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Pigeon-raising and sustainable agriculture at the fringe of the desert: a view from the Byzantine village of Sa'adon, Negev, Israel

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Deposits rich in bioarchaeological materials were unearthed in two dovecotes found near Sa'adon, a Byzantine-period village (5th–6th century CE) in the semi-arid part of the Negev. One structure contained a layer of pigeon manure and articulated pigeon skeletons, preserved occupation levels and evidence of sudden destruction (mid-6th century CE), whereas the other lacked distinct occupation debris indicting more orderly human abandonment. Our findings demonstrate the importance of raising pigeons for their high-quality manure in connection with agricultural development around the Negev Byzantine settlements. This product was essential for fertilizing vineyards and orchards; our findings provide direct evidence for the intensive nature of desert agriculture and a new approach to addressing questions of past human sustainability in an environmentally marginal area.

Keywords sustainable agriculture, Byzantine archaeology, marginal areas, dovecotes, pigeon manure

Introduction

The Byzantine Negev Agricultural Complex based on sophisticated arid land farming has been a focus of research for several decades, much of it devoted to investigating the ways that water and soil were collected within runoff agricultural systems (e.g. Ashkenazi *et al.* 2012; Avni *et al.* 2013; Avni and Rosen 1993; Bruins 1986; Erickson-Gini 2013; Evenari *et al.* 1982; Haiman 1995; Kedar 1957; see also, Barker 2002). Additional key factors underlying the success of this agricultural complex, which remain largely unexplored, include the composition of crops and management techniques employed in ongoing maintenance strategies. Understanding the contribution of these factors is critical if we are to arrive at a comprehensive explanation for the viability of large-scale, organized agricultural pursuits in an arid environment, as well as the eventual demise of Byzantine occupation in the Negev *c.* 1400–1500 years ago.

Historical documents refer to the agricultural achievements of the Negev population in the Byzantine period, particularly praising the high quality of the region's wine, which was exported throughout the empire (Decker 2013: 107; Mayerson 1959; 1992; McCormick 2012). Large-scale, local wine production in the Negev is further evidenced by the finding of widespread winepress installations in association with Byzantine sites (Decker 2009; Mazor 1981). Recent discoveries include high abundances of grape pips found in domestic midden deposits and landfills in Shivta (Subeite) and Haluza (Elusa) (Bar-Oz *et al.* 2016; Fuks *et al.* 2016) and botanical

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remains, such as fig, olive, date, garden pea, cereals, barley and grape uncovered in a Byzantine dovecote in Shivta (Ramsay and Tepper 2010; Ramsay *et al.* 2016).

A fundamental impediment to developing intensive and sustainable agriculture in the northern Negev concerns the nutrient-poor conditions of local loess soils (e.g. Nitrogen), presumed unsuitable for crop-growing (Sher *et al.* 2013; Ward *et al.* 2001). Manuring of cultivated soils to enhance their fertility is thought to have been widely practiced in antiquity (Fenton 1981; Tepper 2007a), though direct evidence from the Negev, as well as other key regions of Byzantine settlement, has been lacking. In a recent study employing chemical analysis of soils in relict fields, we showed that pigeon manure could have been used by Negev Byzantine agriculturists to fertilize fields (Tepper *et al.* 2017). However, these localized indications could not provide a basis for more thorough assessment of the scale of Byzantine fertilizer production and use.

Here we report on the excavation of two dovecotes near the village site of Sa'adon in the Negev. These were discovered in the surrounding landscape of the settlement, which preserves abundant evidence of intensive agricultural activities (Hirschfeld 2006; Rubin 1990: 145–50; Shereshevski 1991: 78–82; Tepper and Bar-Oz 2016 and references therein). Our excavations provide new and direct evidence to assess the significance and scale of manure production. Specifically, in one of the structures studied we unearthed an exceptionally well-preserved deposit of rich organic material overlying the stone floor, including numerous pigeon skeletal remains, vegetal nesting material and fossilized droppings. Analysis of the construction method and contents of these dovecotes allows us to assess their precise chronological context, mode of use and role in the maintenance of agricultural activities in the Byzantine Negev. Dating of the destruction and abandonment phases of the dovecotes, as revealed through excavations, also allows us to estimate much more precisely the timing of the end of intensive Byzantine agriculture in the environment of Sa'adon.

Site setting

The site of Sa'adon (Kh. Saadi; Sudanon) was a small agricultural village in the north-western Negev, about 30 km south-west of the modern city of Beer-Sheba. The site is mentioned in the Nessana papyri (identified as *Σουδανον*; papyrus number 79; dated to the beginning of 7th century CE, Kraemer 1958: 124; see also Negev 1977; Tsafrir *et al.* 1994: 236). The village was established on the south bank of wadi Sa'adon, on a small chalky hill *c.* 280 m above sea level, and is located about 9 km from the much larger and better known urban Byzantine site of Elusa (Fig. 1a–b). The climate in this region is semi-arid with 100 mm average annual rainfall (Fig. 1c).

Sa'adon, first documented in the late 19th–early 20th century (Kühtreiber 1914: 5; Musil 1907: 78; Palmer 1871: 34; Weigand 1920: 60–61; Woolley and Lawrence 1914–1915: 111–12), extends over an area of approximately 0.35 ha and features two churches. Researchers agree that the site flourished during the Byzantine period (4th–7th centuries CE) and was abandoned at the end of that period (Hirschfeld 2006; Rubin 1990: 145–50; Rubin and Shereshevski 1988; Shereshevski 1991). Only sporadic evidence, including rare pottery fragments and graffiti on Church walls, indicate later human presence, probably of nomads, belonging in the Early Islamic period (7th–9th centuries CE) and Late Ottoman Period (19th–20th centuries CE).

The hinterland surrounding the site reveals abundant remains of agricultural activities, which include remains of dams along wadi Sa'adon and its tributaries (Fig. 2). The slopes of the wadi are also strewn with small stone heaps (*Tuleilat-el-Ainab* in Arabic), which may have been used to enhance the flow of water and soil into the fields below (Kedar 1957; Tadmor *et al.* 1957). We focus on three structures discovered approximately 300 m north-west and west of the site, at the top of small hills abutting wadi Sa'adon, previously suspected of being dovecotes (structures A–C; Fig. 2a–b, e; see also: Hirschfeld 2006: 40–43).

Description of the Sa'adon dovecotes

We excavated two of the three suspected dovecote structures known near Sa'adon. These included a circular (Structure A) and a square-shaped (Structure B) structure (Fig. 2a–b, e). Excavations of the structures showed that the deposits within them were associated either with the period of abandonment (Structure A) or of use (Structure B) of the structures, each characterized by different types of material and biological finds.

The circular dovecote (A)

This dovecote is especially well preserved (Fig. 3). Its diameter is 6.2 m and it is constructed directly on bedrock. The structure is composed of a circumference wall >1 m thick (W-104), its outer part constructed of large local field stones with typical sizes of 30 × 40 × 40 cm, hewn on their external side only. What we

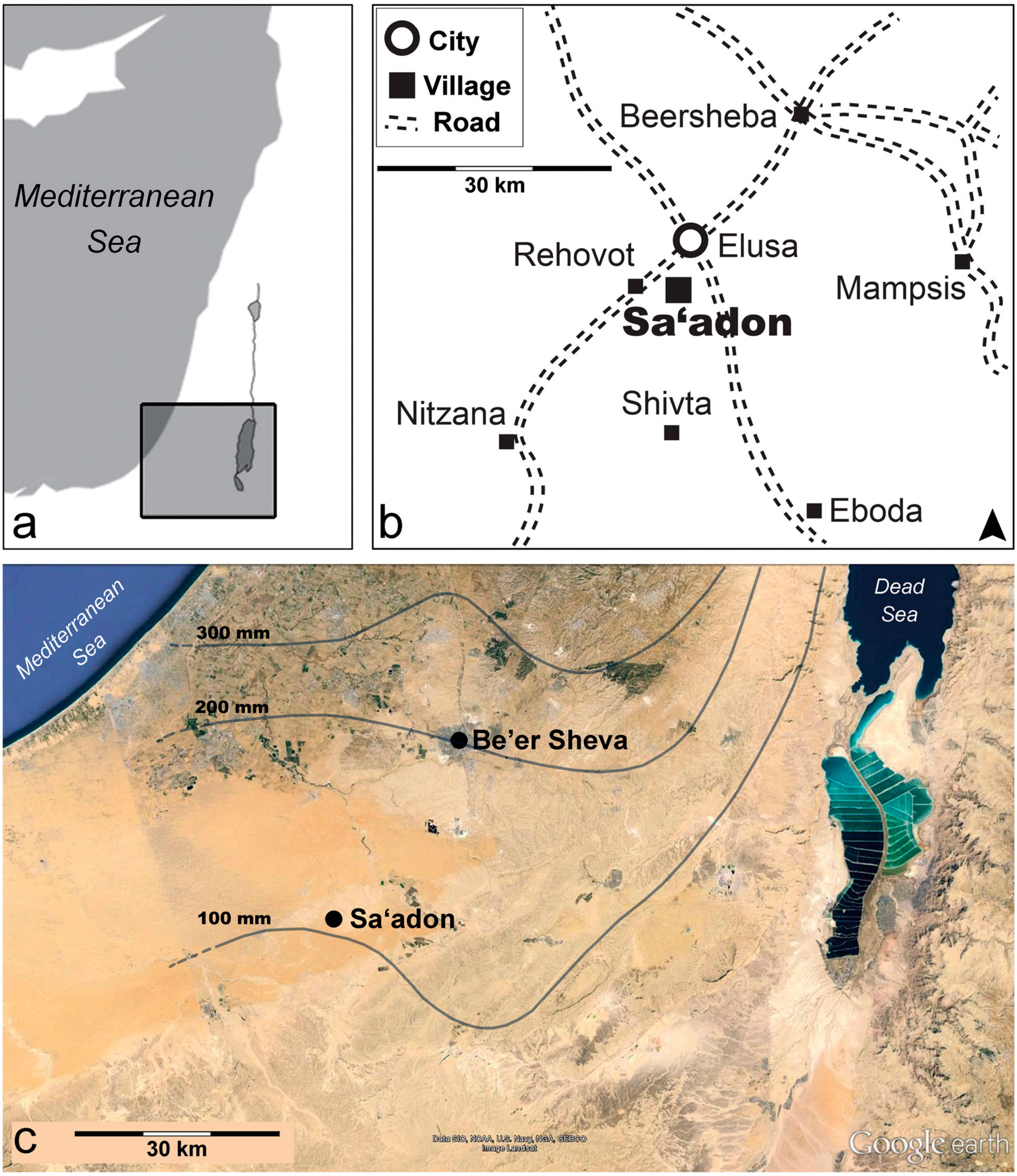


Figure 1 a–b. Location map of the Negev, the village of Sa'adon and other sites in the region, and main roads (after Hirschfeld 2006: fig 1); c. Average annual rainfall isoyets in the Negev (Google Earth; Meteorological Service of Israel: http://www.ims.gov.il/ims/all_tahazit/).

identify as the original floor of the structure (F-109), is composed of mortar mixed with pulverized chalk and lime spread over compressed earth, which, in turn, overlies the bedrock. This distinct composition may have provided a means of pest control, as well as a form of water-proofing for the structure. The bedrock underlying the floor of the structure was modified in places through chiseling but remains conspicuously uneven. In one location a 15 cm depression was chiseled out of the bedrock indicating that the builders opted for an uneven, rather than levelled infrastructure, and the presence of depressions. Such an uneven floor could have functioned in the efficient accumulation and collecting of pigeon manure.

