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Sustainable farming in the Roman-Byzantine period: Dating an advanced agriculture system near the site of Shivta, Negev Desert, Israel

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ABSTRACT

Ancient agricultural systems in the Negev Desert preserves abundant evidence of dryland farming from the Roman, Byzantine and Early Islamic periods. These systems consist of dams, field plots, field towers, cisterns and thousands of human-made stone mounds. In the environment of Shivta, these systems also included built dovecotes to produce dung to fertilize vineyards and orchards. All of these elements established an intensive agronomic practice. Extensive survey and excavations in one completely preserved agricultural system in a small wadi in the hinterland of Shivta, followed by OSL dating of loess accumulations in the adjacent agricultural installations, in addition to dates from archaeological finds, revealed clear stratigraphic and chronological sequences. We found that the first human-made components were established in the Roman period (1st–2nd centuries CE) and the agricultural system flourished during the Byzantine period (5th–6th centuries CE) before it was abandoned in the post-Byzantine era. At its peak, all artificial components of the system would have had to operate together at an optimum level to make intensive agriculture possible. This agricultural system is a prime example of the enormous skill and knowledge of Shivta farmers in synergizing different agricultural installations to maintain agriculture in a desert environment.

1. Introduction

Remnants of intensive ancient agriculture in the climatically marginal area of the arid Negev Highlands of Israel preserve abundant evidence of dryland farming. Rainfall is low (ca. 50–150 mm annually) and characterized by high seasonal and year-to-year variability and agriculture was based on utilization of runoff and floodwater from local rainfall. Vast agricultural remains were found in a large area in the hinterland of the main ancient Negev settlements of Shivta, Avdat (Eboda), Mamshit (Mampsis), Nessana, Rehovot, Sa'adon, and Elusa. The ancient agricultural remains attest to a widespread and thriving agrarian culture with the engineering skills required to establish and maintain a flourishing agriculture society in a desert environment (Kedar, 1957a; Mayerson, 1960; Evenari et al., 1982; Shereshevski, 1991; Lavee et al., 1997; Goldreich, 2003; Bruins, 2012; Bruins and Ore, 2008; Bruins and Jongmans, 2012; Avni, 2014; Avni et al., 2013, 2019; Bruins et al., 2019; Ackermann et al., 2019).

Travelers and scholars exploring the Negev Desert in the late 19th and early 20th centuries CE were the first to describe the large agricultural areas surrounding the ancient sites (Shereshevski, 1991). the Nessana Papyri, discovered by Colt, further portray the impressive agricultural achievements of the Byzantines in the Negev (Colt, 1962; Kraemer, 1958; see also the Petra Church papyri: Frosen et al., 2002; Arjava et al., 2007). The rich botanical findings uncovered at the Byzantine Negev sites likewise confirm these descriptions (Fuks et al., 2016; Bar-Oz et al., 2019).

Massive landscape modifications were needed to create the advanced agro-technological elements that have been preserved in the hinterland of the ancient village of Shivta (Kedar, 1957b), described in detail by Segal (1983). These included widespread construction of artificially built stone mounds on slopes to enhance soil and slope runoff to the agricultural fields in the wadis and impoundment dams to catch alluvial soil and floodwater in the fields (Kedar, 1957b). The site reached its peak during the Byzantine period (5th–6th centuries CE). A rapid decline followed, around the 7th-century CE Islamic conquest (Hirschfeld, 2006; Tepper et al. 2015, 2018a).

Across the 10,000 ha surveyed around Shivta, Baumgarten (2004) found 45 sites dated to the Early Roman period, 90 to the Late Roman period and 181 to the Byzantine period, roughly a 400% increase in sites from the Early Roman period. A significant increase was noted

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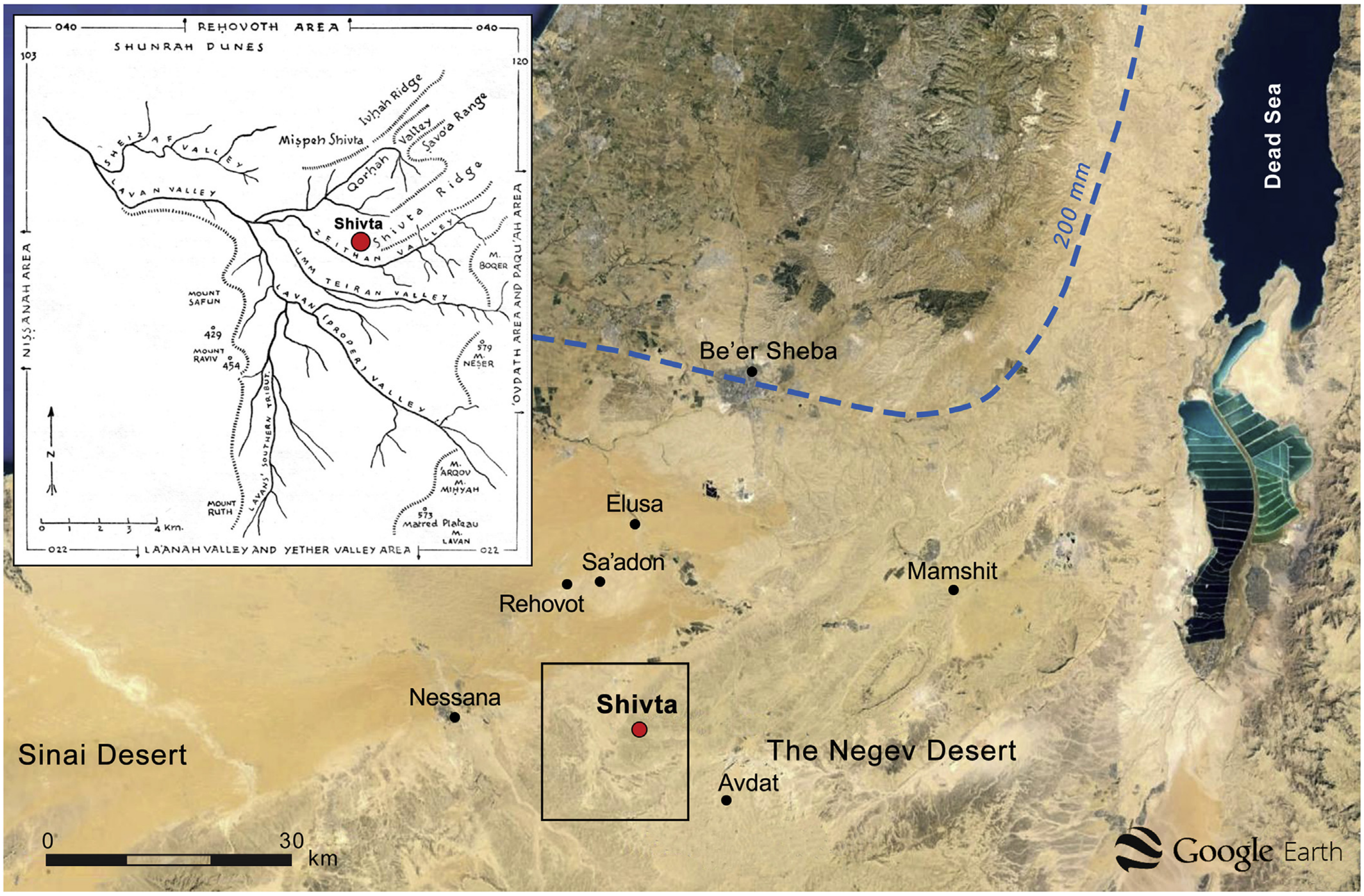

Fig. 1. Location of Shivta in the Negev, in the heart of the Nahal Lavan Basin (source: Kedar, 1957b; Google Earth).

primarily in the number of field installations, including field towers and cisterns in agricultural areas, tripling in number from the Early Roman to the Byzantine periods (Baumgarten, 2004: 9–21). This dramatic rise in the agricultural sphere demonstrates the magnitude of agricultural development and the enormous sustainability skills of the Negev farmers (Kedar, 1957a; 1957b; Evenari et al., 1982; Avni et al., 2019). Additional agricultural installations scattered across the landscape at the site are dovecotes, which were built during the Roman and Byzantine periods (2nd–6th centuries CE) near the fields to produce fertilizers, enriching the nutrient-poor desert soil (Hirschfeld and Tepper, 2006; Tepper, 2007; Tepper et al., 2017). The presence of three large winepresses in Shivta confirm written sources of the Byzantine period describing extensive grape cultivation and wine production at the site (Mayerson, 1985; Hirschfeld, 2003a; Decker, 2013).

The Negev agricultural systems have been studied for several decades (e.g., Mayerson, 1955, 1960, 1959; Shereshevski, 1991; Avni and Rosen, 1993; Bruins, 2012; Ashkenazi et al., 2012; Erickson-Gini, 2012). Hundreds of agricultural farms were surveyed and documented in the core area of the Negev Highlands (Avdat and Shivta to the south, Nessana to the west and Mamshit to the east). The temporal span and sociocultural context of the rise and fall of this desert agricultural phenomenon has been extensively debated among scholars (Avni and Rosen, 1993; Avni, 1996, 2014; Haiman, 1995, 2012; see also Magness, 2003: 131–138). Based on numerous OSL ages of sediments from agricultural terraces in various sites Avni et al. (2013) date the main phase of desert agriculture between the 3rd and 4th centuries and the 10th and 11th centuries CE (recently reviewed in Avni et al., 2019; see also Avni et al., 2006; Avni et al., 2012). The intensive agricultural system reached its peak in the 4th–7th centuries CE, as also reflected in the regional prosperity of sites (Magness, 2003; Avni, 2014). Various triggers including global climate change, spread of disease and wider socio-political changes were likely among the proxy causes for the decline of desert agriculture, leading to its final demise after the 10th century CE (Magness, 2003; Hirschfeld, 2006; Avni, 2008; Bar-Oz et al., 2019).

Study of the precise nature and makeup of this sophisticated system has focused extensively on characterization of these agricultural systems and examining the performance and functionality of water and soil harvesting. It is commonly agreed that these systems were built primarily for systematic collection of rainwater runoff (Evenari et al., 1982). Collection of soil that was washed to the plots was another successful achievement that allowed agriculture to be maintained. (Kedar, 1957a, 1957b; Avni et al., 2006, 2019; Erickson-Gini, 2012). Previous studies demonstrated the critical role of pigeon-raising for agricultural success (Tepper et al., 2017), a feature also well attested in Roman agricultural-historical sources, especially with regard to orchards and vineyards (Varro – *Rerum Rusticarum* III: VII; Columella – *De Re Rustica* VIII: 3–5; Pliny the Elder – *Naturalis Historia* X: 53). We have shown that pigeons were raised near the fields primarily for their manure, which was used to enrich the region's loess soil (Hirschfeld and Tepper, 2006; Tepper, 2007; Ramsay et al., 2016; Tepper et al., 2018b; Marom et al., 2018).

Near one of the pigeon towers in the Shivta hinterland we identified a preserved Byzantine agricultural complex, which encompassed the main elements needed for sustainable desert agriculture. It consisted of several complete dams and associated agricultural field plots, a built field tower, a cistern and artificial stone mounds ('*tulleilat el-anab*') on the surrounding hills (Hirschfeld and Tepper, 2006; Tepper et al., 2017).

These installations are typical of Shivta's agricultural system and therefore can serve as an important case study to examine the synchronous nature of a complete, intensive agricultural system.

In this article we present the results of our survey and excavations of this particular agricultural system. Our goal is to date and analyze the chronology of this system within its well-defined landscape, and address three main research questions: (1) When were the various components built? (2) Did they function simultaneously? (3) When were they abandoned?

1.1. The agricultural systems around Shivta

The extensive archaeological landscape with its abundance of agricultural installations around Shivta extends over approximately 500 ha (Fig. 1; Kedar, 1957b). Some 55% (~280 ha) are dams built in the broad wadi, causing the accumulation of large quantities of eroded soil behind them. The smaller systems constitute 45% (~220 ha) of the total cultivated area. These typically featured dams built upstream in smaller tributaries and surrounded by stone enclosure walls (tributary wadi cultivation: Mayerson, 1959).

On the wadi slopes the local drainage is toward the field plots in the wadi bed (Baumgarten, 2004: 54). Evenari et al. (1982), whose pioneering research also studied the runoff agriculture systems near Shivta, estimated the average ratio of slopes arranged with stone heaps to field plots in the wadi beds at approximately 1:20 (see also Ashkenazi et al., 2012). This kind of ground preparation enhanced soil- and water-harvesting from the slopes toward the plots in the wadis, creating conditions for year-round cultivation of orchards and vineyards (Kedar, 1957b; Evenari et al., 1982; Wieler et al., 2016; Avriel-Avni et al., 2019).

