions for the constructional/stratigraphic interpretation of any archaeological complex, and likewise for elucidating the chronological and functional association between the artifacts in those ‘fills’ and surrounding architecture. A characteristic example is Ussishkin [38], in which major issues regarding Iron Age monumental architecture and chronology were based on the characterization of fill deposits, albeit with no analysis of the deposits themselves. Although it has long been realized that the composition and micromorphology of ‘fill’ deposits is not always similar, this study shows empirically how the ‘fill’ deposit of layer D differs from all the other ‘fill’ deposits studied here, and at least in part is the product of continuous activities. Thus sedimentological information, in addition to stratigraphic information, can help resolve this issue. Matthews et al. [25] noted, based on micromorphological considerations, that sediments accumulated through continuous habitation are characterized by micro-laminated structures while discarded deposits, e.g., 'constructional fills', are characterized by random orientations of their components. Following their observations, layers F, H and J reflect 'constructional fills' whereas layers G and I, considered by the excavators as 'floors', are in fact 'accumulated fills' formed through continuous, probably stabling, activities. This implies that the true constructed floors on which these deposits accumulated are the topmost surface of the 'constructional fill' below them, i.e., 'dirt floors'. Moreover, layer D can now be divided into three parts; the lowermost is 'constructional fill' overlain by 'accumulated fill' composed of fish remains, that in turn is overlain by 'constructional fill'. This implies that the interface between the lower 'constructional fill' and the 'accumulated fill' in layer D was in fact a 'dirt floor' that was not detected during the excavation.

### 5.3. Past human activities

Reconstruction of activity areas in urban sites from historical periods is usually based on the form and macroscopic contents of structures. We note that much time and resources were invested in order to construct the layer C kurkar plaster floor (10-cm thick of heated crushed rock over an area of at least 16 $m^2$ and covered by true lime plaster). This layer therefore represents the floor of an important structure and it is thus tempting to relate the layer above it, layer D, to the activities that took place on this floor. Moreover, the fact that the materials that were found in layer D differ from the other 'fill' deposits in the studied profile may be regarded as evidence in support of layer D representing the primary activities that took place on the elaborate kurkar plaster floor. Ethnoarchaeological observations, however (e.g., [16,32,44]), point to the fact that the deposits on floors often reflect activities that post-date the primary use of structures. Therefore, it is more likely that the activities related to fish processing (in layer D) reflect a later use of the space. This is consistent with the presence of a thin layer of pure sand found in the section directly on the kurkar plaster floor and clayey sediment with low amounts of phytoliths and ceramics (this layer was not noted during the excavation itself). In a prehistoric site or a domestic context in a historic site, this sand film would probably have been interpreted as dust accumulation on the floor and the clayey sediment as decayed mud bricks, thus leading to the conclusion that the fish processing activity post-dated a phase of abandonment. However, in the context of public architecture in such a strategic location, and in light of the detailed ceramic analysis which does not point to an occupational gap, only a very short discontinuous use of this space can be considered. Alternatively, these thin layers of pure sand and clay may represent the preparation of the space for fish processing. Later activities taking place in the studied area include possible livestock stabling. Layers G and I were not prepared as surfaces for stabling of animals but formed as a by-product of the stabling activities. These layers are in themselves direct evidence for this activity in the area and should have been dubbed 'accumulated fills' or 'superimposed living horizons'.

Conventional interpretations of monumental architecture such as the Monumental Building at Tel Dor are that they are 'fortresses' or 'palaces', implying that the use of space is for military, administrative, or ceremonial functions. This study indicates that a much wider variety of activities need be considered, especially if we take into account the fact that the studied sediments have accumulated in one room of this building only, and that other spaces in it must have housed a variety of different activities. This does not necessarily mean that the primary function of the building was not administrative or ceremonial – especially if 'administration' included gathering, stowing and redistributing foodstuffs and livestock or if 'ceremony' included large-scale preparation and consumption of same. However, combining macro-stratigraphy and the results of the sedimentological study, it is clear that new interpretations regarding the use of public space at early Iron Age Tel Dor are possible, which were not considered before.

Having noted above that evidence for the activities that took place *directly* on the elaborate kurkar plaster floor (layer C) were not found, we suggest that only materials found within such floors or in the few millimeters below the very surface of plaster floors can be indicative of the activities that took place on them. The reason is probably that plaster floors can be routinely swept. Matthews et al. [24] reached a similar conclusion for Neolithic Catalhöyük. It will probably be difficult to routinely identify the primary activities on plaster floors. On the other hand, evidence for the activities that took place on 'dirt floors' in this study is abundant (i.e., fish processing and livestock stabling), probably because these floors cannot be swept and thus remains of the activities are trampled into them and also accumulate on them. Similarly, in an ethnoarchaeological study of a hunting–fishing camp in northern Kenya, Gifford [16] observed that small bones were trampled into the sandy sediments in her study area (i.e., 'dirt floor') and thus had a better chance of being preserved for long periods of time.

Layer J is a thick 'fill' deposit similar to the 'fills' of layers F and H, except that it is burned. This layer was leveled and covered by a thick 'fill' (locus L17138). Layer J may thus reflect a destruction event, either intentional or accidental.

### 5.4. Other implications to macro-stratigraphy

All of the studied layers slope (about 14° below the horizon) towards the northeast. It is improbable that this represents intentional construction, even in order to facilitate drainage, because the slope is too steep for daily use. A more likely scenario is that the slope developed as a result of post-depositional subsidence. This is supported by the observation of the folded southern part of the studied profile (see Fig. 3a). Post-depositional 'floor' subsidence is often observed in archaeological sites, but the reasons for its occurrence are not well understood. Schiegl et al. [30] noted sediment volume reduction in a prehistoric cave due to ash diagenesis. We propose that another mechanism for subsidence is due to the in situ degradation of the large amounts of organic, vegetal material whose remains (i.e., phytoliths) are found in large quantities in 'fill' deposits and in even larger quantities in animal enclosures (that are manifested as 'phytolith floors'). In the case of the profile examined here, this would imply that there are more 'phytolith floors' below layer A, a viable possibility because the base of the studied profile is still well above bedrock.

The volume reduction associated with the formation of phytolith layers, from the accumulation of the dung to the complete degradation of its associated organic material, calls for re-examination of stratigraphic relationships between 'floors' and walls. The down-shifting of originally organic-rich sedimentary layers implies that the original points of contact between floors and walls may be difficult to determine. A maximum estimate could be made based on the volume change from pure dung to pure phytoliths. We also observed that certain areas subside more than others (e.g., the studied layers subside in a northeasterly direction). It is therefore possible that the lowermost area of subsiding floors will separate horizontally from the walls they originally reached, a possibility that cannot be ruled out as an explanation for the problematic macro-stratigraphy within the Monumental Building (see Table 1). These are clearly important issues, as such site formation processes may complicate the archaeological interpretation of many such sedimentary sequences.

## 6. Conclusion

Careful field observations, together with micromorphological, mineralogical and phytolith analyses can be used to elucidate the different ways in which space associated with building construction was utilized. Such an integrated approach to studying the sediments that accumulate in and around structures at sites such as Tel Dor has the potential to contribute significantly to our understanding of the ways tell sites were formed, and in turn to past human behavior.

This integrated approach not only means that archaeologists excavating large and complex sites will have to devise systematic protocols in order to characterize the sediments they excavate, but that geo-archaeologists, usually accustomed to prehistoric sites, or other locales of relatively low complexity and modest architecture, will need to develop interpretative frameworks appropriate for urban contexts.

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