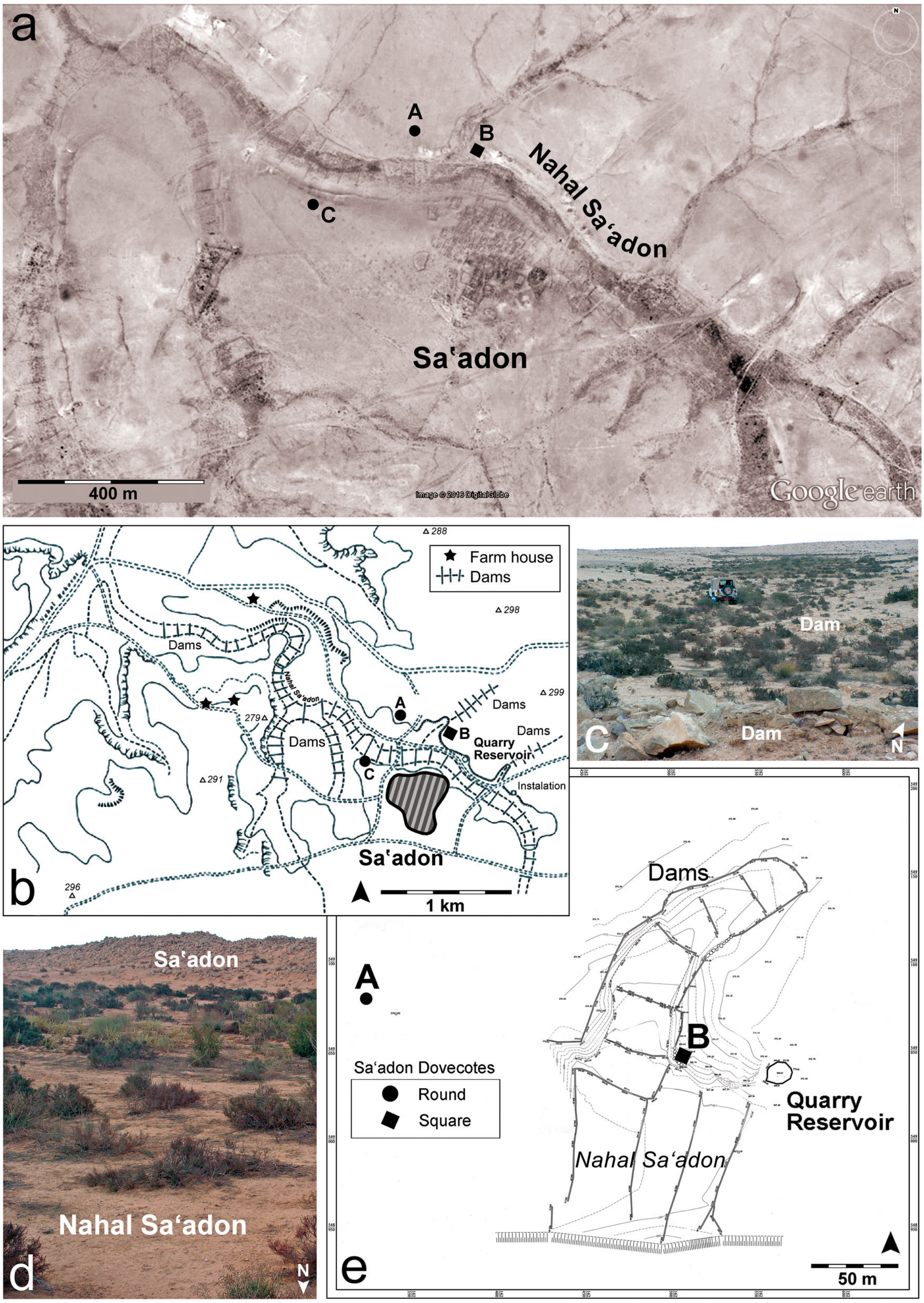


Figure 2 The hinterland surrounding the site, near wadi Saʿadon showing the location of structures A–C (a–b; after Hirschfeld 2006: fig 2), remains of dams and walls near the site (c–d; Photos: Yotam Tepper) and an agricultural complex near the A–B structures (b, e).

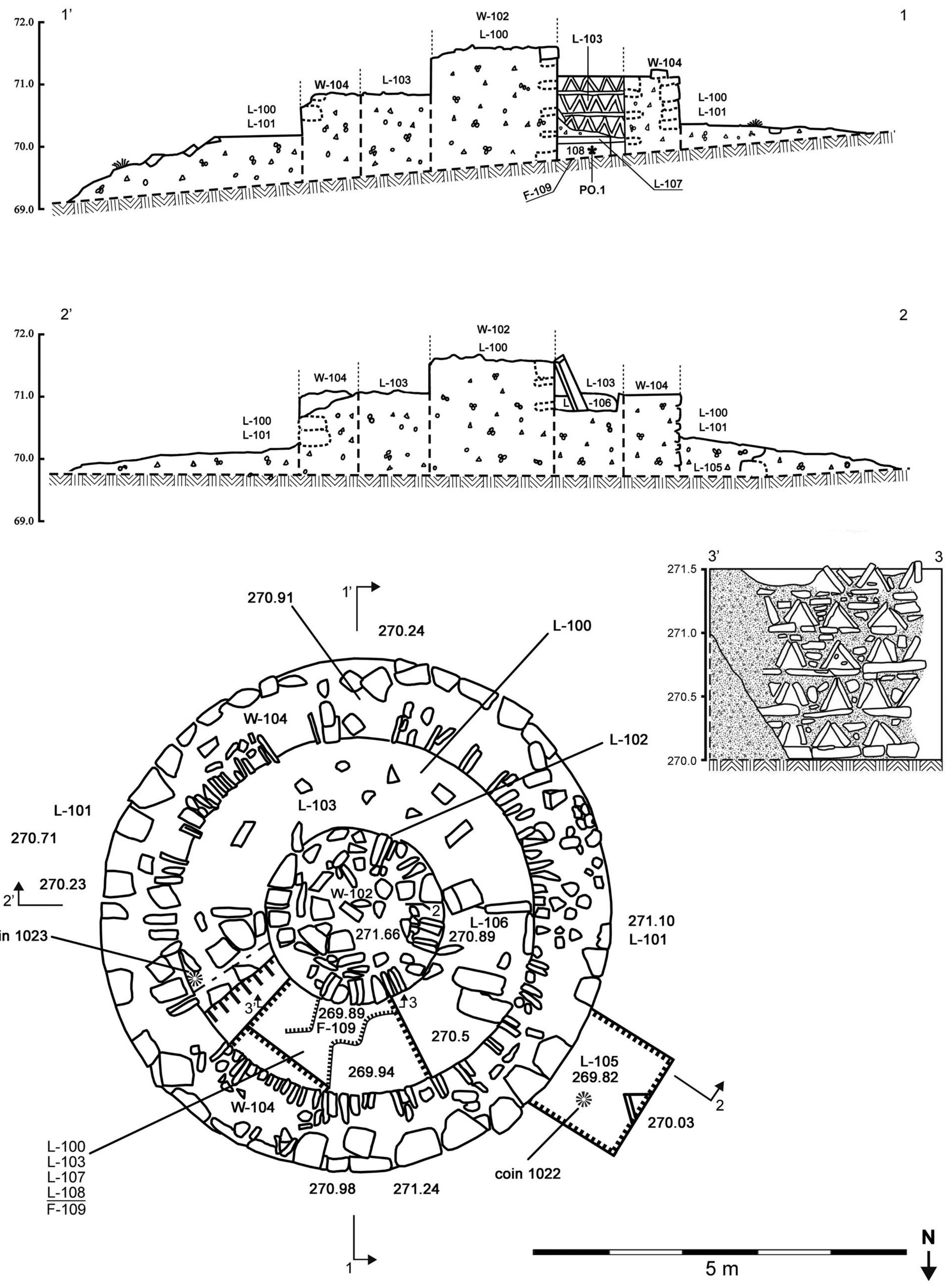


Figure 3 Plan and sections of structure A at Sa'adon.

Above the floor we uncovered a thin layer (*c.* 25 cm) of sediment (Fig. 4; Locus 108) and above it another thinner (5–10 cm) dark-colored deposit, both encompassing remains of small mammals (Locus 107). These deposits were overlain by collapsed debris from the upper part of the structure, including

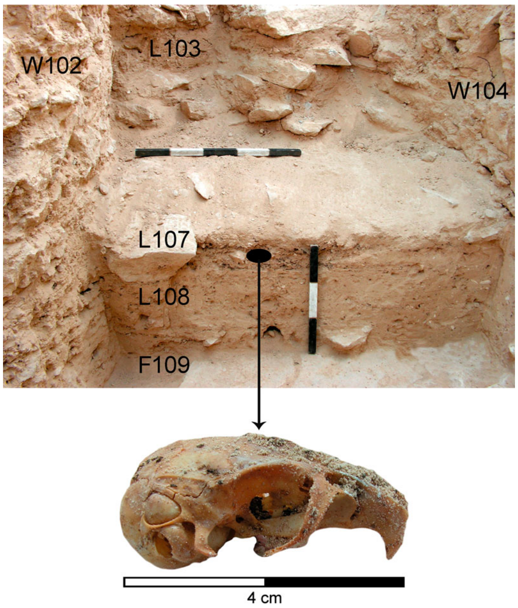


Figure 4 A section within Structure A at Sa‘adon showing sediment accumulation above the floor. Remains of small mammals in this deposit included the complete skull of a jird (Meriones sp.) from L-107 (Photo: Yotam Tepper).

roof slabs with a typical size of *c.* 105 × 65 × 10 cm (Fig. 3: section 2-2’). Within this debris we uncovered part of a stone slab, likely a door lintel, decorated with a ring type cross (Fig. 5). Crosses appearing on decorated lintels form a dominant motif in Byzantine ornamentation across the Negev (e.g., Shivta: Erickson-Gini 2013: fig. 11; Golan 2014: vol. I: 35; vol. II: plates: 39; Segal 1988: 25–52, 152–54).

The inner part of the wall is constructed of stacked stone slabs, typical size 20 × 40 × 30 cm, with rows of evenly-spaced triangular cavities, which we interpret as compartments for pigeon nests (Fig. 3: section 3-3’; Fig. 6). The rows begin at a height of 20 cm above the floor of the structure, and continue to a height of 1.5 m in the surviving part of the wall. Within the rows, every other cavity (‘upside down’

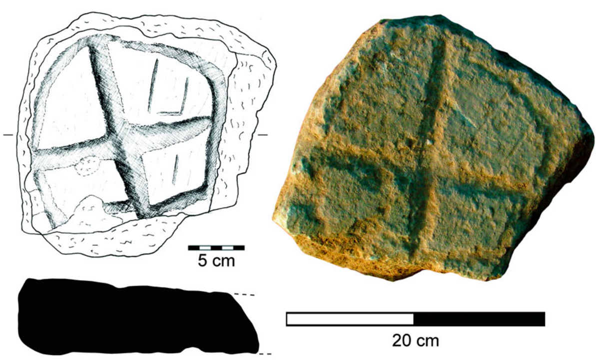


Figure 5 Stone slab with ring cross decoration (Photo: Yotam Tepper).

Figure 6 Structure A at Sa‘adon with stone-built pigeon nests in the inner part of the peripheral wall (Photo: Yotam Tepper).

triangles) is stopped up with a mixture of compressed small stones, earth and mortar.

At the center of the structure a 2.5 metre-wide pillar (Fig. 3: W-102) was constructed of stacked stone slabs arranged in a similar fashion to the stacks in the adjacent inner part of the circumference wall. The inner core of the pillar is constructed of large shaped stones with a filling of earth and small stones. A 1.0 m wide corridor separates the circumference wall and the central pillar. The rows of rectangular cavities in the pillar begin at a height of 20 cm above the floor and extend to a height of between 1.8 and 1.9 m. The raising of the cavity rows above the floor of the structure could have been a consideration in order to allow the accumulation and collecting of pigeon manure, similar to the construction of the uneven bedrock infrastructure.

The square dovecote (B)

The square dovecote with a 4.0 × 4.0 m outline is situated on a low rock promontory, its walls preserved to a height of *c.* 1.0 m above the surface (Fig. 7). Excavation was focused on the better-preserved eastern part of the structure, containing a fairly complete external wall (W-221). We excavated 2.5 m wide trenches on the internal and external sides of this wall. This revealed a uniform deposit within the structure. Unlike in the post-abandonment deposits of structure A, remains of small mammals were rare in structure B. This indicates rapid abandonment and structural collapse while the dovecote was still in use or soon after; preserving an especially rich deposit from the period of use of the structure.

The wall of the dovecote, built directly on bedrock, was constructed of quarried stone with typical dimensions of 40 × 30 × 20 cm, interspersed with smaller flat stones and containing remnants of mortar and lime. The width of the wall was 70 cm and it survived to a

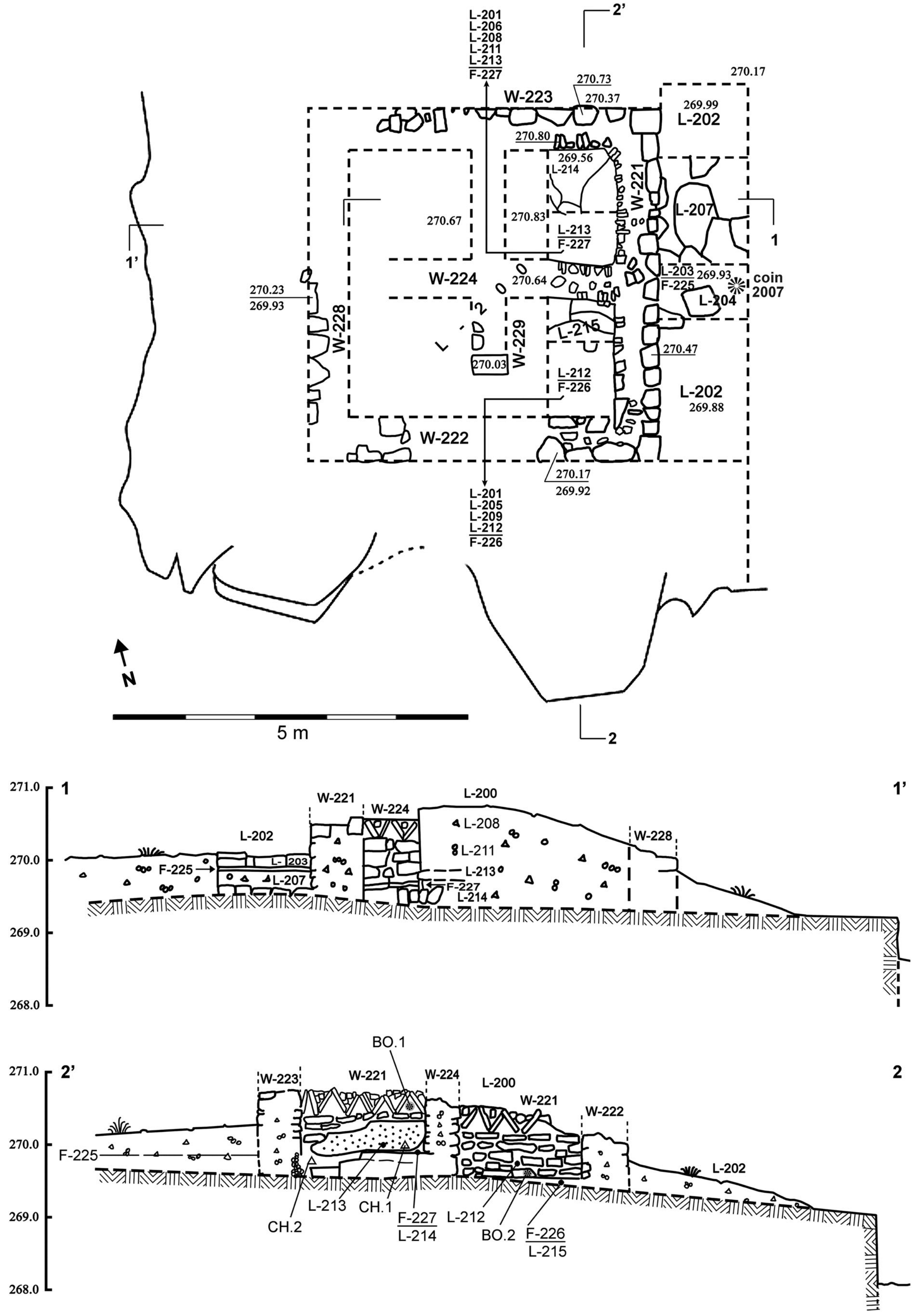


Figure 7 Plan and sections of Structure B at Sa'adon.