The case study presented here is of the smaller tributary type, consisting of a local drainage basin on the slopes of a wadi bed north of Shivta. The wadi, which runs southeast to northwest and drains into the bed of Nahal Zeitan (Zeithan; Figs. 1–2), contains an agricultural system with several human-made components: (1) stone mounds and stone strips (rake lines) constructed on the wadi slopes and surrounding hills to expose the loess soil and enhance soil and water runoff; (2) dams in the wadis for collecting flood water and alluvium; (3) stone walls enclosing the agricultural areas to protect the fields from grazing animals; (4) built and hewn installations, including a cistern, a dovecote and a field tower. The field tower was probably used as a shelter for the farmer and for storage of products and tools during the agricultural season.

This agricultural system covers 9.17 ha (Fig. 3). The area of the drainage basin on the slopes is 7.95 ha, and the area of the agricultural plots in the wadi is 1.22 ha, a ratio of only 1:6.5. The boundaries were estimated according to local topographical conditions and human-made elements. In the northeast the boundary was set on the chalk slope, along an artificial line of soil and stones (Fig. 3, points 103 and 109) and continues from the line of the upper watershed to near the field plots in the wadi (Fig. 3: d–e).

In the southeast and the south, on the upper part of the slope, the watershed of the local drainage basin continues along an artificial soil channel down which surface runoff flows beyond our agricultural system into a neighboring one (Fig. 3: points 66–73). The boundary of our agricultural system's drainage basin then continues north–northwest, to the field plots in the wadi (Figs. 3–4: e) near the field tower (Figs. 3–4: Area C). Its western boundary lies between the dovecote (Figs. 3–4: VI) and the field of flint-rock mounds (Fig. 3: point 62, B).

Stone mounds and strip lines were documented on the wadi slopes running northeast to southeast. They were created by the collection of soil and stones of various sizes into heaps and long lines (Figs. 3, 5), exposing the underlying loess. Bedrock is either limestone or chalk and chert. On the western slopes, where chert was found on the surface, dozens of stone heaps were documented, averaging 3–5 m in diameter and 1 m in height, and dozens more rows of heaps. Similarly, on the eastern slopes, where limestone covered the surface, additional heaps of

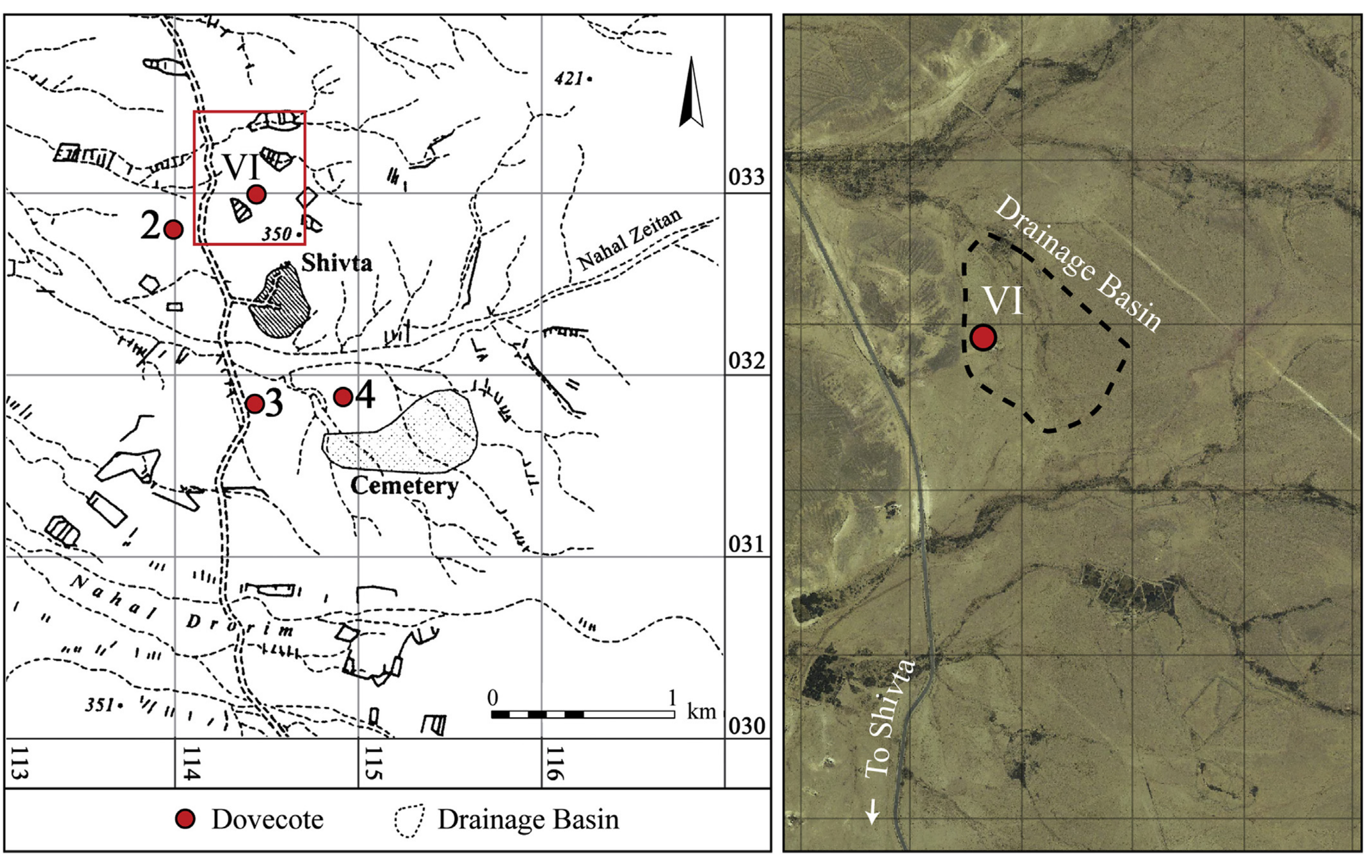

Fig. 2. Shivta and the distribution of dovecotes in the agricultural hinterland (left) and the boundaries of the drainage basin of the agricultural system marked next to Dovecote VI (right) (Aerial photography by PW).

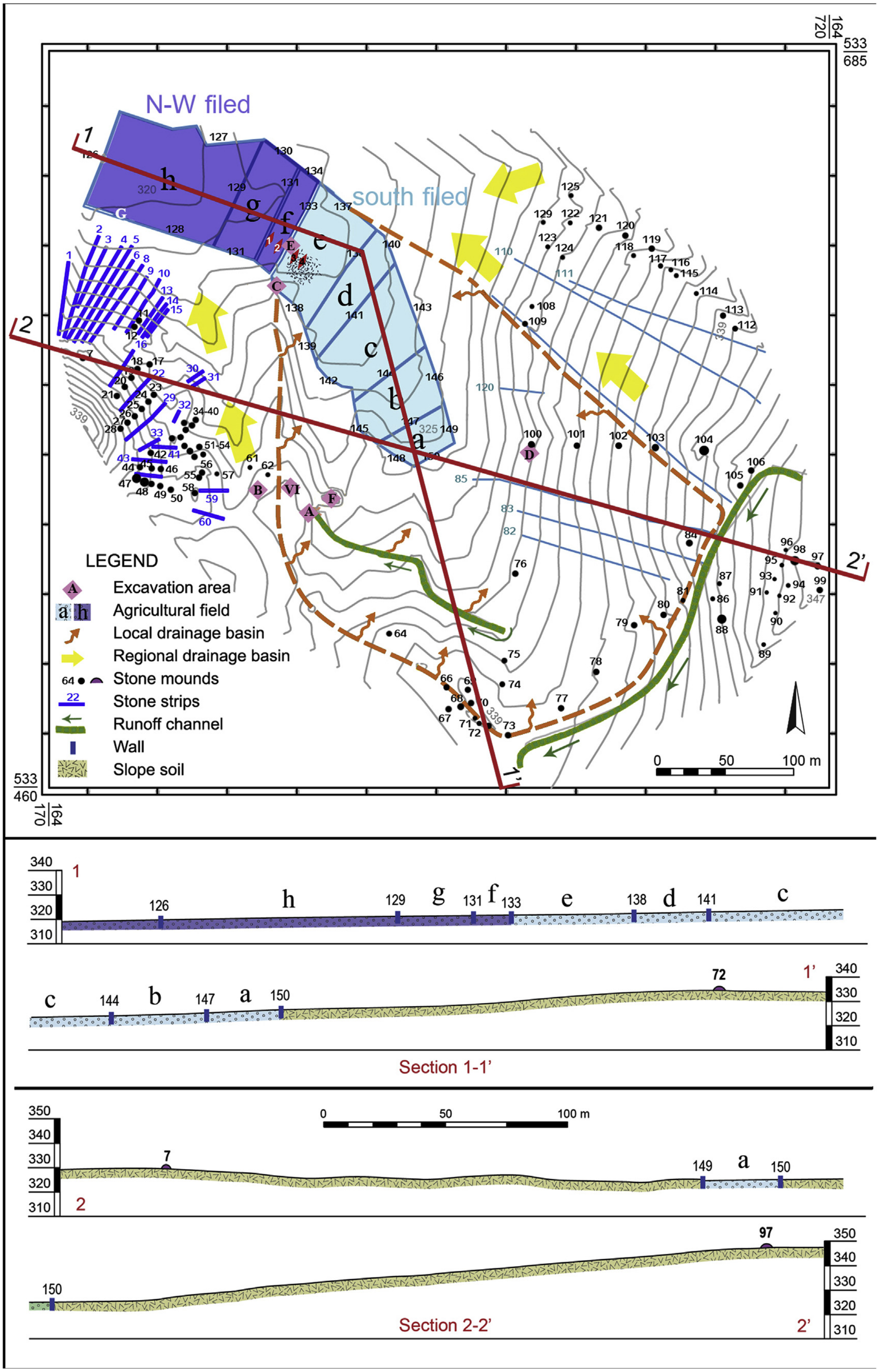

Fig. 3. Plan of Shivta agricultural system (plan: Michael Shomroni and Avi Blumenkrantz).

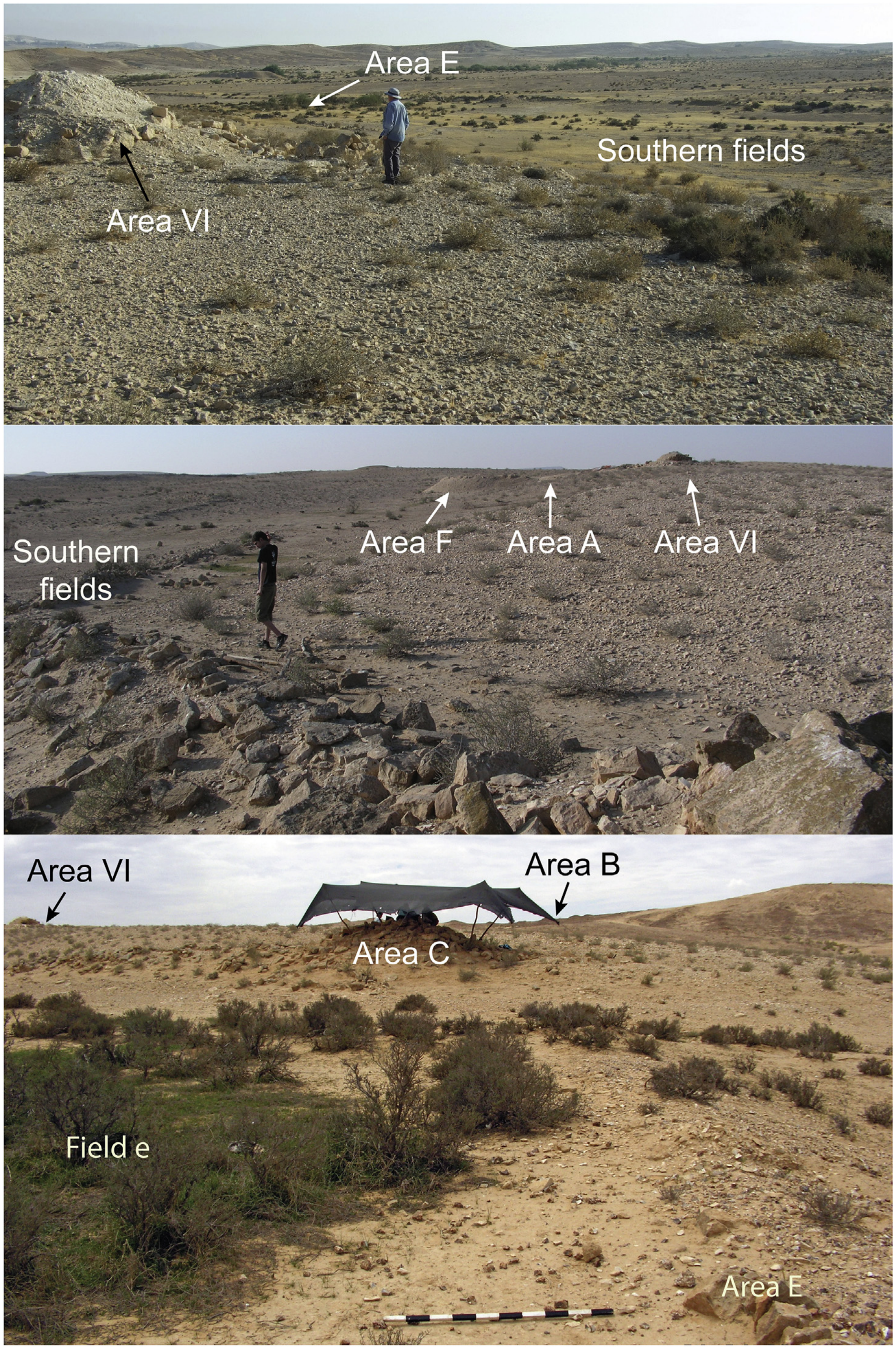

Fig. 4. General view of some of the components of Shivta agricultural system: (Area A) the cistern; (Area B) stone mounds; (Area C) field tower; (Area E) plots; (Area F) mound of earth; (Area VI) dovecote (photo: Yotam Tepper).

similar size with several long lines of heaps of soil and stones were found. The total length of the lines of stone strips on both parts of the slope is hundreds of meters; the average inclination in the drainage basin is moderate, not exceeding 8° (Fig. 3).

The cistern (Fig. 3: Area A) is located in the upper part of the southern slope. It is approximately 4 m deep and its estimated volume is 150–200 m^3. The upper opening of the cistern is cut through the hard calcrete roof. An inlet channel (see below) enters the cistern's lower opening in the southeast (Fig. 3). This opening, cut into a layer of soft chalk, leads to a descent to the cistern's bottom by a staircase of at least 15 steps. The walls of the cistern bear remnants of a layer of pink-gray plaster set on a base of grayish ash-rich mortar. Where there were cracks in the natural bedrock, their sides were widened, filled with the foundation layer, and sealed with plaster.

A channel dug into the soil, c. 0.5 m wide and c. 200 m long, follows a moderate east to west contour on the upper part of the southeastern slope leading to the lower opening of the cistern (Fig. 3: marked in green). The channel is completely silted up, and no built remains have been documented along it. The drainage basin is estimated at 2 ha.

A large mound of sediment (loess soil; Fig. 3: Area F) was documented adjacent to the cistern to the northeast (diameter c 30 m; height c 3 m). A few stones and sherds were found on top of it. This mound was

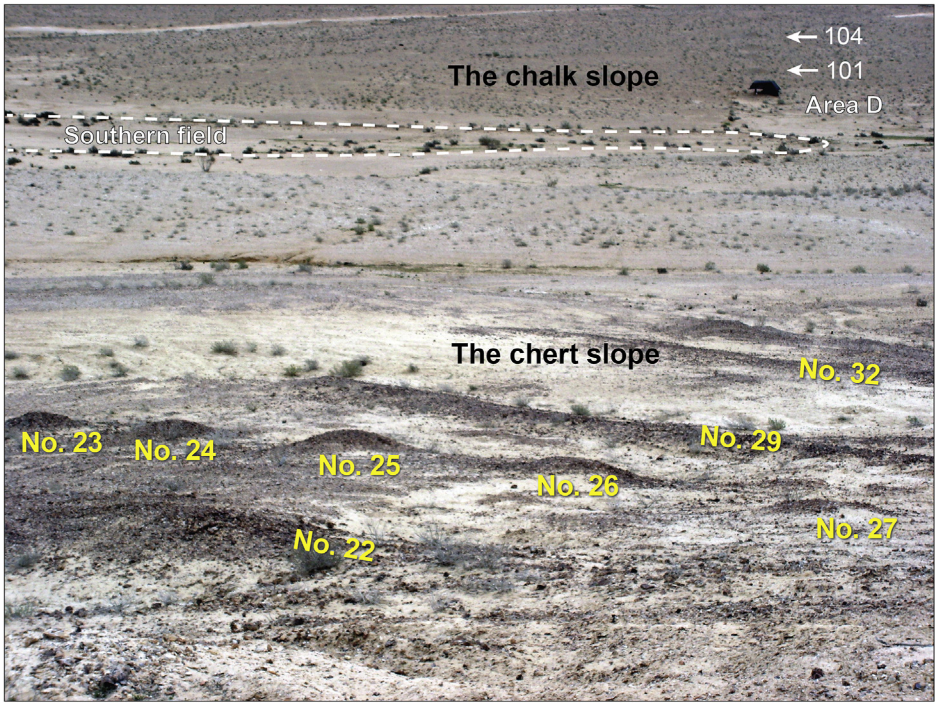

Fig. 5. The field of stone mounds on the chert-bearing slope above the field plots in the wadi. The limestone mounds on the other side of the wadi are also marked (stone mounds are numbered according to Fig. 3; photo: Yotam Tepper).

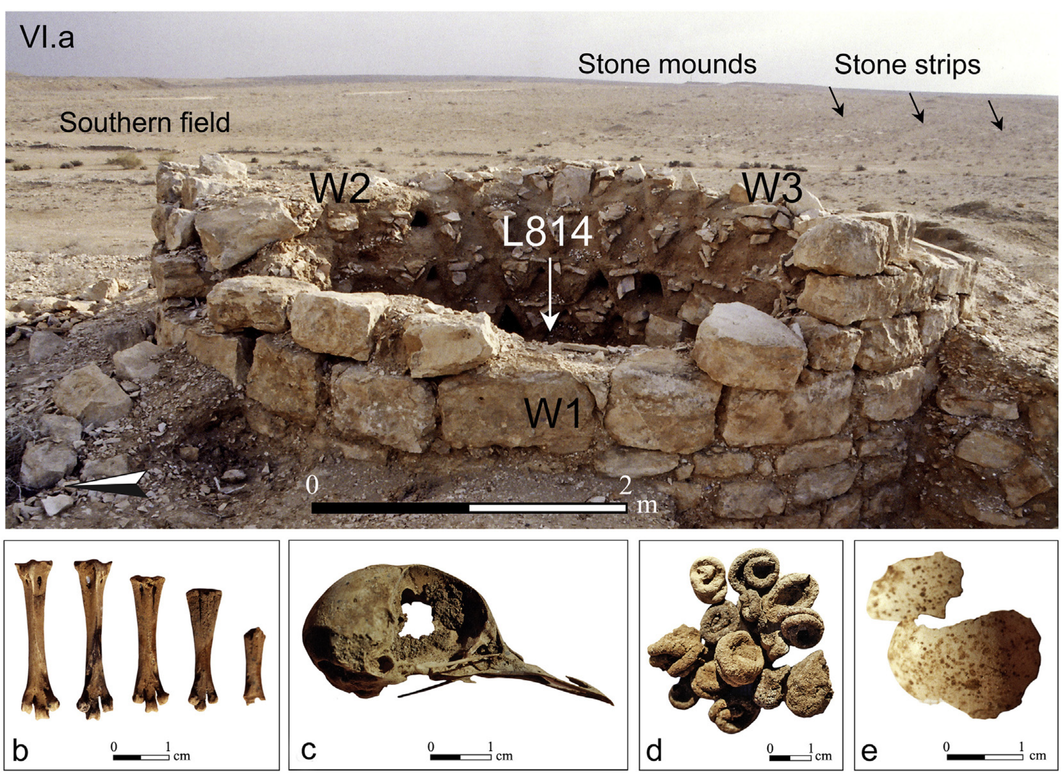

Fig. 6. View of Dovecote VI at the end of its excavation and selected finds from the dung layer above the floor (L814): (b) pigeon bones; (c) pigeon skulls; (d) pigeon droppings; (e) fragment of a pigeon eggshell (photo: Yotam Tepper).

probably formed by repeated clearing of the silt that had accumulated in the cistern. The volume of the mound, down to the natural underlying surface, is estimated at c. 220 m^3 (see also Junge et al., 2018).

The round dovecote (Fig. 3: Area VI), 5.2 m in diameter, is built of local limestone field stones and has survived to a height of 1.2 m. It is situated at the top of the southwestern slope, just above the cistern. Inside, the dovecote is divided into three chambers by a Y-shaped wall. Built openings afford passage between the chambers. A layer of pigeon dung (c. 40 cm thick) was discovered above the floor. This layer also contained pigeon bones and eggshell fragments indicating the last use

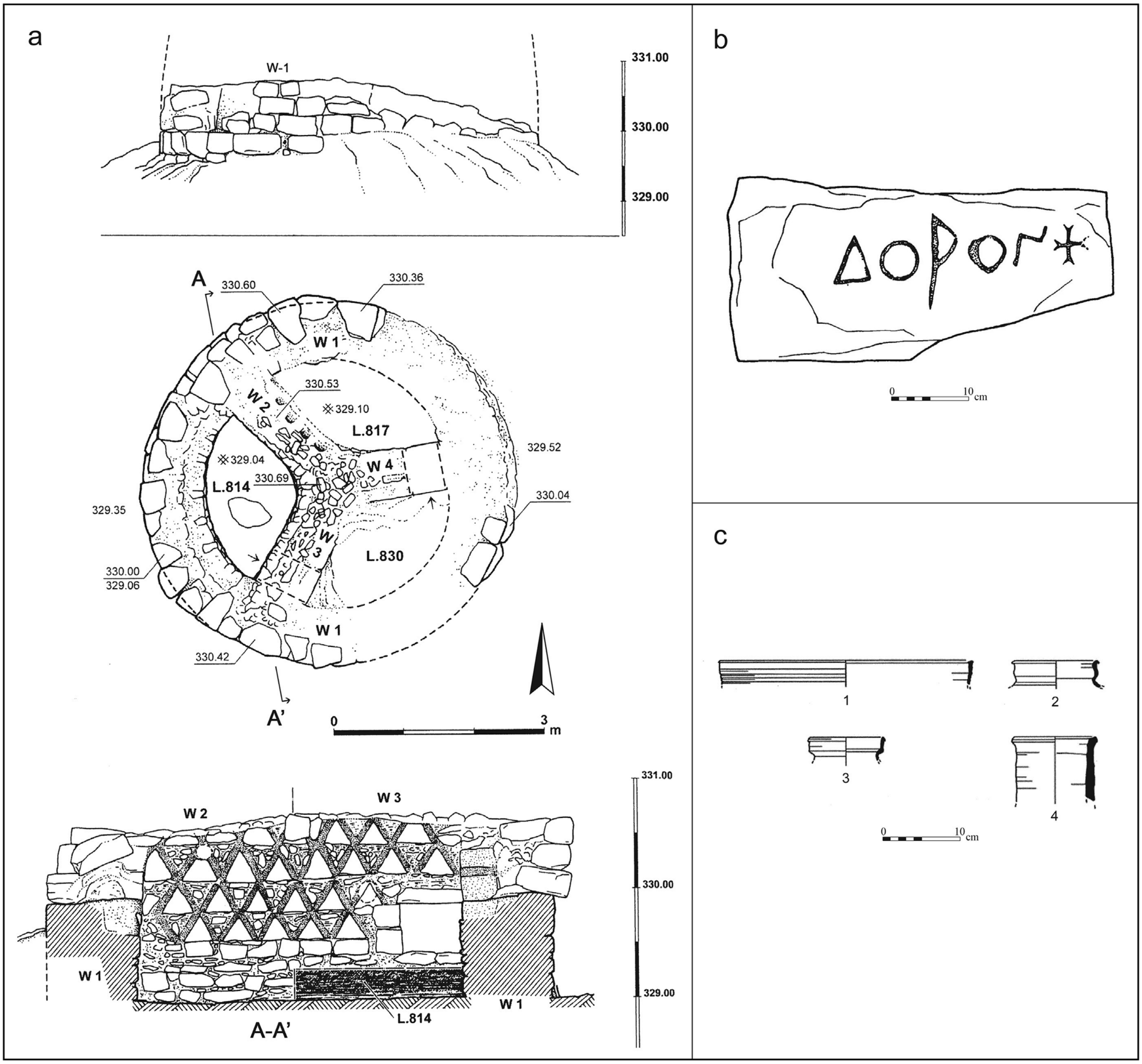

Fig. 7. Plan and section of Dovecote VI (a); Greek inscription (b); Byzantine pottery fragments, including frying pan (1), cooking pots (2, 3) and pipe (4) (c): (modified from Hirschfeld and Tepper, 2006).