Figure 8 Structure B at Sa'adon — ceramic pipes (Photo: Yotam Tepper).

height of 1.4 m or 6–7 courses. Abutting the external side of the wall below ground level was a constructed surface of flat stones underlain by a 10 cm thick layer of crushed chalk and lime, likely forming part of the structure (F-225).

Excavation in the inner part of the dovecote revealed an internal subdivision, with a 50 cm wide wall (W-224) separating two chambers. Rows of triangular cavities 30 × 30 cm in size and 30 cm deep, constructed of stone slabs, were installed along the internal dividing wall, a single such row surviving on either side. Similarly, a single row of cavities survived on the inside of the external eastern walls (W-221; see Fig. 7: sections 1-1', 2-2'). Similar to Structure A, the rows of cavities are raised 80 cm above the original floor of the structure. A thick coating of plaster was found adhering to the internal walls in one of the chambers (the northern one). Floor preparation inside the structure included a layer of compressed earth mixed with gravel, and in places also smoothed stone slabs and chiseling of the bedrock.

The fill of Structure B consisted of sediment accumulation above the floor (L-212; L-213), composed of a distinct loose gray deposit, 20 cm thick. This deposit contained large quantities of organic remains including numerous pigeon bones and droppings, seeds and charcoal. This thin deposit was overlain by debris from the collapse of the structure and contained pulverized chalk, abundant ceramic pipes and fragments of gray plaster 2–3 cm thick and as much as 15 × 10 cm in size. A large number of ceramic pipe (N = 330) and pipe rim (N = 114) fragments were found in this debris. Presence of ceramic pipes (Fig. 8) points to the use of light material in constructing the upper part of structure B. It is important to note the near absence of these ceramic pipe fragments within the thin sediment accumulation above the floor. Only three small pipe rim fragments were found within the floor deposit as opposed to their much greater abundance in the overlaying collapse debris. Numerous skeletal elements of pigeons, among them two nearly complete skeletons discovered in articulation, and several complete eggshells, provide additional evidence for rapid abandonment and collapse in structure B (Fig. 9). These observations support our conclusion that the thin sediment deposit above the floor of Structure B and below the collapse debris represents the period of human use.

Chronology of the dovecotes

The pottery assemblage consists predominantly of ceramic pipes, most of which were found in Structure B (Fig. 10; Table 1). These pipes are 12–14 cm in diameter with an elongated flat rim, most are made of a greenish fabric, with only a few made of a pinkish-red fabric (Figs 8 and 11). Other pottery sherds include dozens of Gaza storage jars and a single fragment of a cooking pot, which were found in the circular dovecote (Table 1). Gaza jars are represented by the rims of two types: Majcherek's Form 2 (Fig. 12: 2–5) dated to the 4th–mid-5th centuries CE, and Form 3 (Fig. 12: 6–7), dated to the mid-5th–mid-6th centuries CE (Majcherek 1995: pl. 3:2–3). The typology of the cooking pot (Fig. 12: 1) with its sharp rim and triangular profile associates it with the late 6th–early 7th century CE (Magness 1993: 219–220; Form 4B:1–2). Thus, ceramic typology indicates a maximum range of use for the circular structure that spans the middle and late phases of the Byzantine period.

Additional artifacts uncovered during excavation include three badly preserved bronze coins (Table 2). One (No. 1) was found on the foundation layer of Structure A within a probe made near the external wall (see Fig. 3: Structure A; L-105; Reg. L-105; No. 1022), and another (No. 2) was found within a white plaster layer, adjacent to the square structure (B), possibly becoming incorporated into the plaster at the time when the floor was laid (Fig. 13; Structure B; L-204; Reg. No. 2007). Both coins can be tentatively dated to the Late Roman or Early Byzantine periods (late 4th–5th centuries CE), providing a *terminus post quem* for the plaster layer and quite possibly of the construction of the structures. The third coin (No. 3) was found on top of the collapse debris of Structure A (see Fig. 3: Structure A; L-103; Reg. No. 1023). The suggested date, to the Late Byzantine or Early Islamic period, is based on the size and shape of the flan. This accords with recovery of five Late Roman-Byzantine coins from the 4th–6th centuries CE,

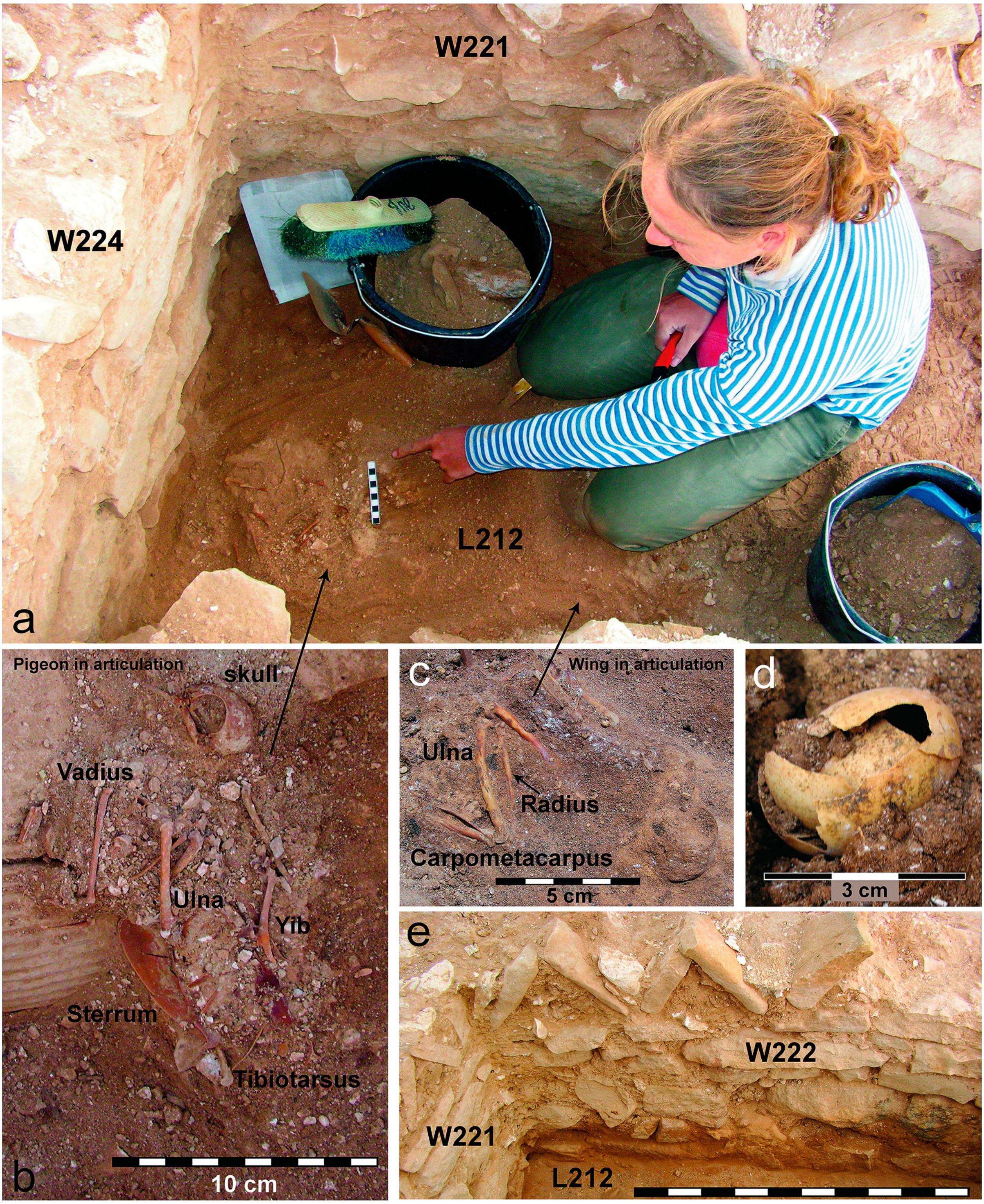


Figure 9 **Southern cell in Structure B at Sa'adon: Pigeon's skeletons (a) discovered in articulation (b–c) and with complete eggshells (d). Note the corner of the cell (e) and the stone-built pigeon nests (Photos: Yotam Tepper).**

which were previously found during survey within the site of Sa'adon (Hirschfeld 2006: 12–13, figs 4a–b).

Radiocarbon dating was undertaken on three pigeon bones from Structure B: Samples RTD-8971–RTD-8972 (L213, Basket B2121), and Sample RTD-8976 (L 212, Basket B2120), all from the deposit directly above the floor (see Fig. 7).

The bones were prepared for collagen extraction followed by prescreening procedures (Yizhaq *et al.* 2005) at the D-REAMS radiocarbon laboratory, Weizmann

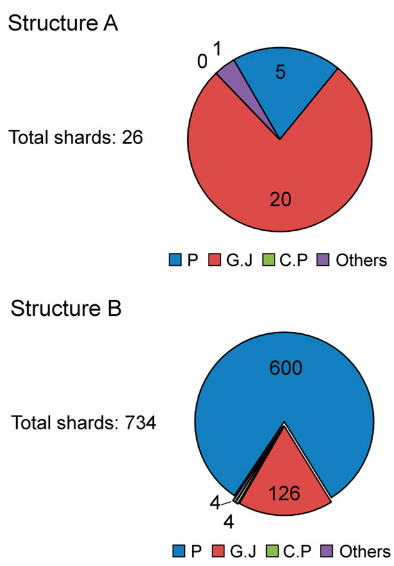


Figure 10 Composition of diagnostic pottery in Structures A and B: P — pipes; GJ — Gaza storage jars; CP — cooking pot; Others — unidentified.

Institute. Fourier Transform Infrared Spectroscopy (FTIR) was applied to untreated bone powder and collagen fraction. FTIR spectra were used to calculate the splitting factors (SF), which measures the crystallinity of carbonate apatite in relation to diagenesis of the bone mineral fraction (Weiner and Bar-Yosef 1990), with known ranges between 2.5–2.9 mineral content in fresh bone (Weiner and Bar-Yosef 1990). The percentage of collagen was estimated by the weight of collagen recovered divided by the weight of bone powder before acid dissolution. Spectra of the insoluble fraction were used to qualitatively evaluate the preservation of bone collagen and screen for possible contaminants. Samples with spectra indicative of well-preserved collagen were selected for radiocarbon dating.

Bone collagen was purified for radiocarbon dating by the Acid-Base-Acid procedure, followed by gelatinization and filtration (Brock *et al.* 2007; Yizhaq *et al.* 2005). For each sample between 100–200 mg of bone powder was treated with 0.5 N HCl until the mineral was dissolved (~1 hour) and then washed with Nanopure water until pH = 7. Samples then received 0.1 N NaOH (30 minutes) and were washed until pH = 7. A final acid treatment of 0.5 N HCl (5 minutes) was followed by washing until pH = 3. Solutions were gelatinized in a vacuum oven for 20 hours at 70°C, and then passed through Eezi-filters™ and ultrafilters (Vivaspin™15, 30kD MWCO) and cleaned by established procedures (Brock *et al.* 2007). Purified gelatin samples were lyophilized for 24 hours, combusted with ~200 mg CuO in sealed quartz tubes, and reduced to graphite in a vacuum line. Samples were measured by accelerator mass spectrometry (AMS) at the D-REAMS radiocarbon laboratory and reported as radiocarbon years (^{14}C BP). The calibrated ranges were determined using the OxCal 4.2.4 (2013; using the calibration tables of Reimer *et al.* 2013).