(Hirschfeld and Tepper, 2006; Ramsay et al., 2016, Fig. 6). Excavation of the dovecote (Fig. 7a) uncovered a lintel bearing an inscription in Greek (ΔOPON) meaning "offering" or "gift" next to a cross. The lintel apparently came from an upper opening that did not survive (Fig. 7b; Hirschfeld and Tepper, 2006). Radiocarbon dating of pigeon dung from the floor of the dovecote (L817) gave a calibrated age of 550 years CE (Ramsay et al., 2016). This dating closely matches that of the Byzantine pottery associated with the dovecote (Fig. 7c).

A system of five stone-wall dams (Fig. 3: 133, 136, 141, 144, 147) was built to stop sediment and rainwater from flowing downstream. The sediment accumulating above these dams formed the plots for cultivation. We documented five plots (Fig. 3: a–e), all enclosed by stone boundary walls. The plots measure 0.10–0.35 ha and are surrounded by stone walls 0.4–1.1 m thick, built of large and medium field stones. The dams consist of a double wall (upper and lower) perpendicular to the wadi, built of large and medium-size undressed stones, with a fill of soil and small stones in between. Each wall has the width of a single stone. Silt that accumulated in the wadi bed covers much of the top of the upper wall (Fig. 8), while the height of the lower walls reaches as much as 3–4 courses above the level of the loess infill. The fill between the two walls is c. 2 m wide. Carpets of herbaceous vegetation and small shrubs grow at a number of points near the dams (Fig. 4: Field e; Fig. 9) showing that water continues to accumulate here during and after winter flood events.

The field tower (Fig. 3: C) is a stone structure whose external measurements are 3.75 × 4.20 m, standing west of the dam and the field plots (Fig. 3: E, southwest border of plot e). The top of the structure is c. 1.5 m above the ground. It was built higher than the wadi bed and is abutted on the south and the north by boundary walls (Fig. 3: 131, 138; Fig. 10a). At its foot are the remains of a paved stone surface, apparently a front courtyard. The walls of the structure were built of large field stones, dressed on their outer faces, averaging 20 × 30 × 40

Fig. 8. The dam in the wadi (Area E): (a) general view before excavation; (b) two walls and the excavated sections on either side; (c) lower wall (W2); (d) upper wall (W1) (photos: Yotam Tepper).

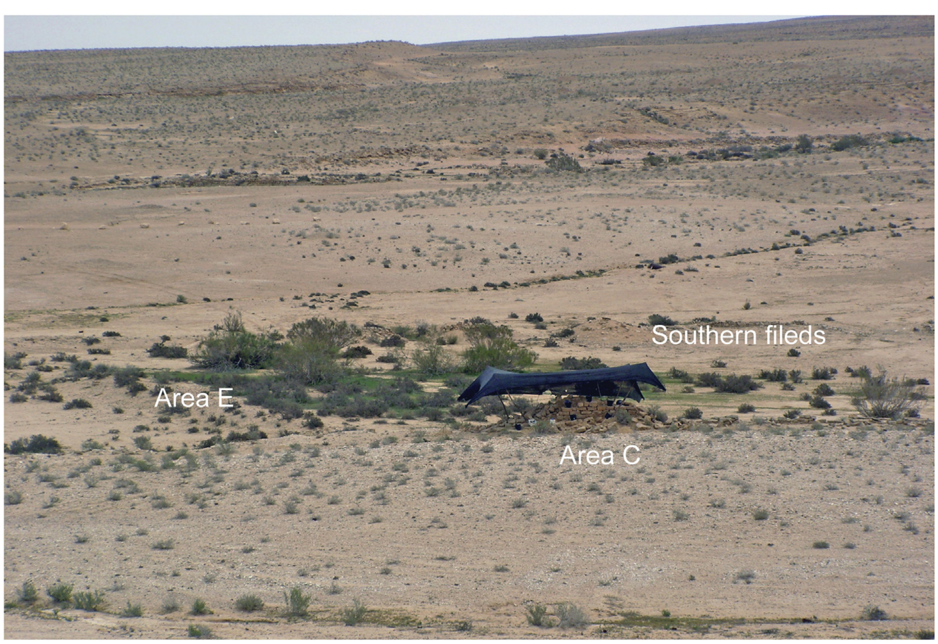

Fig. 9. The field plots in the wadi. Note the patch of vegetation behind the dam (Area E) and the field tower (Area C) (photo: Yotam Tepper).

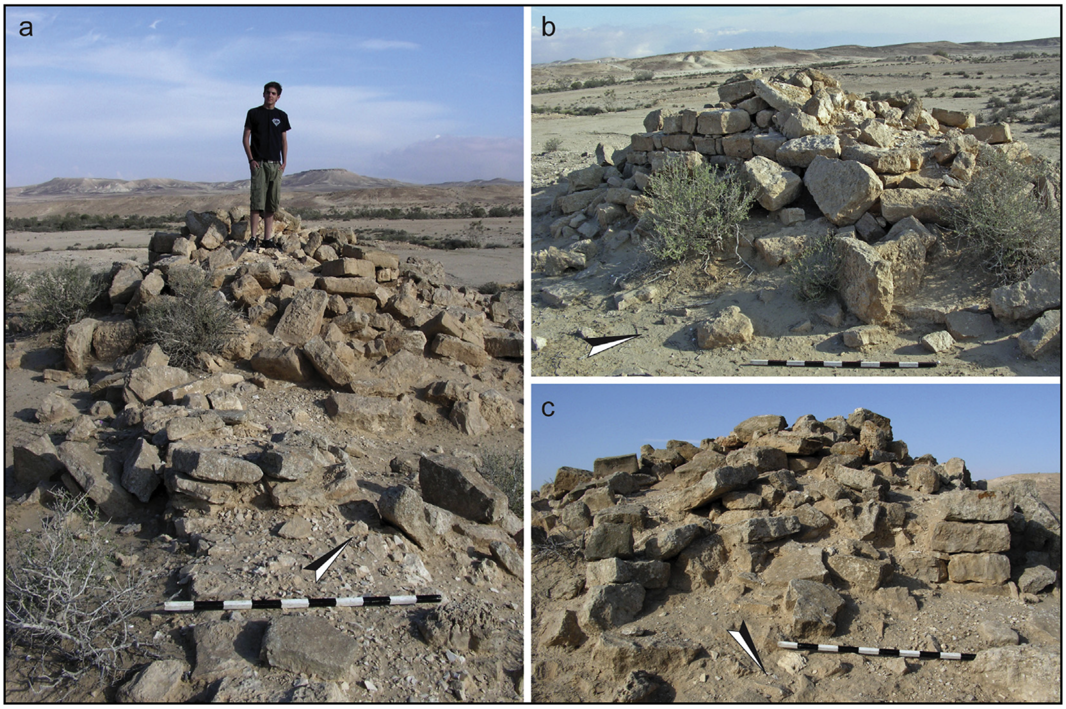

Fig. 10. Field tower: (a) general view; at the bottom of the photo is a stone wall (W138), abutting the tower on the south; (b) the tower's southern wall and scattered fallen stones; (c) northwestern corner of the tower (photo: Yotam Tepper).

cm. The walls are c. 70 cm wide. The northwestern corner has survived to a height of 3–4 courses, and many fallen stones are scattered around it (Fig. 10).

2. Material and methods

We excavated each of these installations (except for the dovecote, see above), each of which is typical of Shivta's agricultural system. From each context we collected archaeological artifacts for dating, and we documented each installation's characteristics and construction method. Since most excavated contexts were poor in archaeological artifacts, we also based the installation's chronology on Optically Stimulated Luminescence (OSL) dating of the sediments. Since the samples were collected from well-stratified archaeological sections (rather than ground drillings), we could assume that we had mapped our results from a clear archaeological-chronological context.

OSL dates the last time a quartz mineral grain was exposed to sunlight (Wintle, 2008), hence its most recent event of deposition. The OSL signal accumulates within the crystal due to environmental ionizing radiation (dose) and it is reset (or bleached) when exposed to sunlight. Signal intensity is measured in the lab and is proportional to time elapsed since resetting and burial, and to the environmental dose. In Israel's arid region, surface sediments are often derived from dust deposits (desert loess), mixed with weathered local bedrock. Very fine, sand-size quartz is abundant in this loess (Crouvi et al., 2008), and has proven highly suitable for OSL dating (Porat et al., 2006; see also: Junge et al., 2016, 2018; Dunseth, at al 2017). Samples were processed using routine procedures in the luminescence dating laboratory at the Geological Survey of Israel (Porat et al., 2012).

Samples for OSL dating were collected from sediments associated with the structures as described below, under suitable conditions to prevent any exposure to sunlight:

2.1. *The stone mounds (Figs. 11–12)*

These were constructed of stones that were piled into a heap on the surface. Over time dust was deposited among the stones; this dust can be used for OSL dating. All dust post-dates construction but the lowermost is the closest in age to that time. Dust from three stone mounds and their underlying surfaces was sampled – two mounds on the western slope and the third some 300 m to the south. Probes were excavated across the mounds down to natural soil-loess. The time of construction can be pinpointed to sometime between the age of the soil and that of the lowermost infiltrating dust.

2.2. *The cistern (Fig. 13)*

Like other water reservoirs, the cistern filled with silt carried in as sediment by surface runoff. This sediment is remobilized surface loess (dust) that had been well bleached on the slopes; the sediment's OSL age is the time of its deposit. When the cistern silted up, it was cleared and the material removed was piled up beside it (Fig. 14). We dug a trench into this sediment pile, exposing roughly 1.5 m of sediment and substrate, and samples were collected down the vertical section. Currently the cistern's floor is covered with ~50 cm of sediment; an additional sample was collected from this sediment to ascertain how well it had been bleached at the time of deposition.

2.3. *The dam and cultivated field (Fig. 15)*

The dam was constructed by building a stone wall, which retained sediment behind it, creating a plot for cultivation. As with the cistern, the sediment on either side of the dam walls was transported by runoff from the slopes, and was probably bleached. As long as the sediment remained on the plot's surface and was plowed, the quartz grains were repeatedly exposed to sunlight and bleached. Only after the next layer was deposited did the OSL signal start to accumulate. Thus the OSL age of the lowest soil bed dates the wall's construction. The section documents subsequent events of soil accumulation (perhaps associated with the addition of courses to the wall). A trench was dug across the wall, exposing ~1.2 m of soil infill behind the wall and reaching the underlying sediment. Three soil samples were collected along the section for OSL dating.