All three pigeon bones provided sufficient collagen for radiocarbon dating. The splitting factors of the three bones were 2.8 indicating their good state of preservation. Percent of collagen ranged between 7.3% and 9.9% and the carbon content of the collagen was around 41–47%, as expected for standard collagen. The radiocarbon calibrated ranges are reported in

Table 1 Pottery from Structures A and B (P—Pipes; GJ—Gaza storage jars; CP—Cooking Pots; BS—Body Sherds; Other—unidentified)

Structure	Locus	Basket	P rims	CP rims	GJ rims	GJ base	CP base	GJ handle	P BS	GJ BS	CP BS	Other BS	Total
A	100	1001	0	0	0	0	0	0	0	1	0	0	1
	100	1002	0	0	0	0	0	0	1	4	0	0	5
	101	1003	0	0	0	0	0	0	0	2	0	0	2
	103	1012	0	0	0	0	0	1	0	0	0	0	1
	103	1017	0	0	0	0	0	1	4	11	0	1	17
Total A			**0**	**0**	**0**	**0**	**0**	**2**	**5**	**1**	**0**	**1**	**26**
B	200	2000	0	0	0	0	0	0	8	0	0	0	8
	201	2001	12	0	1	0	0	1	45	5	1	1	65
	202	2002	1	0	0	0	0	0	8	3	0	0	12
	203	2003	0	0	0	0	0	0	0	0	0	1	0
	205	2005	27	1	2	0	0	1	65	11	0	2	107
	206	2006	33	0	0	0	0	1	75	0	0	0	109
	208	2009	36	0	2	1	1	0	135	25	0	0	200
	209	2010	5	0	2	2	0	3	47	35	1	0	95
	211	2009	2	0	1	0	0	3	65	20	0	0	91
	212	2020	1	0	0	1	0	1	35	1	0	0	39
	213	2021	0	0	0	0	0	0	0	4	0	0	4
Total B			117	1	8	4	1	10	483	104	2	4	734

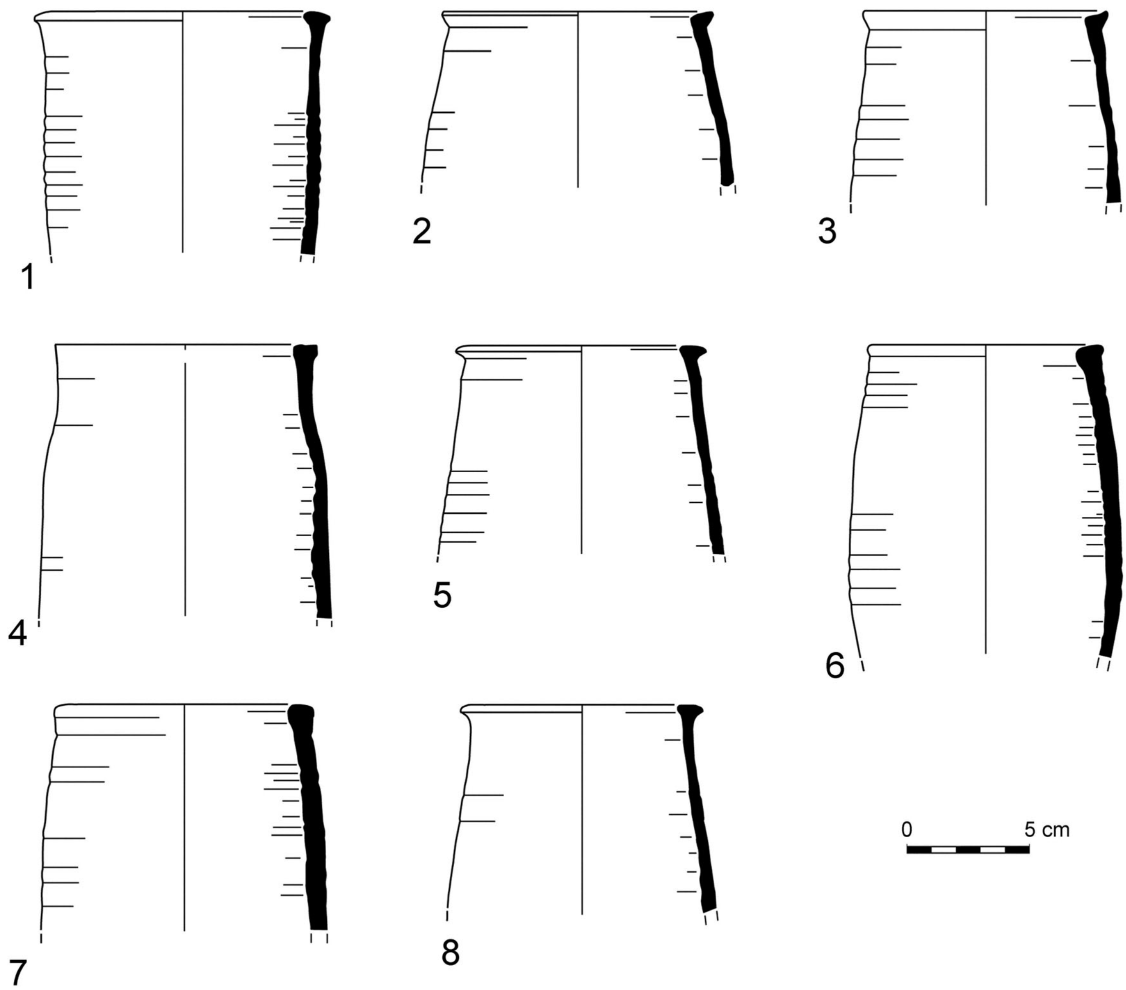


Figure 11 Structure B at Sa'adon—ceramic pipe fragments.

Table 3. The combined range of the three radiocarbon dates, assuming that the pigeons died in the same event, shows that with the highest probability the time of abandonment of Structure A in Sa'adon is between 530–580 CE (Figs 14–15).

Pigeon dung

Structure B includes a high concentration of pigeon dung (Figs 9a and 16a–b), including fully-preserved pigeon droppings within both the floor deposit (Fig. 16d) and pigeon nest cavities. Some animal hair (probably of a goat), found in this layer, was possibly brought in as nesting material (Fig. 16c). Composition of organic matter (OM), Nitrogen (N), Carbon (C) and Phosphorus (P) was measured in six soil samples from Structure B (analytical methodology follows Tepper *et al.* 2017), in two samples from below and above the floor, and four additional ones collected from outside the structure at a distance of 5 m to the north, east, south and west of the external walls. Measurements show high values for all parameters within the dung layer relative to the control samples (Table 4: organic matter > x2; Nitrogen x2; Carbon > x2; Phosphorus ~x7). These finds, together with the intact pigeon droppings, support identification of the living floor deposit of Structure B as a layer of pigeon dung and accords with similar findings from other Byzantine dovecotes in the agricultural hinterlands of the Negev (Hirschfeld and Tepper 2006: 97–107, fig. 17; Tepper 2007a: 45–47; Tepper *et al.* 2017).

Pigeon bones and crop stones

A large quantity of pigeon bones (*Columba livia*) was recovered from Structure B (Table 5), most found directly on the floors (L212; L213) with pigeon droppings. In the southern chamber two pigeon skeletons were found in articulation (Fig. 9b–c). No other remains of species of birds, or large mammals, were recovered from the same context.

The pigeon bone assemblage represents a minimum of seven individuals (Marom *et al.* 2018). The pigeons appear to represent a small-bodied population, rather than large-bodied ones bred for

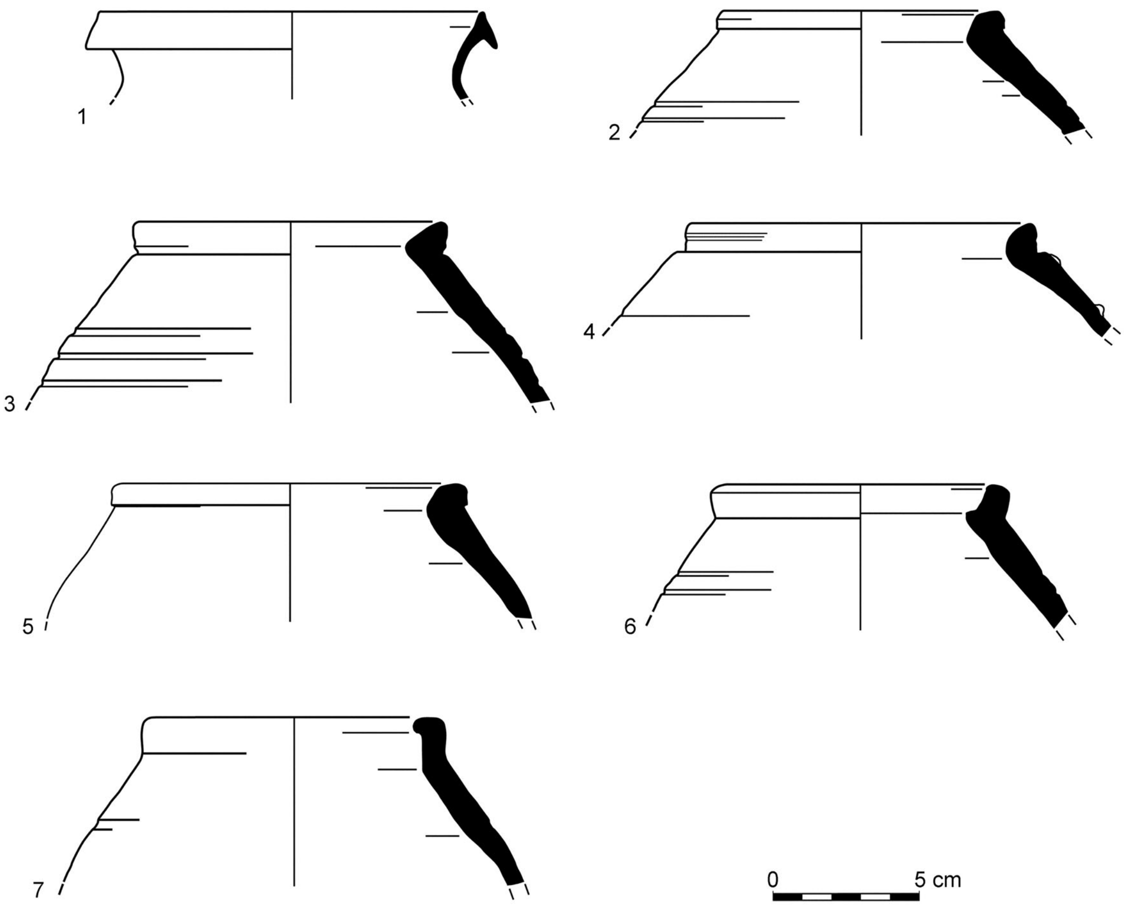


Figure 12 Pottery in Structure A at Sa'adon: 1. Cooking pot; 2–7. Gaza storage jars.

meat. The bones that were identifiable to taxon (N = 103) are almost all complete and hence the number of specimens is equivalent to the Minimum Animal Units (MNU; see Lyman 2008; Fig. 17). The finds include relatively fragile skeletal elements including the pelvic and shoulder girdle bones. Skull, sternum and vertebrae, which are much more delicate, are represented in relatively low frequencies. In addition, 39 crop stones the size of pigeon gastroliths were identified in one soil sample from the dung layer of Structure B (see Fig. 7: section 2-2', BO-2; L-212).

Age-at-death of the pigeon remains was obtained from 81 of the bones; 25% were porous and thus represent juveniles. No modifications such as human

Table 2 Coins from Structures A and B at Sa'adon

No.	Structure; locus; Reg. No.	Wt. (gm)	Diam. (mm)	Axis	Obverse	Reverse	Date of coin	Notes
1	Stru. A 105 1022	1.06	13–14	—	[---] Bust r., pearl-diademed.	*Vota* type. Mintmark Obliterated.	Late 4th cent. CE	Found on the foundation layer of the dovecote, within a probe made near the external wall.
2	Stru. B 204 2007	0.26	9	—	Obliterated	Obliterated	5th cent. CE (?)	Date based on shape and size of flan. The coin was found stuck within a white plaster layer (see Fig. 13). It was disintegrated during the conservation treatment.
3	Stru. A 103 1023	1.90	15–18	—	Obliterated	Obliterated	6th–7th cent. CE(?) or Mamlūk (13th–15th cent. CE)	Date based on shape and size of flan. Found on top of the debris of the dovecote.

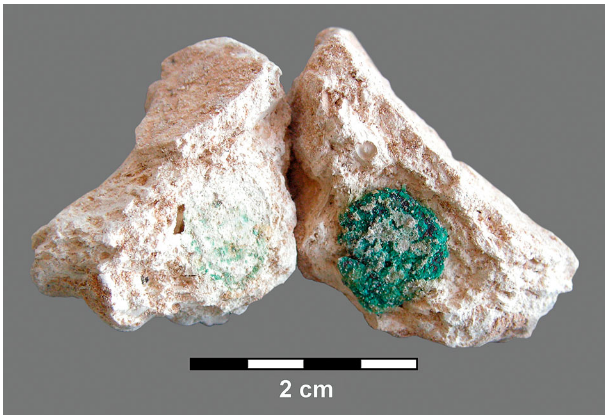


Figure 13 Structure B at Sa'adon — a coin in the plaster (Photo: Yotam Tepper).

butchery marks, burning or animal gnawing were identified. The pigeon remains thus seem to represent natural mortality. We interpret these *in situ* pigeons as representing carcasses accumulated due to a sudden destruction event that caused the collapse of the structure.

Small mammals

Remains of small mammals (Rodentia and Insectivora; MNI (Minimum Number of Individuals) based on molar teeth: 204) were uncovered, mainly in Structure A (Figs 4 and 18: L-107, 108), which showed a high diversity of species composition (Fried *et al.* 2018; retrieval and identification methods follow Lyman 1994). The remains occurred within the dark soil layer (L-107) and the accumulation below it (L-108). The list of taxa in order of abundance includes (Fig. 18; Table 6): gerbils (*Gerbillus* sp. and *Meriones* sp.), lesser Egyptian jerboa (*Jaculus jaculus*), house mouse (*Mus musculus domesticus*), Asian garden dormouse (*Eliomys melanurus*), black rat (*Rattus rattus*), mole rat (*Spalax* sp.), sand rat (*Psammomys* sp.) and insectivorous shrews (*Crocidura* and *Suncus etruscus*).

The assemblage shows an exceptional state of preservation. All major elements are present, including complete skulls as well as fragile and delicate bones. Digestion marks, most probably caused by nocturnal raptors were observed on a fairly high proportion of the remains (a combined average of 20% for long bones and teeth; Fig. 19).

The high abundance of remains is likely to be the result of accumulation by raptors during an extended period of time after the structure was no longer in human use.

A contrasting picture was found in structure B, where the number of small mammalian remains is quite small and most were found directly on the living floor (L-212, L-213). Here, remains of commensal rats and mice are more common, indicating the possibility that they invaded the structure to obtain food and shelter. However, digestion marks observed on some of these remains suggest the contribution of raptors in structure B as well, likely occurring soon after human abandonment, and collection of the prey from nearby.

Wood remains

Excavation in Structure B recovered several pieces of non-carbonized wood and short twigs. Cross and longitudinal, tangential and radial sections made for each sample enabled microscopic identification of the wood to species level (Liphschitz 2007: 13). The diameter of most branches is relatively small (*c.* <6–7 mm) and it is possible that they were either brought by the pigeons as nesting material, or by humans as raw material for the construction of the walls, ceilings, or for other uses. Identification of a sample of 33 such remains (> 0.5 cm^3) obtained from debris in and above the pigeon dung layer reveals that all samples derived from two species of

Table 3 Archaeological and faunal identification, radiocarbon ages and calibrated ranges of the bones from Structure B at Sa'adon

Sample ID	Archaeological Context	Bone type	^{14}C Date Year BP	Calendar Date CE ±1σ (68.2%)	Calendar Date CE ±2σ (95.4%)
RTD-8971	L213 B2121	Radius	1537 ± 33	430 (40.2%) 490 530 (28.0%) 570	425 (95.4%) 595
RTD-8972	L213 B2121	Synsarcum	1547 ± 23	430 (51.2%) 490 530 (17.0%) 550	425 (95.4%) 565
RTD-8976	L212 B2120	Radius	1511 ± 30	475 (4.6%) 485 535 (63.6%) 600	430 (22.3%) 495 510 (1.9%) 520 530 (71.2%) 620
Combine	X2-Test: df = 2 T = 0.9 (5% 6.0)		1534 ± 16	435 (10.3%) 450 470 (14.1%) 485 535 (43.8%) 565	430 (42.0%) 495 510 (1.2%) 515 530 (52.1%) 580

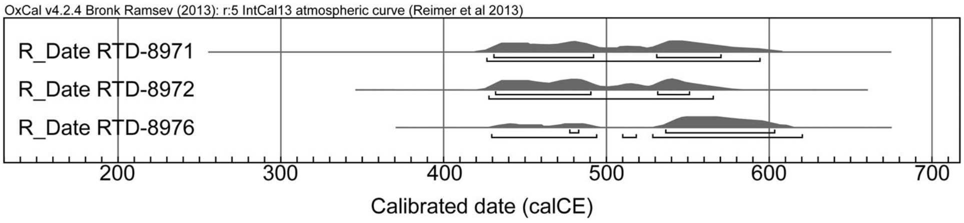


Figure 14 Radiocarbon ages and calibrated ranges of the bones from Structure B at Sa'adon.

Tamarix: most from Tamarix (X5) and only four specimens from Tamarix (X4). Both tree species are native to the drier areas of the Negev and grow naturally in the region (Table 7).

Seeds

While excavating sediments overlying the floor of Structure B we manually retrieved four peach (*Prunus persica*) endocarps (pits) (Fig. 16e). Additional seeds were obtained from floatation of two sediment samples from this structure (Fig. 7: section 2-2'; Bo 1-2): a sample of two liters from a pigeon nest in the eastern wall (W-220), and an additional two liters from the dung layer above the floor of the southern chamber (retrieval and identification methods follow Ramsay *et al.* 2016).

Botanical remains from flotation samples yielded mainly charred and desiccated seeds and fruits. These included eight taxa: two fruit species, including grape and fig (*Vitis vinifera* and *Ficus carica*), a cultivated legume of an unidentifiable species and five wild or weedy species (Fig. 20; Table 8). The most numerous weed species identified was mezereon (*Thymelaea passerina*). The remaining weeds are each represented by a single specimen.

Palynology

Two samples were analyzed for pollen. The first was collected from the dung layer in structure A (L-108) about 10 cm above the floor (Fig. 3: section 1-1'; Po-1), representing a time when the structure was in use. A second sample was collected as a control from outside the same structure, about 10 m to the south (analytical procedures follow Ramsay *et al.* 2016). Each sample yielded >200 pollen grains (Table 9). The two samples are quite similar in composition, with arboreal pollen (AP) including mainly Tabor oak (*Quercus ithaburensis*) and pistachio (*Pistacia* sp.). A low overall AP percentage, together with the presence of *Ziziphus* pollen, reflects an arid environment. Oak pollen frequencies are higher in the archaeological sample than in the recent

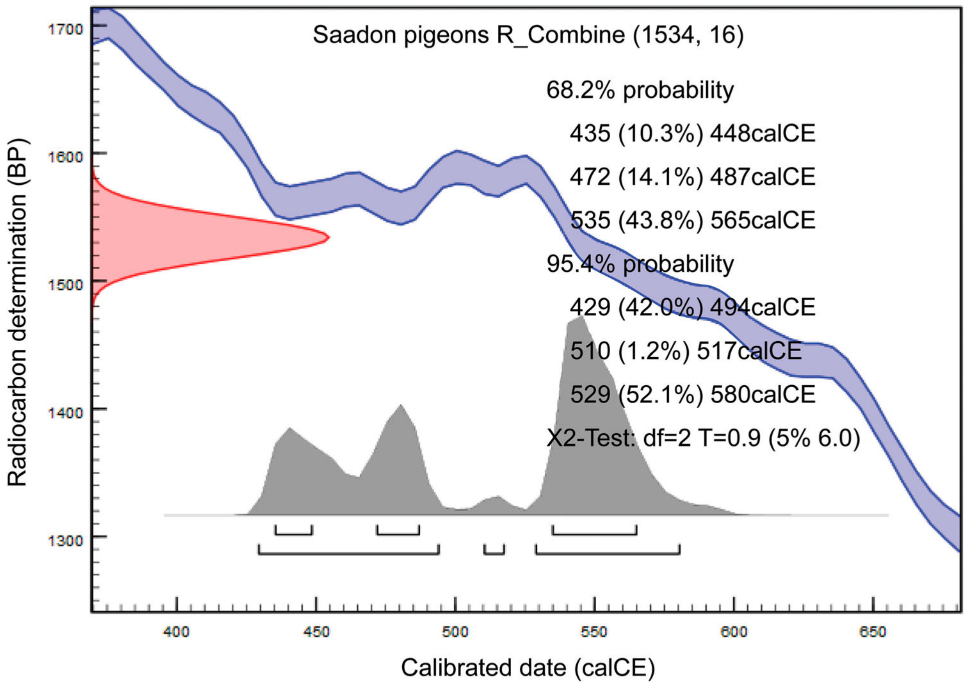


Figure 15 Combined ranges of radiocarbon dates of the three samples from Structure B at Sa'adon.

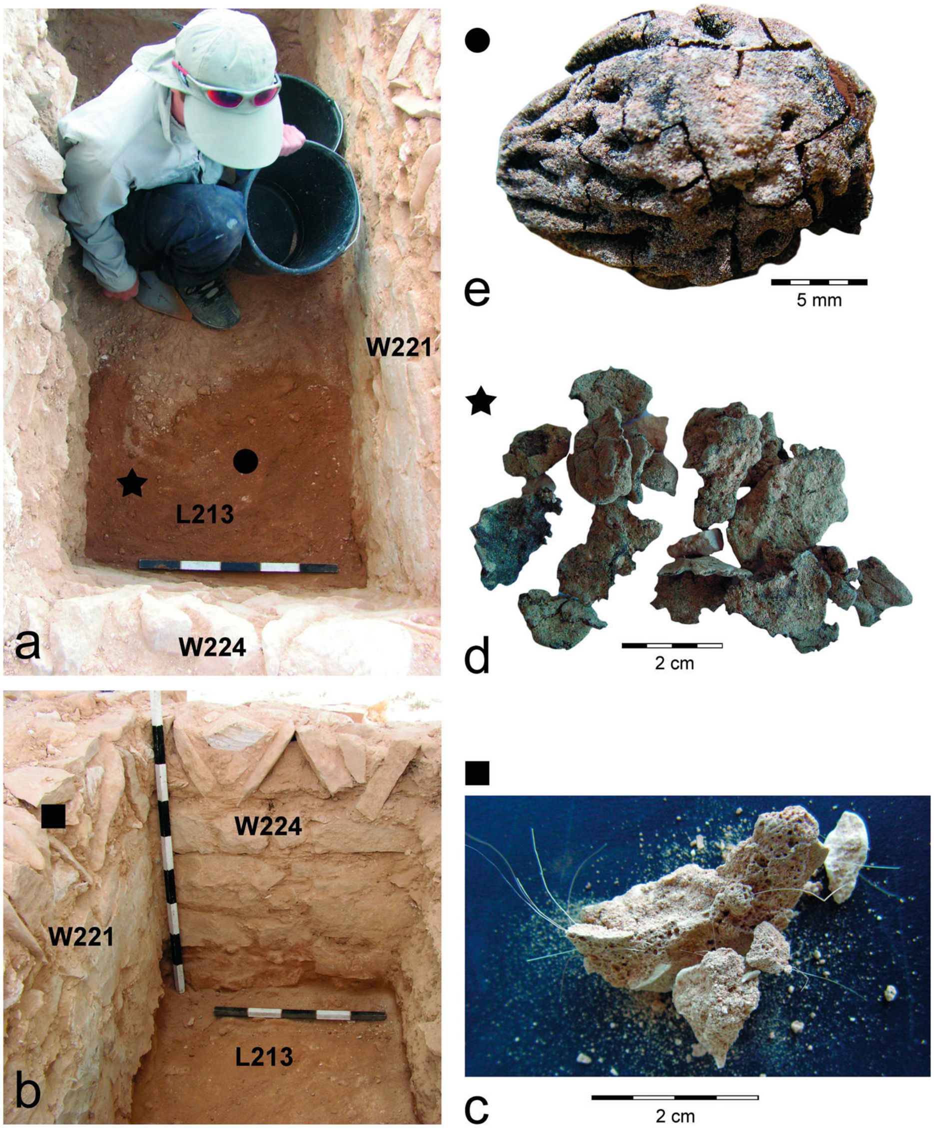


Figure 16 Structure B at Sa'adon — dung layer in the north cell, note the corner of the cell and the stone-built pigeon nests (a–b), animal hair from pigeon nests (c), pigeon droppings (d) and peach seed (e). (Photos: Yotam Tepper).

control, possibly indicating a slightly more humid climate in antiquity. This is also suggested by the higher frequencies of willow (*Salix* sp.) in the archaeological sample, though fairly high percentages of this genus in both samples is difficult to explain given the absence of perennial springs or

Table 4 Chemistry of soil samples at Sa'adon

Sample	Location	Org. Mat. %	P %	K %	C %	N %	C/N
CH-1	Dung layer (L-213)	2.440	0.383	0.350	1.440	0.480	3.00
CH-2	Under floor (L-214)	1.690	0.248	0.510	0.990	0.300	3.30
CH-3	5 m. To the north	1.060	0.042	0.280	0.620	0.160	3.90
CH-4	5 m. To the south	1.090	0.048	0.220	0.640	0.170	3.80
CH-5	5 m. To the west	1.180	0.048	0.220	0.690	0.190	3.70
CH-6	5 m. To the east	0.550	0.048	0.320	0.320	0.260	1.20
Average values							
CH-1&2	Dung layer	2.065	0.3155	0.430	1.2150	0.390	3.15
CH-3-6	Surface	0.970	0.0465	0.235	0.5675	0.195	3.15

Table 5 **Number of identifying specimens (NISP), minimum number of animal units (MAU) and percentage of the highest MAU represented by each element in the pigeon bone assemblage from structure B at Sa'adon**

Skeletal element	NISP	MAU	%MAU
Skull	3	2	29
Vertebra	20	3	43
Rib	2	1	14
Sternum	1	1	14
Forcula	2	2	29
Coracoid	6	3	43
Scapula	5	3	43
Humerus	11	6	86
Radius	7	4	57
Ulna	9	5	71
Carpometacarpus	5	3	43
Pelvis	2	1	29
Synsacrum	5	5	71
Femur	13	7	100
Tibiotarsus	14	7	100
Tarsometatarsus	6	3	43
Total	111	7	

streams in the immediate area of the site today. Pine (*Pinus halepensis*) pollen ratios are rather modest and possibly indicate long-distance transport (Weinstein-Evron and Lev-Yadun 2000). Both *Olea europaea* (olive) and *Vitis* (vine) probably represent local cultivation. In contrast with the predominance of grape pollen in the archaeological sample, the modern control sample is richer in olive pollen relative to that of grape.