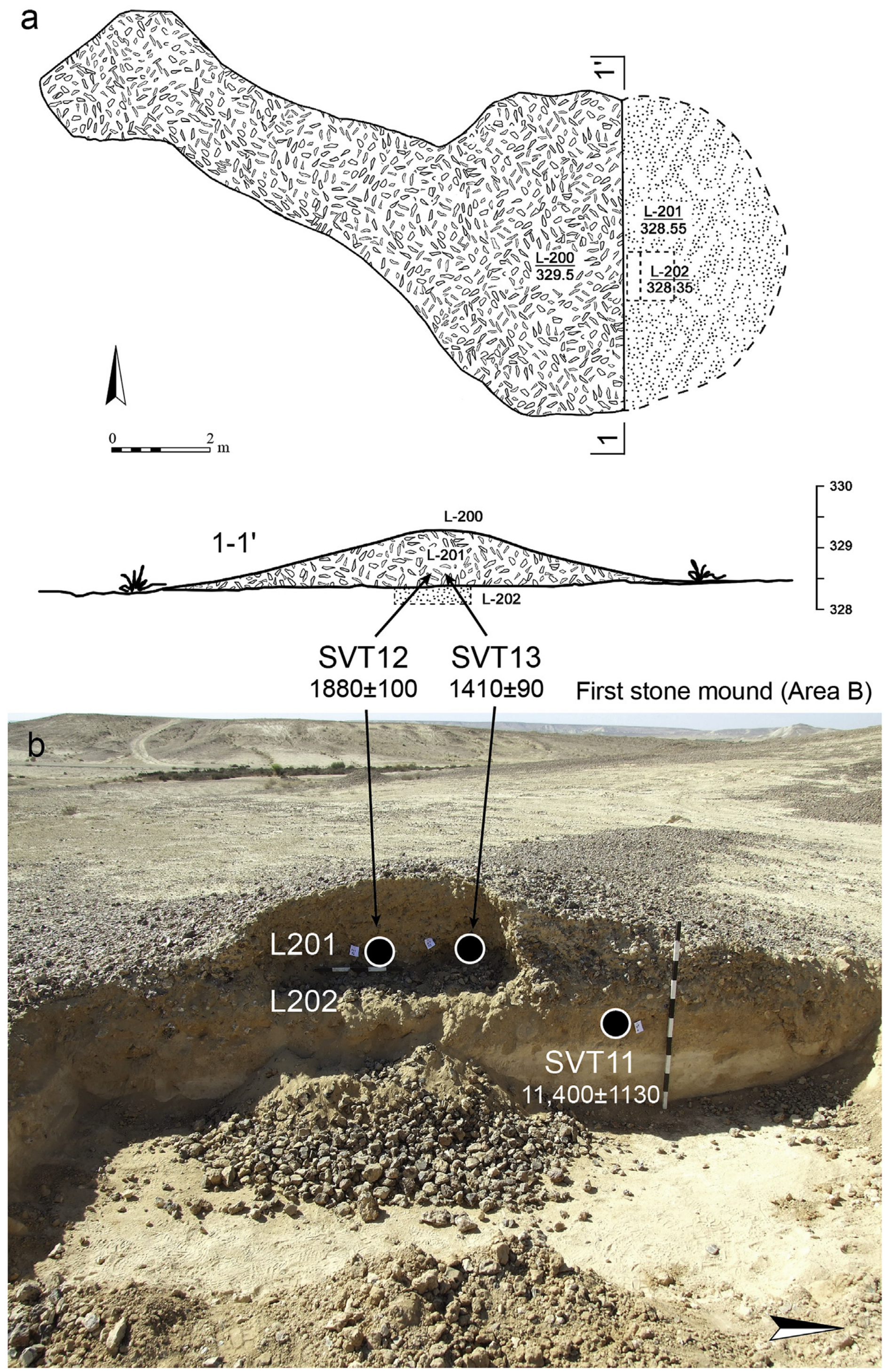

Fig. 11. Plan and section of the first excavated stone mound in Area B (a); and location of the OSL samples (b) (photo: Yotam Tepper; plan: Avi Blumenkrantz).

2.4. *The field tower (Fig. 16)*

We also excavated a probe in the field tower next to the dam, from the top of the heap of stones to the bedrock. Context was dated by archaeological finds.

3. Results

3.1. *The mounds*

The two excavated stone mounds on the southwestern slope are c. 4 m in diameter and c. 1 m above the surface (Figs. 11 and 12b). The probes in each mound showed great similarity in their physical structure; both contained local dust/loess and numerous chert pebbles and gravel. Organic material and archaeological finds were entirely absent. A probe was excavated in the third stone mound (Fig. 12d) north of the reconstructed agricultural system. Sherds from the Byzantine period (6th century CE; Fig. 12c:1–2) were collected from the mound's surface. These three mounds were sampled for OSL dating.

Another stone mound was excavated on the northeastern slope (Fig. 3:D), which was very similar to the others in both its composition of many small and medium-size limestone rocks and in its construction

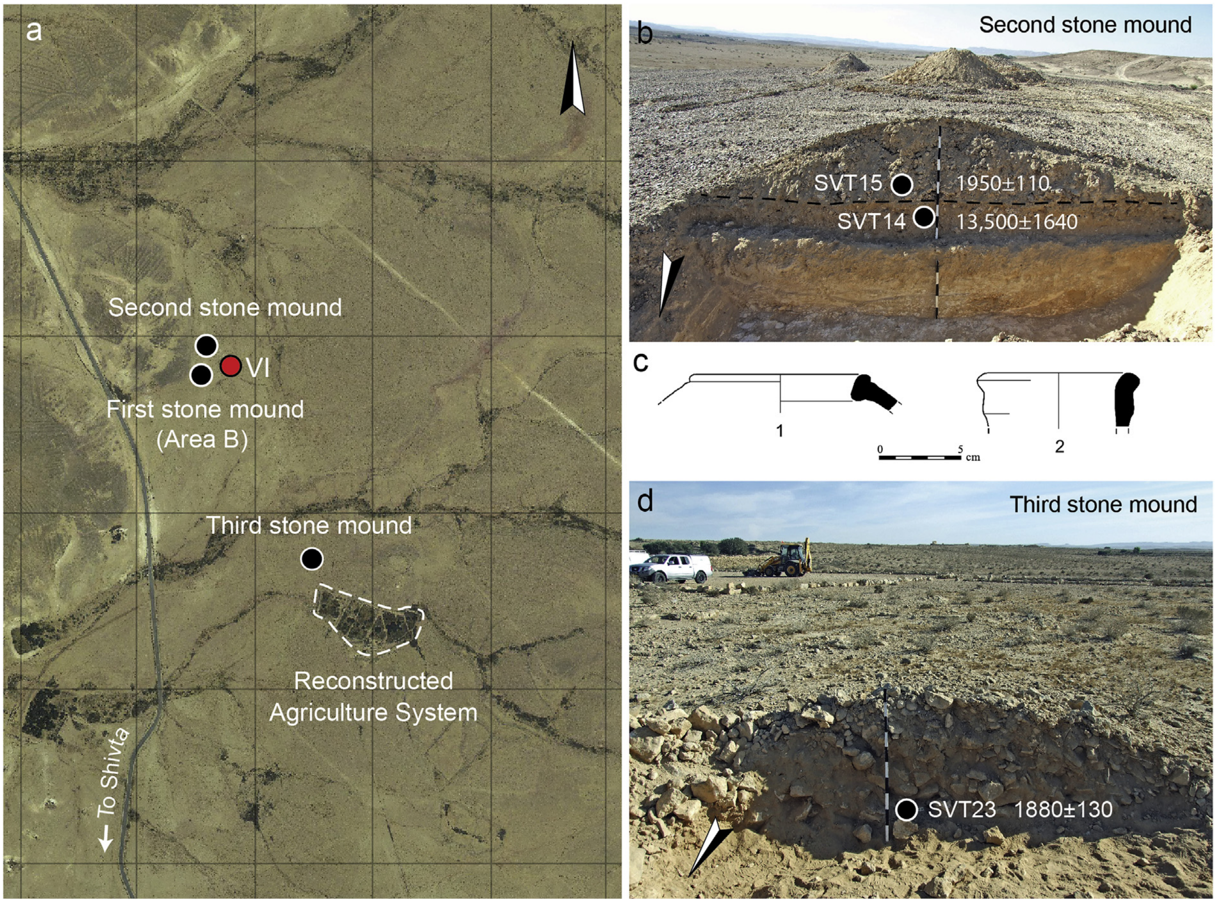

Fig. 12. Location of three excavated stone mounds: first stone mounds (Area B); second stone mounds near Dovecote VI and third stone mounds near the reconstructed agricultural system (Michael Farm) (a); section of second stone mound and location of OSL samples SVT-14-15 (b); Byzantine jars (1–2) found on the surface of the third stone mound (c); and section of the third stone mound and location of OSL sample SVT-23 (d); (source: Aerial photography by PW; photo: Yotam Tepper).

method on the natural bedrock (Fig. 17).

The loess beds underlying the first and second mounds were dated to latest Pleistocene-Early Holocene, 11,400 ± 1130 to 13,500 ± 1640 yr (years before the present). This age is similar to OSL ages obtained from the top of other loess deposits in the Negev Highlands, 14,000–10,000 yr (Faershtein et al., 2016; Crouvi et al., 2008), indicating that the mounds were constructed on natural sediments.

The OSL ages of sediments at the base of the three mounds are (1st–2nd to 6thcenturies CE) Roman to Late Byzantine periods (Table 1) providing a minimum age for their construction. The age of the youngest sample (SVT-13, 1410 ± 90 yr; 520–700 CE) from the second mound might be underestimated as its dose rate is much higher than all other samples while its De value is the same as sample SVT-12 (1880 ± 100 yr; 30–230 CE) from the same stratigraphic level, thus resulting in a younger age. The sediment sample collected for dose rate evaluation from SVT-13 might not have been representative of the gravel-dust mixture, and could have been biased toward the fine-grain fraction, which has a much higher dose rate than the accompanying interbedded chert pebbles.

3.2. Dam and field plots

Four probes were excavated mechanically in the field plot below the dam (probes 1–2) and above it (probes 3–4; Fig. 18; see also Fig. 3–E. nos. 1–4). In probes 3 and 4 a gray layer of organic material was found down to a depth of 0.2 m. Beneath it was a layer of loess of uniform color, and the stratification of the wadi bed was reached at a depth of c. 0.5–0.7 m. The loess layer in all four probes revealed neither sherds nor other datable organic material. In the southern field above the dam a few pottery vessels – a fragment of an amphora and a bowl – were collected from the surface layer, dating to the Byzantine period (Fig. 18b:1–2).

In addition, a section was excavated across the dam as well as the loess above and below it. A layer of dark soil rich in organic material, c. 0.1 m thick, was found above the dam (Fig. 15: L503; see also Fig. 8d). Beneath it a uniform layer of loess was excavated to a depth of 1.2 m. The dam's upper wall (Fig. 15: W1) was built of local dressed and undressed stones (average size 15 × 20 × 30 cm). The lower wall (Fig. 15: W2) was uncovered to a depth of 0.9–1.0 m, revealing 5–7 courses of dressed and undressed stones (of similar sizes; Fig. 15a).

A few sherds in the upper part of the excavated sections (L503) near the dam (Fig. 15b:1–2) were dated to the Byzantine and Early Islamic periods (6th–7th centuries CE). They had apparently accumulated with the sediments covering the upper parts of the wall (W1) at a relatively late phase in the history of the dam, certainly post-dating its construction.

Three OSL samples were taken from the excavated section across the dam (Table 1, Fig. 15). The ages range from the second half of the 4th century CE at a depth of 45 cm to the 12th and 8th centuries BCE at a depth of 115 cm (Table 1). The oldest sample (SVT-19, 2960 ± 210 yr; 1150–730 BCE) was taken from between two beds of wadi material (pebbles and small stones: L1–2 in Fig. 15d), which probably predates the construction of the dam by significant flood events.

The wall's OSL ages suggest that the dam was built in several stages. First, the lower wall (W2), which pre-dated the 3rd century CE, was

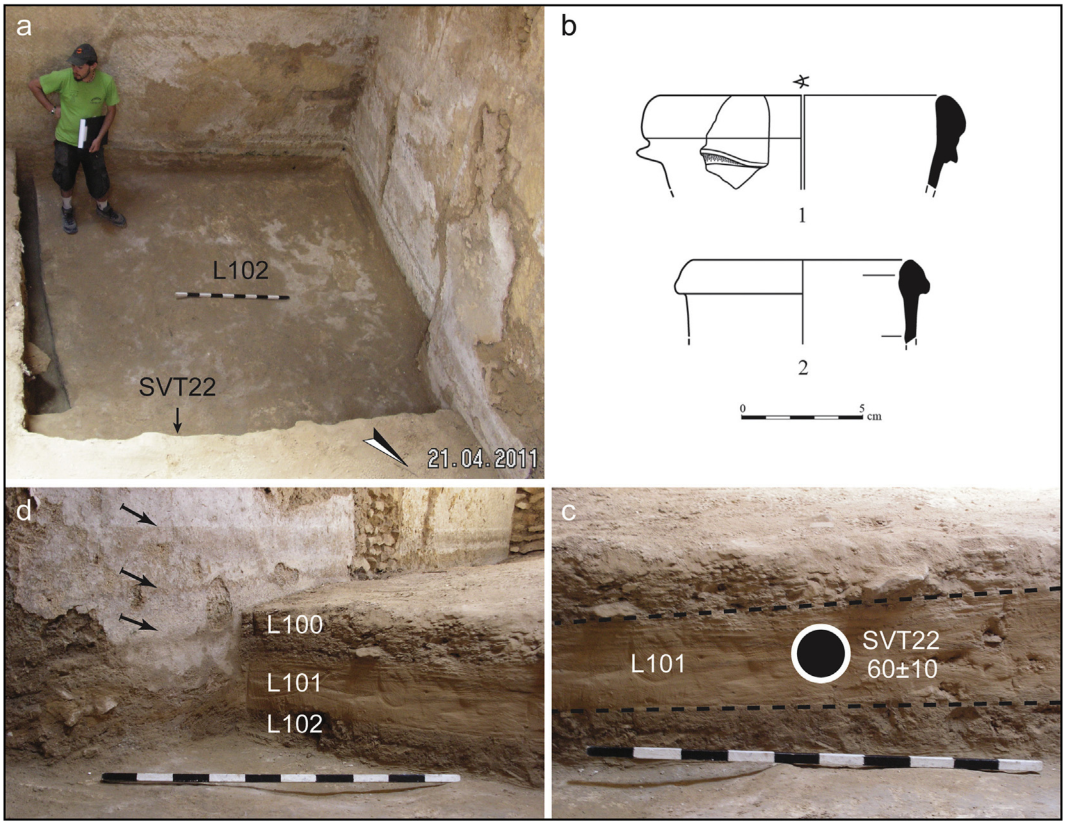

Fig. 13. Excavated probe on the floor of the cistern (a); 20th-century CE Gaza ware jars (1–2) (b); location of the OSL sample (c); and marks left by water level as seen on the plaster of the cistern wall (marked with arrows) (d); (photo: Yotam Tepper).

built. By that time loess had begun to accumulate in the field plot above it. As accumulation continued, W2 was built higher to accommodate the additional silt. This process continued until the 4th century CE at the latest. Later the dam's upper wall (W1) was built and loess has continued to accumulate covering its top.

3.3. The cistern and mound of sediment

An engraved cross was documented in the upper part of the cistern, near the northwestern corner opposite the eastern opening, 3.5 m above the floor. The cross (Fig. 19e and f), was engraved in a square frame resembling a capital. It was carved in high relief and is flanked by palm trees. This finding supports dating the use of the cistern to the Byzantine period.

A 3 × 3 m probe was excavated in the cistern's northwest corner (Fig. 13a; 19a-b,d), below the cross (Fig. 19f). On the cistern's floor we documented remnants of gray plaster resembling the plaster on the walls. Signs of quarrying in the cistern's floor and walls show that building stones were removed when the cistern was dug. Three main layers were documented, including sherds dating to the 20th century (Fig. 13b: 1–2), indicating that the cistern was used until recent times. A recent OSL age of ~60 yr (Fig. 13c; Table 1: SVT-22) was obtained for a sediment sample from the base of this fill, supporting the pottery dating and indicating that the cistern was cleaned sometime in the 20th century and that sediment entering the cistern is well bleached.

A stratified mound of silt removed from the cistern during its cleaning and maintenance had accumulated near the exit of the cistern (Fig. 14). A trench dug from the top of the mound to the natural surface (Fig. 14b) revealed layers of loess mixed with small and medium-size stones, with no datable material (Fig. 14d). A few 20th-century pottery vessels were found on top of the mound (Fig. 14c: 1–2).

Two OSL ages from samples taken from this mound (Fig. 14d) at a height of 0.5 m and 1.0 m above the natural surface revealed that these sediments were stratified during the Ottoman period (Table 1: SVT17–18; 320–380 years ago). This attests to episodes of clearing the cistern during the last few centuries, and accords with the very young age of the sediment in the cistern. The base of the clearing pile gave an unexpectedly old age (SVT-16, 20,000 ± 3,500 yr); this sample is similar to ages of loess in the Negev Highlands.

3.4. Field tower

A probe was excavated across the western part of the field tower (Fig. 16a). The southern side of the probe was excavated down to bedrock that had apparently been leveled by fairly careless hewing. The tower's walls, and an engaged column uncovered in the middle of the southern wall were built on bedrock. Above the bedrock was a layer of compacted loess and above that layer the floor of the structure (Fig. 16c). The floor was made of thin stone slabs on which was a layer of compacted loessy soil c. 20 cm thick. A probe about 1 m deep revealed large and medium-size fallen stones on top of this soil. The inner face of the walls was built of small stones, measuring on average 20 × 30 × 15 cm. No opening was found in the western part of the structure; the doorway probably faced east toward the adjacent agricultural area. The northern part of the probe was excavated only to the top of the layer of collapsed stones. On the line of the engaged columns and the collapsed layer an arched wall that had collapsed with the roof was found, made from local chalk. The average size of the stones is 20 × 35 × 50 cm and they are trapezoid in section. Large, flat stone slabs made of local hard limestone used for roofing were also found in this layer, measuring 7 × 50 × 105 cm and 7 × 70 × 130 cm. On top of the collapsed layer a hearth was documented, attesting to a temporary presence postdating the abandonment of the structure.

A few fragments of pottery vessels found above the tower floor were

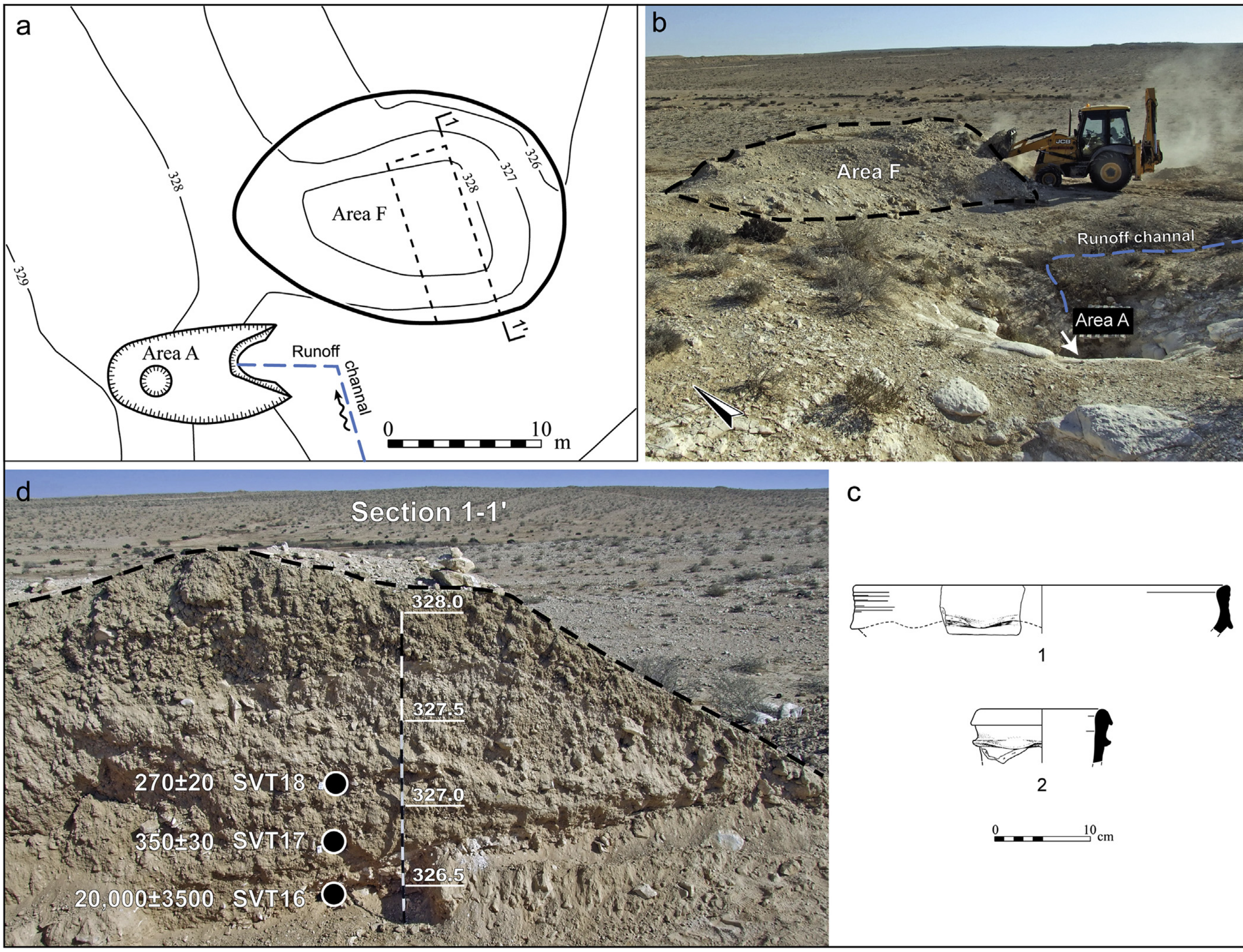

Fig. 14. Plan of the cleaning sediment pile next to the cistern (a); direction from which the surface runoff channel enters the cistern (b); Gaza ware vessel, including krater (1) and jar (2) dated to the 20th century CE (c); and location of OSL samples (d); (photo: Yotam Tepper; plan: Avi Blumenkrantz).

dated to the Byzantine period, including a few fragments of pottery pipes (Fig. 16b:1–2; resembling those found in the dovecote, see Fig. 7c:4) and cooking pot (Fig. 16b:3). The structure apparently collapsed due to a destruction event, perhaps an earthquake (Hirschfeld and Tepper, 2006). Similar finds indicating an earthquake at the end of the Byzantine period have been discovered in other contexts in Shivta (Tepper et al., 2018a).

4. Discussion

This agricultural endeavor was part of a broader regional phenomenon (Rubin, 1996) typical of Provincia Palaestina and Arabia (Cameron, 2012: 168–190; Avni, 2014: 35–37; but see also Haiman, 1995), which was also documented in areas on the edge of the desert in North Africa (Barker, 2002). Historical data show that the growing prosperity in this period (2nd–6th centuries CE) in the Negev was increased by the imperial government, which strengthened the defenses of the frontier in Palaestina Tertia and the status of the Dux Palaestinae as commander of the army. The dux granted land to veterans and enhanced the status of the Church (Rubin, 1996). An atmosphere of increased prosperity is also evinced by archaeological research and an analysis of inscriptions found in Shivta (Di Segni, 1997: 813–853; Hirschfeld, 2003a, 2003b: 17).

The extent of the agricultural activity around Shivta indicates a need for cooperation and a system of rules (see also Baumgarten, 2004: 19). A guiding hand on the part of the government and the Church seems present. These institutions were skilled in organizing and distributing land so as to ensure proper dispersal of the resources of soil and runoff to maintain agriculture on the desert's edge. Once established, these agricultural systems required ongoing operation and maintenance, and investment of time and resources. However, this is what enabled agriculture to flourish and its products to be marketed beyond the Negev.

The distribution of agricultural systems around Shivta, particularly the fact that they abutted each other on the watersheds, further indicates administration by a central government or local religious leadership related to one of the churches or the nearby convent at the site (Hirschfeld, 2003), which was necessary for demarcating the boundaries between the plots of the various landowners. Knowledge of distribution of local drainage basins among farmers is therefore important for understanding the village environment in Shivta, and in other Negev sites. Land distribution is also mentioned in the Nessana Papyri (512–689 CE: Kraemer, 1958). For example, Papyri 31–32 are contracts that divide assets, including land, and mention cultivated areas and a cistern in village surroundings. These documents also refer to marking boundaries between adjacent plots, using physical human-made elements, such as stone walls and surface runoff-harvesting channels like those identified in the agricultural landscape around Shivta.