Non arboreal pollen (NAP) composition is similar in the two samples, but ratios of taxa are somewhat different. The recent surface sample shows greater frequencies of Chenopodiaceae and *Artemisia* (including clumps), seeming to better accord with the present arid Negev environment than the archaeological sample. Relatively high proportions of cereal in the surface sample likely indicate modern cultivation in the area: the occurrence of cereal pollen and especially cereal clumps in the archaeological sample suggests such cultivation in Byzantine times. Grain may also have been part of the pigeon diet. The relatively high Asteraceae pollen, especially from the subfamily Cichorioideae, likely also indicates local cultivation. *Chicorium* (chicory) could have been used as both a culinary and medicinal plant (Zohary 1987). The relatively high Asteraceae pollen, especially Asteraceae Cichorioideae may also suggest the existence of ruderal habitats near the dovecotes. High frequencies of *Allium* type (onion and garlic), in the archaeological sample, could suggest human cultivation.

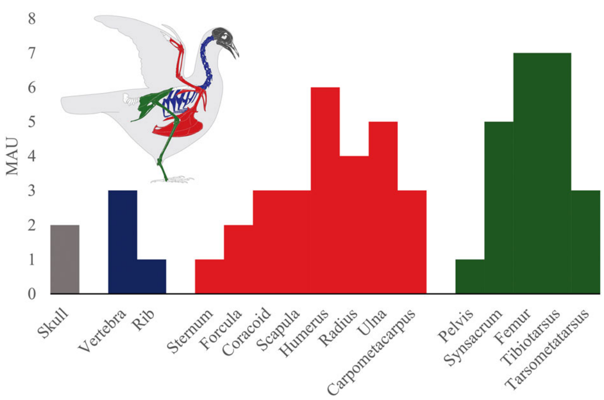
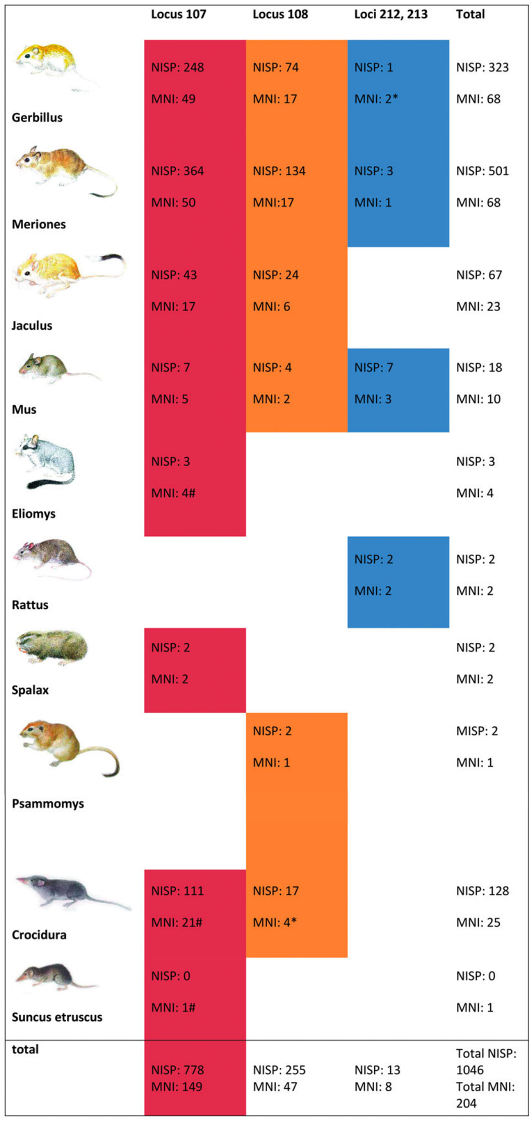


Figure 17 **Structure B at Sa'adon—skeletal element composition of the pigeon bone assemblage.**



*based on counts of maxillas.

#based on counts of mandibles.

Figure 18 **Numbers of specimens and minimum numbers of individuals of taxa according to loci, based on counts of molar teeth, except where indicated otherwise (drawings from Shalmon 1993).**

Table 6 MNI and NISP of taxa according to loci, based on counts of molar teeth except where indicated otherwise

	Structure A				Structure B		Total	
	Locus 107		Locus 108		Loci 212, 213			
	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI
Gerbillus	248	49	74	17	1	2*	323	68
Meriones	364	50	134	17	3	1	501	68
Jaculus	43	17	24	6	0	0	67	23
Mus	7	5	4	2	7	3	18	10
Eliomys	3	4#	0	0	0	0	3	4
Rattus	0	0	0	0	2	2	2	2
Spalax	2	2	0	0	0	0	2	2
Psammomys	0	0	2	1	0	0	2	1
Crocidura	111	21#	17	4 *	0	0	128	25
Suncus etruscus	0	1#	0	0	0	0	0	1
Total	—	—	—	—	—	—	1046	204

*based on counts of maxillas
#based on counts of mandibles

Discussion and conclusions

Pigeon-raising for both cultic purposes and enhancing the fertility of farmland by harvesting pigeon manure, was a widespread practice across the Levant from as early as the Hellenistic period in the 3rd century BCE. This has been demonstrated by a wide range of textual and archaeological evidence in regions, for example Transjordan, Egypt, Iran and ancient Judea-Palestine from the Hellenistic to the Byzantine periods (Boak and Peterson 1931: 51–57; Di Segni 1988: 253–64; Husselman 1953; Gatier and Vérilhac 1989: 337–48; Netzer 1981: 13–14; Tarn and Griffith 1952: 194; Zissu 1995; Hunt 1926: 113–15).

Archaeological fieldwork throughout the arid regions of Judea-Palestine has identified numerous installations as dovecotes; uncovered in association with Byzantine period agricultural contexts (Fraiberg and Tepper 2017; Hirschfeld and Tepper 2006: 83–116; Kobrin and Tepper 2017; Tepper 2007b: 133–59; Tepper *et al.* 2017). That free-standing pigeon towers (dovecotes) were among the most common agricultural structures in a typical farming community in the Roman period, and mentioned in Jewish Mishnaic sources (70–200 CE), which also include explicit regulations as to where and how pigeons should be raised (Safrai 1994: 174–79; Tepper, I. 1986: 170–96). These sources prescribe the use of

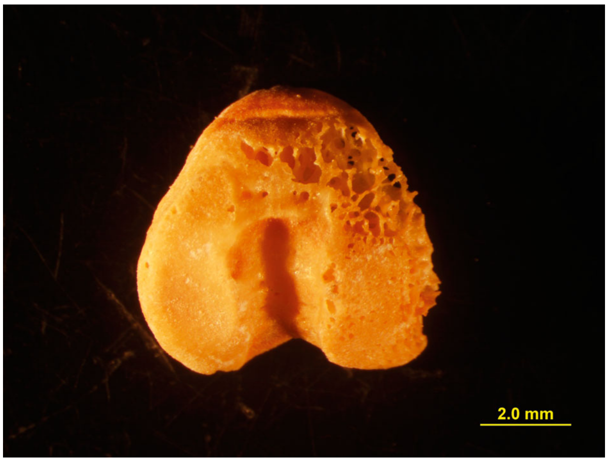


Figure 19 Digestion marks on small mammal bone (Photo: Tal Fried).

Table 7 Wood samples from structure B in Sa'adon

Locus	Basket	Tree species
208	2014.1	*Tamarix (X5)*
208	2014.2	*Tamarix (X5)*
208	2014.3	*Tamarix (X5)*
208	2014.4	*Tamarix (X5)*
208	2014.5	*Tamarix (X5)*
208	2014.6	*Tamarix (X5)*
208	2014.7	*Tamarix (X5)*
208	2014.8	*Tamarix (X4)*
208	2014.9	*Tamarix (X4)*
208	2014.10	*Tamarix (X5)*
209	2010.1	*Tamarix (X5)*
209	2010.2	*Tamarix (X5)*
209	2010.3	*Tamarix (X5)*
209	2010.4	*Tamarix (X5)*
209	2010.5	*Tamarix (X5)*
209	2010.6	*Tamarix (X5)*
209	2010.7	*Tamarix (X5)*
209	2010.11	*Tamarix (X5)*
209	2010.12	*Tamarix (X5)*
209	2010.13	*Tamarix (X5)*
211	2019.1	*Tamarix (X5)*
211	2019.2	*Tamarix (X5)*
211	2019.3	*Tamarix (X5)*
211	2019.4	*Tamarix (X5)*
211	2019.5	*Tamarix (X5)*
211	2019.6	*Tamarix (X5)*
211	2019.7	*Tamarix (X5)*
212	2020	*bark of Tamarix sp.*
205	2005.1	*Tamarix (X4)*
205	2005.2	*Tamarix (X4)*
205	2005.3	*Tamarix (X5)*
205	2005.4	*Tamarix (X5)*
205	2005.6	*Tamarix (X5)*

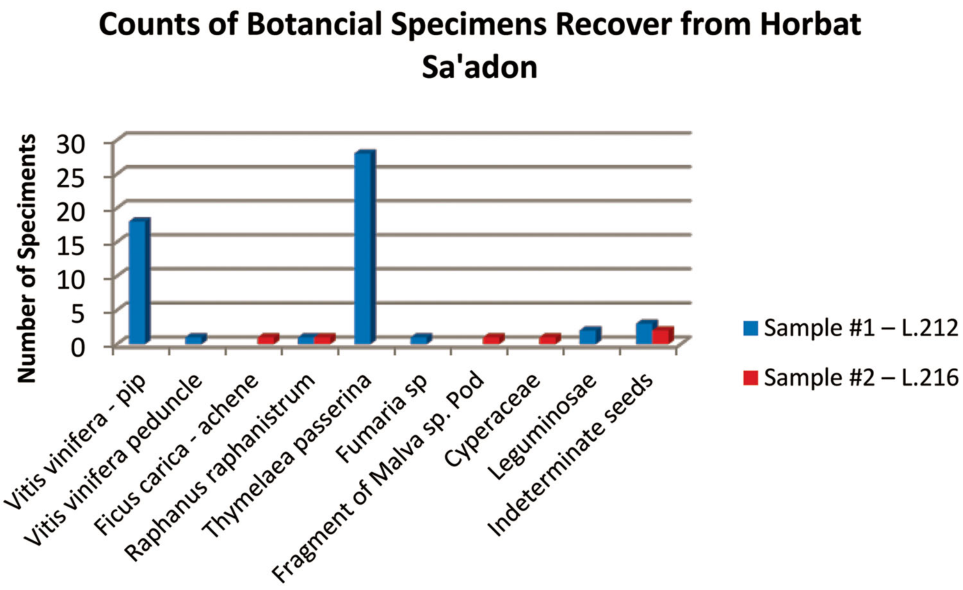


Figure 20. Structure B at Sa'adon—counts of botanical specimens identified.

500 liter per 1.24 acre of pigeon manure for farmed land per year (Feliks 1963: 109–10). Similar amounts are mentioned in Roman documents such as Columella (1926, *De Re Rustica* 2, 5; 2, 10; see also Pliny 1938, *Natural History* 18: 193–94). The grapevines which were grown in the Nile Delta region of Egypt during the Hellenistic period were fertilized with pigeon dung only. Given the nutrient-poor nature of the Negev loess soils, about 10 liters of pigeon dung may have been required per tree annually (Feliks 1963: 93; Schubart 1922: 85; Tepper, I. 1986: 184–86; Tepper 2007a; Conan 2007: 5; see also Miller and Kathryn 1994; Talbot 2002; Wilkinson 1988).

Table 8 Summary of botanical remains from structure B, Sa'adon

Species	Common Name	Sample 2 — L.212	Sample 1 — L.216
Vitis vinifera — pip	Grape	18	
Vitis vinifera peduncle	Grape	1	
Ficus carica — achene	Fig		1
Raphanus raphanistrum	Wild radish	1	1
Thymelaea passerina	Mezereon, spurge flax	28	
Fumaria sp.	Fumatory	1	
Fragment of *Malva* sp. Pod	Mallow		1
Cyperaceae	Sedge Family		1
Leguminosae	Legume Family	2	
Indeterminate seeds		3	2
Totals		54	6

Our excavation focused on two installations, circular and square, which we identify as dovecotes and which formed part of the Byzantine Negev Agricultural Complex. These structures provide an abundance of artefactual and biological evidence for the scale and significance of this phenomenon in ancient arid land farming. A combination of evidence from pottery, coins and direct carbon dating suggests that the time of use was generally between the 5th and 6th centuries CE. The late establishment of Sa'adon's dovecotes, in comparison to those at Shivta (Hirschfeld and Tepper 2006), may be a result of the different history at those sites. Modes of construction, human use and abandonment differed between the two structures at Sa'adon, thereby providing detailed insights regarding links between the dovecotes, pigeon-raising and farming practices in the Byzantine Negev.