The results of this study indicate that the beginning of construction of the first components of this agricultural system should be dated not

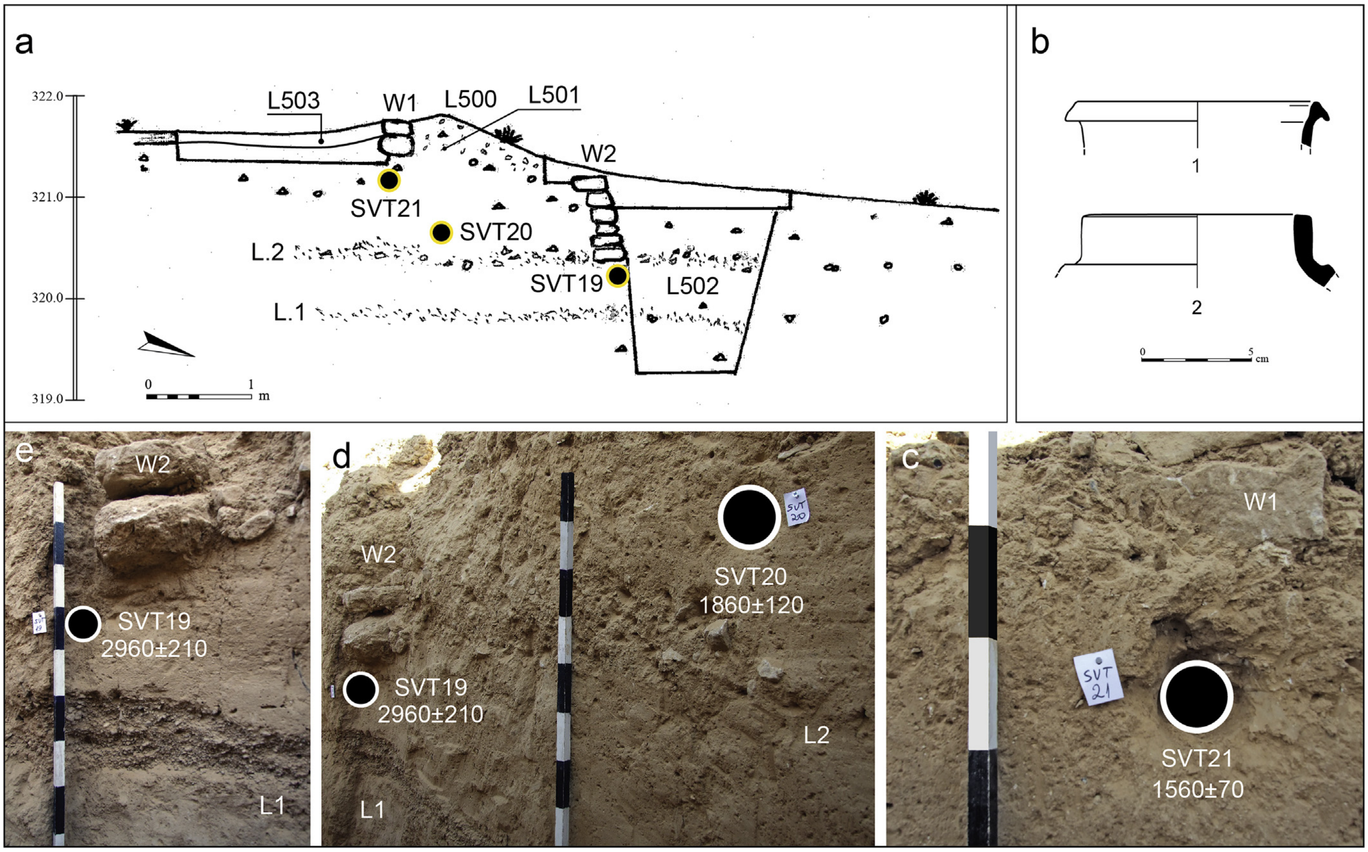

Fig. 15. Section across the dam (a); Byzantine cooking pot (1) and Early Islamic jar (2) (b); location of OSL samples and the levels of stones L1–2 (c–e); (photos: Yotam Tepper; section: Avi Blumenkrantz).

before the Roman period at the 1st century CE (Fig. 20). We demonstrated that the slopes were raked and the mounds were created as the first step in the construction of this agricultural system (their construction continued throughout the period, probably as part of an ongoing process). In that initial period, the dams were built in the wadi to catch the surface runoff. This process continued until the 4th–late 6th centuries CE. We suggest that when the mounds were created they provided a large quantity of erodible soil for the plots demarcated in the wadi (*sensu* Kedar, 1957a). The overlapping of the mound ages with the time the dam was founded attests to its establishment over a similar time range. We also note that the dam was built in late Roman period and the loess accumulated above it as long as the system is maintained, at least until the late Byzantine period. The pottery retrieved from the excavation of the dam and the surface layer of the field plots was dated to the Byzantine period, and no later than the 7th century. During this time all the elements of the system were coordinated and operated simultaneously.

The thick loess soil that accumulated behind the artificial dams is essential for the survival of flora in the desert. Research conducted at the Avdat Farm and the Michael Farm near Shivta found that in agricultural fields in which over 1 m of loess had accumulated, the water percolated to deeper levels, increasing its availability for vegetation for most of the year (Kedar, 1957a; Evenari et al., 1982: 237; Avriel-Avni et al., 2019). Thus, the construction of dams in the small wadis, and enhanced soil erosion on the slopes, resulted in a significant column of soil stored behind the dams. The accumulation of loess over time necessitated the raising of the dam's wall to allow runoff accumulation above the dams. Flooding the plots with runoff by increasing water harvest in this manner was the optimal way to adapt natural environmental conditions to human needs.

Construction of the agricultural system was dynamic and required ongoing annual maintenance and conservation. Other work included surrounding the field plots with stone walls, building a field tower, quarrying permanent water cisterns and construction of dovecotes. All these occurred during the 5th–6th centuries CE and demanded prodigious effort and additional resources to create optimal conditions for intensive agriculture.

The four dovecotes documented in the agricultural areas around Shivta (Fig. 2) provided the ideal habitat for thousands of pigeons, which in the course of a year produced thousands of liters of manure. The location of the dovecotes, hundreds of meters away from the settlement in the heart of the cultivated plots, supports the hypothesis that dung was used as fertilizer to support intensive orchard and vineyard agriculture in this region (Hirschfeld and Tepper, 2006; Tepper et al. 2017, 2018b; Marom et al., 2018).

The excavation of the dovecote south of Shivta revealed evidence that it was built as early as the 2nd century CE (Hirschfeld and Tepper, 2006; Ramsay et al., 2016). This date was found to conform to the time of the initial construction of the agricultural system under discussion here (the mounds and the dam). This dovecote, along with others excavated in the environs of the village, was also operational in the Byzantine period (Tepper et al., 2018b). We can thus suggest that the time of the most intensive fertilizer-based runoff agriculture in the rural-agricultural area around Shivta was the Late Roman and the Byzantine periods (4th–6th centuries CE). Our archaeological research shows no datable findings to support the theory that some agricultural activity in this area started before the 1st century CE or continued into the Early Islamic period, 8th–9th centuries CE (Avni et al., 2013).

The excavated cistern and its associated mound of soil indicate that the cistern was in use in the modern era. In light of the numerous cisterns around Shivta dated to the Roman and Byzantine periods (Baumgarten, 2004: 15–16), it may be postulated that this cistern was

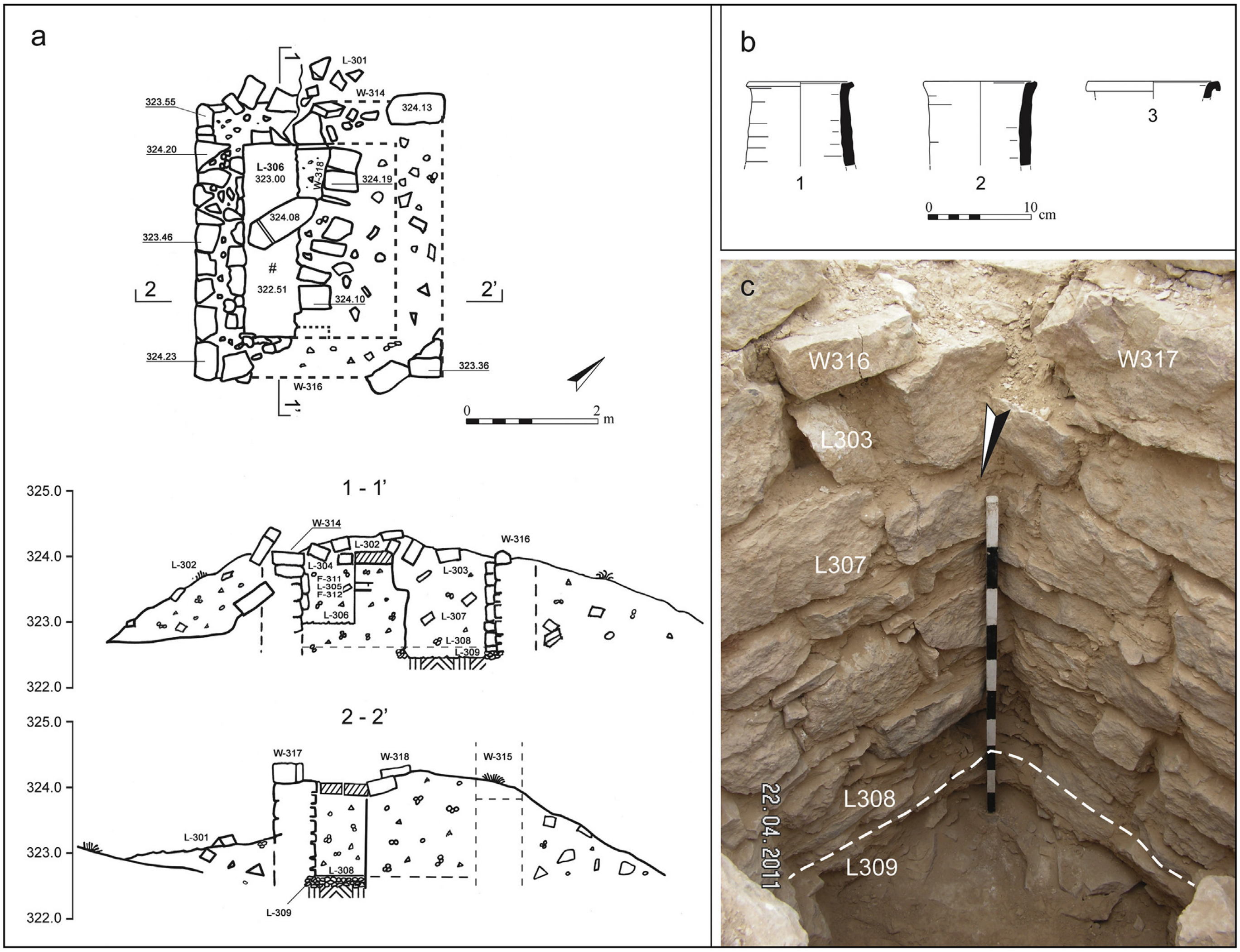

Fig. 16. Plan of the field tower (a); Byzantine pottery vessels: pipes (1–2) and cooking pot (3) (b); and view of the corner of the structure (white dotted line specifies location of the floor) (c); (photo Yotam Tepper; plan: Avi Blumenkrantz).

also an integral part of the local Byzantine agricultural system. The cross incised on the cistern wall (Fig. 19f), and another incised on a stone lintel in the nearby dovecote (Fig. 7b), substantiate this view. Support for this dating is provided by another, similar lintel decorated with a cross and flanked by palm branches found in the atrium of the northern church at Shivta (dated to the 6th century CE: Segal, 1988: 36, 144). Birds, apparently doves, a cross and stylized rosettes decorate the lintel above the doorway of the southern aisle in that same church (Segal, 1988: 34). Doves among grapevines and clusters of grapes were found on a decorated lintel in the southern church (dated to the 6th century: Di Segni, 1997: 823). These decorations in the Shivta churches parallel the Christian motifs in the cistern and dovecote, and may attest to construction or renovation of these installations by Christian entities or under their ownership.

The importance of maintaining the reservoirs at Shivta as part of public works, apparently under Christian or Church ownership or supervision, is underscored by the discovery of an ostracon mentioning the cleaning of a cistern at Shivta before the beginning of the rainy season (Youtie, 1936).

Another component of the Byzantine agricultural system is the field towers that were found by the dozen over the entire Shivta hinterland (Baumgarten, 2004: 14–21). Inside the one that we excavated we found several pottery vessels that date the structure to the Byzantine period (Fig. 16b). Our excavation provides tentative support for the possibility that the tower collapsed due to an earthquake, the same one that we proposed had felled the nearby dovecote (earthquakes in the region were recently reviewed by Zohar et al., 2016). We note a burned layer discovered in another field tower excavated east of Shivta and dated to the 6th century CE (Hirschfeld and Tepper, 2006). It provides additional evidence for the decline process of the agricultural system near Shivta before the 7th century CE (Ramsay et al., 2016; Tepper et al., 2018a; see also: Tepper et al., 2015).