A pigeon dung layer with articulated *in situ* pigeon skeletons was preserved on the living floor of the square dovecote (Structure B), indicating sudden abandonment, possibly due to a destruction event. This would have prevented regular maintenance activities, including the collection of dung, from taking place in the final stage of use. In contrast, such a dung layer was not uncovered on the floor of the circular dovecote (Structure A), and was presumably removed in an orderly fashion prior to its abandonment. Together with the accumulation of large numbers of small mammalian remains within deposits overlying the floor of the circular structure, these

Table 9 Palynological samples from structure A in Sa'adon (percentages)

	Po-2 Resent sample, 10 m downhill, south to external wall	Po-1 Dovecote layer, 10 cm above the floor
Quercus ithaburensis type	2.1	4.4
Pistacia	2.1	1.5
Pinus	5.1	2.4
Olea europaea	4.7	1.0
Salix	3.8	5.9
Aceraceae	—	1.5
Rhus	0.9	—
Ziziphus	2.6	2.0
Vitis	—	3.4
Total AP	21.4	22.0
Poaceae	15.0	28.8
Cereals	16.2	9.3
Cereal clump (~20 units)	0.4	3.4
Helianthemum	1.3	—
Artemisia	2.1	1.5
Artemisia clump (~20 units)	0.4	—
Noaea type	14.5	—
Atriplex type	5.6	1.5
Bunium type	1.3	—
Asteraceae Asteroideae	3.0	4.9
Asteraceae Cichorioideae	5.1	9.8
Ranunculus	0.9	—
Brassicaceae	2.1	—
Fabaceae	6.0	4.9
Asphodelus	—	0.5
Allium type	—	4.9
Lamiaceae	0.9	1.0
Centaurea	—	2.4
Cistaceae	0.9	1.0
Polygonum	0.4	1.0
Malvaceae	—	1.0
Papaver	—	2.0
Echinops	—	0.5
Epilobium	2.6	—
Total counted	234	205
Pollen concentration	7761	6081

observations suggest an abandonment process that was organized and more gradual.

Light construction material of mainly ceramic pipes and bricks was employed in the square structure (see also the Shivta dovecotes in Hirschfeld and Tepper 2006: 85–104, figs 6, 16–18), but not in the circular one built from locally quarried stone. Whereas heavy stone construction was common practice for residential and public architecture in Byzantine sites of the Negev (Ben Yosef 2016; Hirschfeld 2006; Rubin and Shereshvsky 1988; Segal 1983; Shereshevski 1991: 20–102), the use of light construction for dovecotes was widespread across the Levant, Egypt and Iran in antiquity (Beazley 1966; Husselman 1953: 81–91; Gazda 2004: 10–19, figs 19, 22; Zissu 1995: 65, 69; see also Haag-Wackernagel 1998).

Analysis of botanical remains indicates that much of the material in the pigeon dung layer of the square structure may have been collected as pigeon food and nesting material. Seeds of mezereon weed, as well as cultivated grape, fig and legumes, identified both at Sa'adon and previously in a dovecote near the Byzantine site of Shivta (Ramsay and Tepper 2010; Ramsay *et al.* 2016), suggest that these taxa were common pigeon food in the farmed arid environment of the Negev. Pigeons seem to have fed on a combination of cereal crops, locally produced fruits and the weedy by-products of crop processing. Human caretakers may have provided the food, but it is also possible that pigeons were free-roaming and able to feed off local refuse piles and fallow fields, orchards, vineyards and olive groves. Twigs of *Tamarix* may have also been used as pigeon nesting material (see also Ramsay *et al.* 2016). Comparing our ancient and modern control pollen samples we observe that the ancient landscape surrounding the site of Sa'adon was more densely vegetated than at present and, unlike today, was modified through human farming activities, which would have included cultivation of cereal crops, legumes and fruit trees and vines.

An estimate of the number of pigeons inhabiting these structures is made possible by the good preservation of the circular dovecote. If we take into account that a pair of nesting pigeons requires two nesting cavities, the circular dovecote with its 1100 such cavities could have housed some 550 pairs of pigeons at any one time. Historical accounts by Roman agronomists, as well as information on modern pigeon raising practices in Egypt, Israel, Jordan and Iran (Beazley 1966: 107; Tepper, I. 1986: 188–89; Tepper 2007b: 152–55; Varro 1870, *Rerum rusticarum* libri III, III, 7, 1–7, 11), suggest that under optimal conditions each pigeon can produce 10 liters of dung per year. Furthermore, reproduction rates for a pair of pigeons laying two eggs per time, several times per year can reach as many as 10 additional hatchlings every year per single pair. In Sa'adon, a pigeon flock occupying a single dovecote, expected to have produced up to 6000–7000 hatchlings per year, could have also produced as much as 10–11 m^3 of manure per year (Hirschfeld and Tepper 2006: 83–116; Tepper I. 1986; Tepper 2007b: 133–59).

In the square dovecote, which appears to have been built in more modest proportions when compared to the circular one, we estimate around half of the nesting cavities and rate of pigeon manure production. Here, the only surviving course is composed of 60

Figure 21 Dovecote A—at the background a relict agricultural fields and the Sa'adon settlement (Photo: Yotam Tepper).

nesting cavities; at least three such courses would have fit along the wall within a single metre. The relatively thin walls of the square structure suggest that the original height was less than 5 m, though it is possible that a taller column of nesting compartments was achieved through the use of light building materials, including ceramic pipes, in its upper courses. This structure would have comprised no more than 600 compartments when intact, and housed about 300 pairs of pigeons at any given time. A pigeon flock in this dovecote should, therefore, have produced about 3000 pigeon chicks per year and 5–6 m^3 of manure. These installations may have been cleared of manure at least twice a year during normal functioning.

Recently published measurements of pigeon skulls and post-cranial skeletons from dovecotes in Sa'adon and Shivta attest to the use of small-bodied pigeons (*Columba livia*) (Marom *et al.* 2018). Such pigeons would have been more resistant to disease or shortages of food and water in the local arid environment than were larger birds. It appears that the Byzantine population of the Negev forfeited cultivation of fattened domesticated pigeons suitable as a food source, and instead, utilized breeding practices aimed at manure production. This inference is consistent with the location of the dovecotes outside the settlement and near the agricultural fields in both Sa'adon and Shivta (Hirschfeld and Tepper 2006: 108–14; Marom *et al.* 2018; Tepper I. 1986: 189–90).

The clear association of the Sa'adon dovecotes with relict agricultural fields and related infrastructure used for collecting surface runoff, supports a reconstruction of systematic production and collection of pigeon droppings for use as fertilizer in nearby groves, vineyards and orchards (Fig. 21). A stable supply of manure would have been an essential component of maintaining agricultural production in the nutrient-poor loess soils of the Negev (Tadmor and Hillel 1956: 27–32; Tepper *et al.* 2017; see also Pansiot 1961: 104–18; Tepper I. 1982: 51–54). Pigeon manure is well known for its high concentration of minerals, which decompose relatively rapidly to become usable nutrients for plants. It is considered more effective as a plant fertilizer than manure obtained from other livestock species (Feliks 1963: 93; Harlan 1995: 111; Hochberg 1956: 143; Tepper, I. 1986: 185, note. 70). Pigeon manure is also especially suitable for irrigated land and for use with annual crops; the high availability of its decomposed components for vegetation increases productivity by promoting the growth of young seedling plants (Hopkins 1945; Simpson 1986; Tepper, I. 1986; Tisdale *et al.* 1985; Feliks 1963: 91–115).

Intensive and large-scale manure production is proposed for the Byzantine agricultural complex in the Negev through detailed analysis of structural properties of the Sa'adon dovecotes and their rich biological contents. This evidence is combined within a broader reconstruction identifying the overall presence of three dovecotes near Sa'adon and four near the site of Shivta (Hirschfeld and Tepper 2006). These findings strongly suggest the dependence of local Negev agriculture on fertilization with pigeon manure. Pigeon-raising would have had a crucial role in the maintenance of the Byzantine agricultural complex, and in ensuring long-term sustainable agricultural production in the limiting environment of the Negev.

In conclusion, our excavations reveal high-level human expertise in pigeon-raising and manure production, and illustrate the importance of dovecotes in sustainable agriculture in the desert during the Byzantine period. The Byzantine people of the Negev skillfully adapted traditional farming practices to the unique climatic conditions of this arid region. Our dates for the period of use of the structures and their abandonment indicate a late 6th century CE timing for the decline or end of the Byzantine agricultural complex at Sa'adon, possibly preceding the Byzantine-Early Islamic transition towards the mid-7th century CE. Abandonment dynamics comprised a variety of processes including, termination through a single, sudden event, as was the case for the square dovecote at Sa'adon (see also the dovecote at Shivta: Hirschfeld and Tepper 2006: Structure 6), or orderly planned abandonment, as revealed by the finds in the circular dovecote at Sa'adon. Though the precise causes for this compound abandonment process remain largely conjectural (e.g., earthquakes, plague, warfare or climate change), this process appears to have been part of a wider regional dynamic, involving gradual decline and abandonment, which is also documented within some of the other Negev settlements (Avni 2014: 260–67; Hirschfeld 2006; Tepper *et al.* 2015; 2018). The process reflected in the dovecotes in relation to rural agricultural pursuits in the Negev thus combines with settlement decline in the Late Byzantine period to signal the collapse of Byzantine occupation across the Negev.

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References

Ashkenazi, E., Avni, Y. and Avni, G. 2012. A comprehensive characterization of ancient desert agricultural systems in the Negev Highlands of Israel. *Journal of Arid Environments* 86: 55–64.

Avni, G. 2014. *The Byzantine-Islamic Transition in Palestine: An Archaeological Approach*. Oxford: Oxford University Press.

Avni, G., Porat, N. and Avni, Y. 2013. Byzantine-Early Islamic agricultural system in the Negev Highlands: stages of development as interpreted through OSL dating. *Journal of Field Archaeology* 38: 333–47.

Avni, G. and Rosen, S. A. 1993. The edge of the empire: the archaeology of pastoral nomads in the southern Negev highlands in Late Antiquity. *Biblical Archaeologist* 56: 189–99.

Barker, G. 2002. A tale of two deserts: contrasting desertification histories on Rome's desert frontiers. *World Archaeology* 33: 488–507.

Bar-Oz, G., Weissbrod, L., and Erickson-Gini, T. 2016. Haluza. *Hadashot Archaeologiot*: 128. http://www.hadashot-esi.org.il/Report_Detail_Eng.aspx?id = 24991&mag_id = 124

Beazley, E. 1966. The pigeon towers of Isfahān. *Iran* 4: 105–09.

Ben Yosef, E. 2016. The building stones of Byzantine Shivta; their types, sources and contributions to the study of the sites and its surroundings. In, Patrich, J., Peleg-Barkat, O. and Ben-Yosef, E. (eds), *Arise, Walk Through the Land*: 163–82. Jerusalem: The Israel Exploration Society.

Boak, A. E. R. and Peterson, E. E. 1931. *Karanis: Topographical and Architectural Report of Excavations During the Seasons 1924–1928*. Ann Arbor: University of Michigan Studies Humanistic Series XXV.

Brock, F., Bronk-Ramsey, C. and Higham, T. 2007. Quality assurance of ultrafiltered bone dating. *Radiocarbon* 49: 187–92.

Bruins, H. J. 1986. *Desert Environment and Agriculture in the Central Negev and Kadesh-Barnea during Historical Times.* Wageningen: Nijkerk.

Columella, Lucius Junius. 1926. *De Re Rustica*. Translated from Latin by H. B. Ash. London: Loeb Classical Library.

Conan, M. 2007. Learning from the Middle East garden traditions. In, Conan, M. (ed.), *Middle East Garden Traditions: Unity and Diversity*: 5–18. Washington: Dumbarton Oaks.

Decker, M. 2009. Export wine trade to west end east. In, Mungo, M. M. (ed.), *Byzantine Trade, 4th–12th Centuries: The Archaeology of Local, Regional and International Exchange*: 239–52. Oxford: Ashgate.

Decker, M. J. 2013. The end of the Holy Land wine trade. *The Bulletin of the Anglo-Israel Archaeological Soceity* 31: 103–16.

Di Segni, C. L. 1988. L'iscrizone metrica greca di khirbet er-Rajib. *Liber Annuus* 38: 253–65.

Erickson-Gini, T. 2013. 'Shivta'. *Excavation and Survey in Israel*: 125 http://www.hadashot-esi.org.il/Report_Detail_Eng.aspx?id = 5420&mag_id = 120

Evenari, M., Shanan, L. and Tadmor, N. 1982. *The Negev: The Challenge of a Desert*. Cambridge: Harvard University Press.

Feliks, J. 1963. *Agriculture in Palestina in the Period of the Mishna and Talmud*. Jerusalem and Tel Aviv: Magness Press (in Hebrew).

Fenton, A. J. 1981. Early manuring techniques. In, Mercer R. (ed.), *Farming Practice in British Prehistory*: 210–17. Edinburgh: Edinburgh University Press.

Fraiberg, A. and Tepper, Y. 2017. Horbat Kasif (North). *Hadashot Archaeologiot*: 129. http://www.hadashot-esi.org.il/Report_Detail_Eng.aspx?id = 25200&mag_id = 125

Fried, T., Weissbrod, L., Tepper, Y. and Bar-Oz, G. 2018. A glimpse of an ancient agricultural ecosystem based on remains of micromammals in the Byzantine Negev Desert. *Royal Society Open Science Journal* 5: 1–14. DOI:10.1098/rsos.171528. Available at: http://rsos.royalsocietypublishing.org/content/5/1/171528 (accessed 16 September 2018).

Fuks, D., Weiss, E., Tepper, Y. and Bar-Oz. 2016. Seeds of collapse? Reconstructing the ancient agricultural economy at Shivta in the Negev. *Antiquity* 353: 1–6.

Haiman, M. 1995. Agriculture and nomad — state relations in the Negev in the Byzantine and early Islamic periods. *Bulletin of the American Schools of Oriental Research* 297: 29–53.

Haag-Wackernagel, D. 1998. *Die Taube*. Basel: Verlag Schwabe.

Harlan, J. R. 1995. *The Living Fields: Our Agricultural Heritage*. Cambridge: Cambridge University Press.

Hirschfeld, Y. 2006. Settlement of the Negev in the Byzantine period in light of the survey at Horvat Sa'adon. *Bulletin of the Anglo-Israel Archaeological Society* 24: 7–49.

Hirschfeld, Y. and Tepper, Y. 2006. Columbaria towers (dovecotes) and other structures in the environs of Shivta. *Tel Aviv* 33: 83–116.

Hochberg, N. 1956. Nutruring of the Grapevine. *Hasade* 45: 137–52 (Hebrew).

Hopkins, D. P. 1945. *Chemicals, Humus, and the Soil; a Simple Presentation of Contemporary Knowledge and Opinions About Fertilizers, Manures and Soil Fertility.* London: Faber and Faber.

Hunt, A. S. 1926. A Zenon papyrus at Corpus Christi College, Cambridge. *Journal of Egyptian Archaeology* 12: 113–15.

Husselman, E. M. 1953. The Dovecotes of Karanis. *Transactions and Proceedings of the American Philological Association* 84: 81–91.

Gatier, P. L. and Vérilhac, A. M. 1989. Les colombas de Déméter à Philadelphie-Amman. *Syria* 66: 337–48.

Gazda, E. K. 2004. *Karanis, An Egyptian Town in Roman Times. Discoveries of the University of Michigan Expedition to Egypt*. Michigan: Kelsey Museum Publication 1.

Golan, K. 2014. *The Stone Architectural Decorations of the Byzantine Negev: Characterization and Meaning*. PhD. Ben-Gurion University.

Kedar, Y. 1957. Ancient agriculture at Shivtah in the Negev. *Israel Exploration Journal* 7: 178–89.

——— 1959. Ancient agricultural installations in the Negev Highlands. *Israel Exploration Society* 23: 232–33 (in Hebrew).

Kobrin, F. and Tepper, Y. 2017. Be'er Sheva', the Zoological Park. *Hadashot Archaeologiot*: 129. http://www.hadashot-esi.org.il/Report_Detail_Eng.aspx?id = 25300&mag_id = 125

Kraemer, C. J. 1958. *Excavation at Nessana*: *The Non Literary Papyri Voll III*. Princeton: Princeton University Press.
Kühtreiber, T. 1914. Bericht Über meine Reisen in Pälistina in Jahre 1912. *Zeitschrift des Deutschen Palästina-Vereins* 37: 1–20.
Liphschitz, N. 2007. *Timber in Ancient Israel: Dendroarchaeology and Dendrochronology* (Monograph Series no. 26). Tel Aviv: Tel Aviv University Press.
Lyman, R. L. 1994. Relative abundances of skeletal specimens and taphonomic analysis of vertebrate remains. *Palaios* 9: 288–98.
——— 2008. *Paleozoology*. Cambridge: Cambridge University Press.
Marom, N., Rosen, B., Tepper, Y. and Bar-Oz, G. 2018. Pigeons at the edge of the empire: bioarchaeological evidences for extensive management of pigeons in a Byzantine desert town in the southern Levant. *PLoS One* 13: e0193206.
Magness, J. 1993. *Jerusalem Ceramic Chronology, Circa 200–800 CE*. Sheffield: Sheffield Academic Press.
Majcherek, G. 1995. Gazan amphorae: typology reconsidered. In, Meyza, H. and Młynarczyk, J. (eds), *Hellenistic and Roman Pottery in the Eastern Mediterranean — Advances in Scientific Studies*: 163–78. Warsaw: Nieborów.
Mazor, G. 1981. The wine-presses of the Negev. *Qadmoniot* 53: 51–60 (in Hebrew).
Mayerson, P. 1959. Ancient agricultural remains in the central Negev: the Teleilat El-Anab'. *Bulletin of American Schools of Oriental Research* 153: 19–53.
——— 1992. The Gaza wine jar (Gazition) and the 'lost' Ashkelon jar (Askalonion). *Israel Exploration Journal* 52: 76–80.
McCormick, M. 2012. Movements and markets in the first millennium. In, Morrison, C. (ed.), *Trade and Markets in Byzantium*: 51–98. Washington: Dumbarton Oaks .
Miller, N. F. and Kathryn, L. G. 1994. Fertilizer in the identification and analysis of cultivated soil. In, Miller, N. F. and Kathryn, L. G. (eds), *The Archaeology of Garden and Fields*: 25–43. Philadelphia: Philadelphia University Press.
Musil, A. 1907. *Arabia Petraea, 11, Edom*. Vienna: Hölder.
Negev, A. 1977. Preservation and disappearance of early place names in the Negev. *Cathedra* 4: 121–32 (in Hebrew).
Netzer, E. 1981. Greate Herodium. *Qedem* 13. Jerusalem: Hebrew University.
Palmer, E. H. 1871. *The Desert of Exodus*. Cambridge: Deighton.
Pansiot, F. P. 1961. *Improvement in Olive Cultivation*. Rome: FAO.
Pliny, Gaius Secundes. 1938. *Natural History*. Translated from Latin by H. Rackham. London: Loeb Classical Library.
Ramsay, J. and Tepper, Y. 2010. Signs from a green desert: A preliminary analysis of archaeobotanical remains from tower no. VI near Shivta, Israel. *Vegetation History and Archaeobotany* 19: 235–42.
Ramsay, J., Tepper, Y., Weinstien- Evron, M., Bratenkov, S., Liphschitz, N., Marom, N. and Bar-Oz, G. 2016. For the birds: an environmental archaeological analysis of Byzantine pigeon towers at Shivta (Negev Desert, Israel). *Journal of Archaeological Science Reports* 9: 718–27.
Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., Grootes, P. M., Guilderson, T. P., Haflidason, H., Hajdas, I., Hattž, C., Heaton, T. J., Hoffmann, D. L., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., Manning, S. W., Niu, M., Reimer, R. W., Richards, D. A., Scott, E. M., Southon, J. R., Staff, R. A., Turney, C. S. M., and van der Plicht, J. 2013. IntCal13 and marine13 radiocarbon age calibration curves 0–50,000 Years cal BP. *Radiocarbon* 55: 1869–87.
Rubin, R. 1990. *The Negev as a Settled Land. Urbanization and Settlements in the Desert in the Byzantine Period*. Jerusalem: Yad Ben Zvi (Hebrew).
Rubin, R. and Shereshvsky, Y. 1988. Sa'adon: an urban settlement of the Byzantine period in the Negev. *Qadmoniot* 21: 49–54 (Hebrew).
Safrai, Z. 1994. *The Economy of Roman Palestine*. London: Routledge.
Schubart, W. 1922. *Ägypten von Alexander dem Grossen bis auf Mohamed*. Berlin: Bilabel.
Segal, A. 1983. *Shivta: The Byzantine City of Shivta (Esbeta), Negev Desert, Israel*. Oxford: Oxford Univerisity Press (BAR International Series 179).
——— 1988. *Architecture Decoration in Byzantine Shivta, Negev Desert, Israel*. Oxford: Oxford Univerisity Press (BAR International Series 420).
Shalmon, B. 1993. *A Field Guide to the Land Mammals of Israel Jerusalem*. Jerusalem: Keter Publishing House (Hebrew).
Shereshevski, J. 1991. *Byzantine Urban Settlements in the Negev Desert*. Beer Sheva: Beer Sheva University Press.
Sher, Y., Zaady, E. and Nejidat, A. 2013. Spatial and temporal diversity and abundance of ammonia oxidizers in semi-arid and arid soils; indications for a differential seasonal effects on archaeal and bacterial ammonia oxidizers. *FEMS Microbial Ecology* 86: 544–56.
Simpson, K. 1986. *Fertilizers and Manures*. London and New York: Marcell Dekker.
Tadmor, N. and Hillel, D. 1956. *Survey of the Possibilities for Agricultural Development in the Southern Negev*. Rehovot: Agricultural Research Institute of Israel Bulletin 61.
Tadmor, N. H., Evnari, M., Shanan, L. and Hillel, D. 1957. The ancient desert agriculture of the Negev. *Ktavim* 8: 127–51.
Talbot, A. M. 2002. Byzantine monastic horticulture: the textual evidence. In, Littlewood, A., Maquire, H. and Wolschke-Bulmahn, J. (eds), *Byzantine Garden Culture*: 37–67. Washington: Dumbarton Oaks.
Tarn, W. and Griffith, G. T. 1952. *Hellenistic Civilisation*. London: Arnold.
Tepper, I. 1982. Hydroponics system in the Byzantine agriculture of Umm-Summer area. In, Lachis, I., and Meshel, Z. (eds) *South Sinai Research. 1967–1982*: 51–54. Tel-Aviv: Tel Aviv University Press (in Hebrew).
——— 1986. The rise and fall of dove-raising. In, Kasher, A., Oppenheimer, U. and Rappaport, U. (eds), *Man and Land in Eretz-Israel in Antiquity*: 170–96. Jerusalem: Yad Ben Zvi (in Hebrew).
Tepper, Y. 2007a. Soil improvement and agricultural pesticides in antiquity: examples from archaeological research in Israel. In, Conan, M. (ed.), *Middle East Garden Traditions: Unity and Diversity*: 41–52. Washington: Dumbarton Oaks.
——— 2007b. Columbarium, peristeron and pigeon tower: pigeon raising in Eretz-Israel in the Hellenistic, Roman and Byzantine periods. In, Arbel, B., Terkel, J. and Menache, S. (eds), *Human Beings and other Animals in Historical Perspective*: 133–59. Jerusalem: Carmel (Hebrew).
Tepper, Y. and Bar-Oz, G. 2016. Horbat Sa'adon. *Hadashot Archaeologiot:* 128. Preliminary Report http://www.hadashot-esi.org.il/Report_Detail_Eng.aspx?id = 24976&mag_id = 124
Tepper, Y., Weissbord, L. and Bar-Oz, G. 2015. Behind sealed doors: unravelling abandonment dynamics at the Byzantine site of Shivta in the Negev Desert. *Antiquity* 348. Available at: http://antiquity.ac.uk/projgall/bar-oz348 (accessed 16 September 2018).
Tepper, Y., Rosen, B., Haber, A. and Bar-Oz, G. 2017. Traces in the desert dust: soil tests characterize a pigeon tower structure near Byzantine Shivta, Israel. *Journal of Arid Environment* 145: 81–89.
Tepper, Y., Erickson-Gini, T., Farhi, Y. and Bar-Oz, G. 2018. Probing the Byzantine/Early Islamic transition in the Negev: the renewed Shivta excavations, 2015–2016 seasons. *Tel Aviv* 45: 55–87.
Tisdale, S. L., Nelson, W. L. and Beaton, J. D. 1985. *Soil Fertility and Fertilizers*. New York and London: Macmillan Publishing Company.
Tsafrir, Y., Di Segni, L. and Green, J. 1994. 'Sudanon', in Tabula Imperii Romani Iudaea-Palestina: Eretz Israel in the Hellenistic, Roman and Byzantine Periods; Maps and Gazetteer: 236. Jerusalem: Israel Academy of Sciences and Humanities.
Zissu, B. 1995. Two Herodian dovecotes: Horvat Abu Haf and Horvat ꞌAleq. In, Humphreys, J. H. (ed.), *The Roman and Byzantine Near East: Some Recent Archaeological Research*: 57–69. Ann Arbor: MI.
Zohary, M. 1987. *The Plant World: Morphology, Taxonomy, Evolution, Biology*. Tel Aviv: Am Oved (in Hebrew).
Varro, Marcus Terentius. 1870. *Rerum Rusticarum*. Translated from Latin by G. Goetz. Leipzig: Loeb Classical Library.
Ward, D., Feldman, K. and Avni, Y. 2001. The effects of loess erosion on soil nutrients, plant diversity and plant quality in the Negev desert wadis. *Journal of Arid Environment* 48: 261–73.
Weigand, T. 1920. *Sinai*. Berlin: de Gruyter.
Weiner, S. and Bar-Yosef, O. 1990. States of preservation of bones from prehistoric sites in the Near East: a survey. *Journal of Archaeological Science* 17: 187–96.

Weinstein-Evron, M. and Lev-Yadun, S. 2000. Palaeoecology of Pinus halepensis in Israel in the light of palynological and archaeobotanical data. In, Ne'eman, G. and Trabaud, L. (eds), *Ecology, Biogeography and Management of Pinus Halepensis and P. brutia Forest Ecosystems in the Mediterranean Basin*: 119–30. Leiden: Backhuys.

Wilkinson, T. 1988. The archaeological component of agricultural soils in the Middle East: the effects of manuring in antiquity. In, Waateringe-Groenman-Van, W. and Robinson, M. (eds), *Man-Made Soils*: 93–114. Oxford: BAR International Series 410.

Woolley, C. L. and Lawrence, T. E. 1914–1915. *The Wilderness of Zin*. London: PEF.

Yizhaq, M., Mintz, G., Choen, I., Khalaily, H., Weiner, S., and Boaretto, E. 2005. Quality controlled radiocarbon dating of bones and charcoal from the early Pre-Pottery Neolithic B (PPNB) of Motza (Israel). *Radiocarbon* 47: 193–206.