The results of our research contribute to the ongoing debate regarding the rise and fall of desert agriculture in the Negev. Though our research was on a small scale, zooming in on one agricultural system allowed us to better determine the timing of construction of each of its components. Based on OSL ages of sediments and archaeological artifacts, we have shown that the main phase of the desert agriculture took place in Byzantine times (no later than the 6th – beginning of the 7th century CE). The maintenance of such an intensive agricultural system would have required constant investment of labor, which included repair of dams, reconstruction of floodwater channels and annual maintenance of cisterns and pigeon towers. We would have expected to find evidence for such large-scale anthropogenic impact if it had persisted in post-Byzantine times. But the only post-Byzantine evidence dated dust accumulation in mound no. 1 to the 6th – late 7th century CE; after that, the only evidence for continued use of the cisterns is from the modern area. These results are in accordance with our research in a nearby

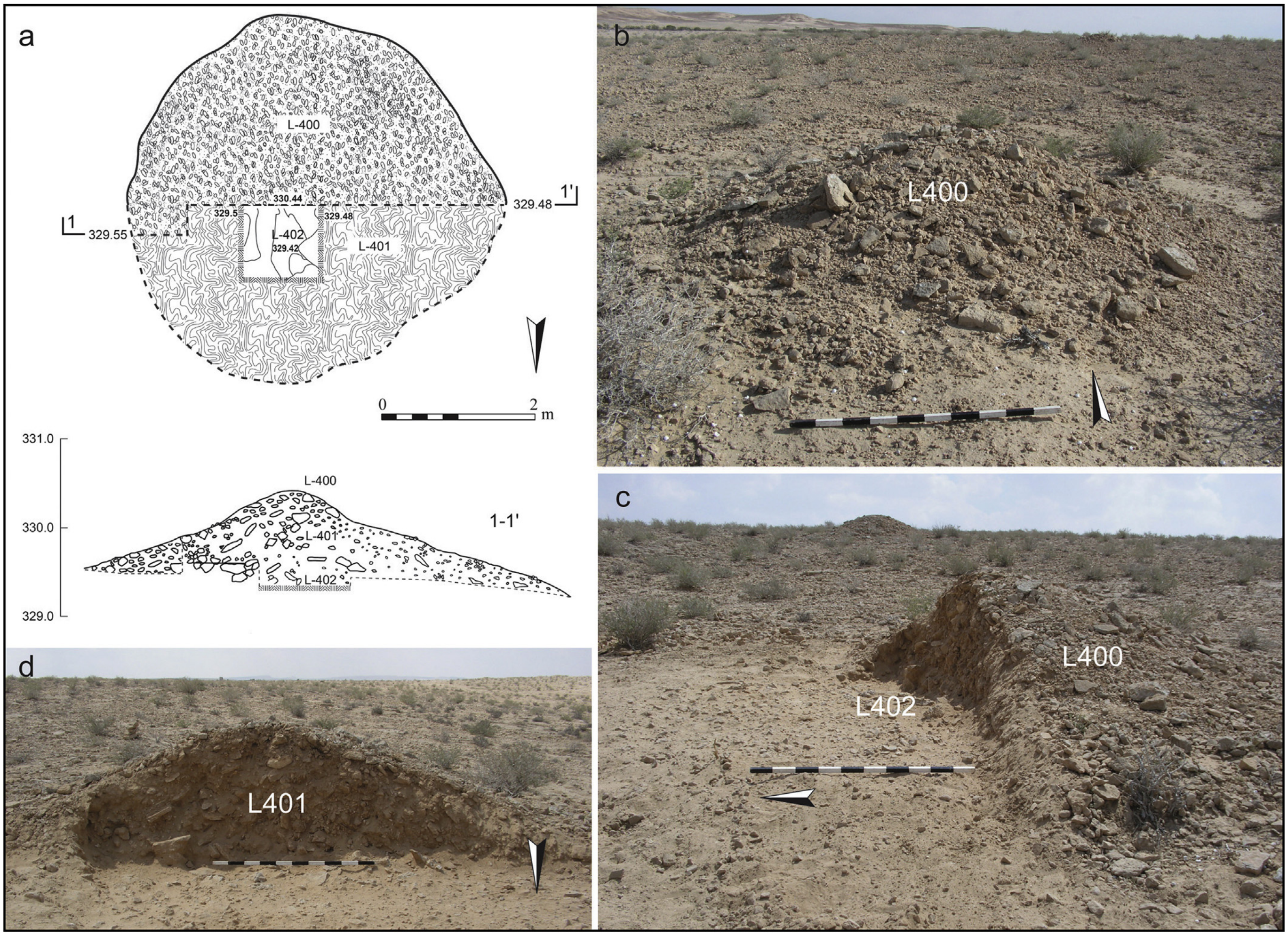

Fig. 17. Plan and section of the stone mound in Area D (a); general view of the stone mound (b); section excavated in the mound, looking east (c); and south (d); (photos Yotam Tepper, plan: Avi Blumenkrantz).

Table 1
OSL field data and ages.

Lab code	Description	Dose rate (μGy/a)	No. aliquots	OD (%)	De (Gy)	Age (years b. 2016)	Calendar years
First mound – 2011							
SVT-11	Loess below the mound	1989 ± 63	17/19	53	23 ± 2	**11,400 ± 1130**	**10,500–9240 BCE**
SVT-12	Dust from base of mound, between stones (lower)	2232 ± 88	18/18	14	4.2 ± 0.2	**1880 ± 100**	**30–230 CE**
SVT-13	Dust from base of mound, between stones (upper)	2982 ± 137	17/19	26	4.2 ± 0.2	**1410 ± 90**	**520–700 CE**
Second mound – 2016							
SVT-14	Loess below the mound	1940 ± 102	18/19	66	26 ± 3	**13,500 ± 1640**	**13,130–9850 BCE**
SVT-15	Dust from base of mound, between stones	1813 ± 66	19/19	17	3.5 ± 0.1	**1950 ± 110**	**70–180 CE**
Third mound (bustan)							
SVT-23	Dust from base of mound, between stones	1299 ± 53	15/18	48	2.5 ± 0.1	**1880 ± 130**	**5 BCE–270 CE**
Cistern							
SVT-16	Cleaning pile, lower unit (digging pile?)	895 ± 31	19/19	74	18 ± 3	**20,000 ± 3500**	**21,430–14,530 BCE**
SVT-17	Cleaning pile, middle unit	1286 ± 47	18/19	32	0.45 ± 0.03	**350 ± 30**	**1640–1700 CE**
SVT-18	Cleaning pile, upper unit	1272 ± 47	16/19	41	0.34 ± 0.02	**270 ± 20**	**1730–1770 CE**
SVT-22	Sand layer –Cistern infill	1386 ± 48	19/19	48	0.09 ± 0.01	**60 ± 10**	**1945–1960 CE**
Trench on field dam							
SVT-19	Below lowermost stone – under W2 (lower wall)	1589 ± 58	19/19	28	4.7 ± 0.3	**2960 ± 210**	**1150–730 BCE**
SVT-20	Base of soil fill under dam (above L1)	1558 ± 52	17/18	27	2.9 ± 0.2	**1860 ± 120**	**30–270 CE**
SVT-21	Below lowermost stone – under W1 (upper wall)	1540 ± 51	16/19	35	2.5 ± 0.1	**1560 ± 70**	**360–500 CE**

For analytical details see Supplementary Table S1.

runoff farming system in Nahal Zeitan (Zetan; Tepper and Bar-Oz, 2019), in the agricultural installations of nearby Sa'adon (Tepper et al., 2018b) and in the eventual decline and abandonment of urban municipal management in the Late Byzantine Negev (Bar-Oz et al., 2019).

As noted, contrary to the excavation results that date the construction, use and abandonment of the agricultural system to the Roman and Byzantine periods, the cistern was apparently cleaned and utilized in later periods right up to modern times. This remnant of a Byzantine agricultural system was exploited to water the flocks of desert nomads long after the farmers of Byzantine Shivta were gone (see

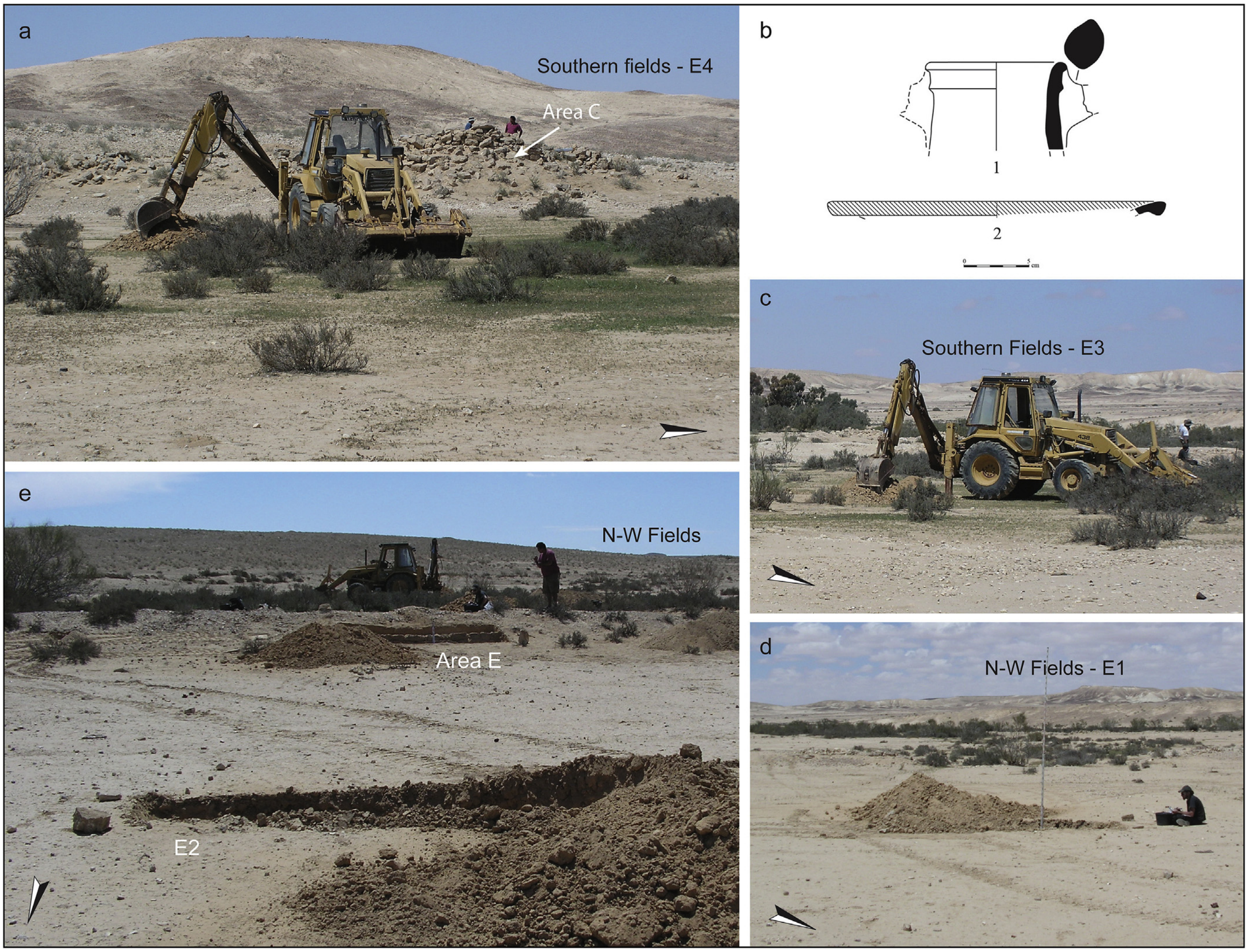

Fig. 18. The field plots in Area E (a); Byzantine pottery vessels: amphora (1) and a bowl (2) found in the field (b); and excavated probes (d and e); (photos: Yotam Tepper).

also: Junge et al., 2018). All other elements of this unique agricultural system were left deserted. The magnificent sustainable agriculture that made parts of the desert greener was thereafter forgotten until modern times.

5. Concluding remarks

The results of this study show for the first time the way the elements of this ancient agricultural system were synchronized. The first human-made components were established in the Roman period (as early as the 1st century CE) and the system reached its height in the Byzantine period (5th–6th centuries CE) before the abandonment of the dovecote (mid 6th century CE). At that time all the components of the agricultural system operated together at an optimal level to develop the high water availability that facilitated intensive agriculture.

The system operated successfully on four levels: (1) it harvested silt and eroded top-soil for the plots above the dams; (2) it harvested and channeled runoff to the field plots above the dams and to the cistern on the slope; (3) it raised a large flock of pigeons to produce fertilizer; (4) it created optimal agronomic conditions for the cultivation and improvement of orchards and vineyards. We believe that these activities, which supported and complemented each other, led Byzantine agriculture to flourish and prosper.

The complex and sustainable agricultural system described above is not unique. Similar systems are common in the hinterland of Shivta and other Roman-Byzantine settlements in the Negev. The agricultural system in the Shivta hinterland is a prime example of its farmers' amazing skill and their broad expertise in synergizing all these agricultural installations to produce sustainable agriculture in an arid environment.

Author contributions section

Yotam Tepper: Conceptualization, Methodology, Investigation, Visualization, Writing - Original Draft, Writing - Review & Editing.; **Naomi Porat**: Methodology, Resources, Writing - Review & Editing, & Editing.; **Guy Bar-Oz:** Conceptualization, Resources, Writing - Review & Editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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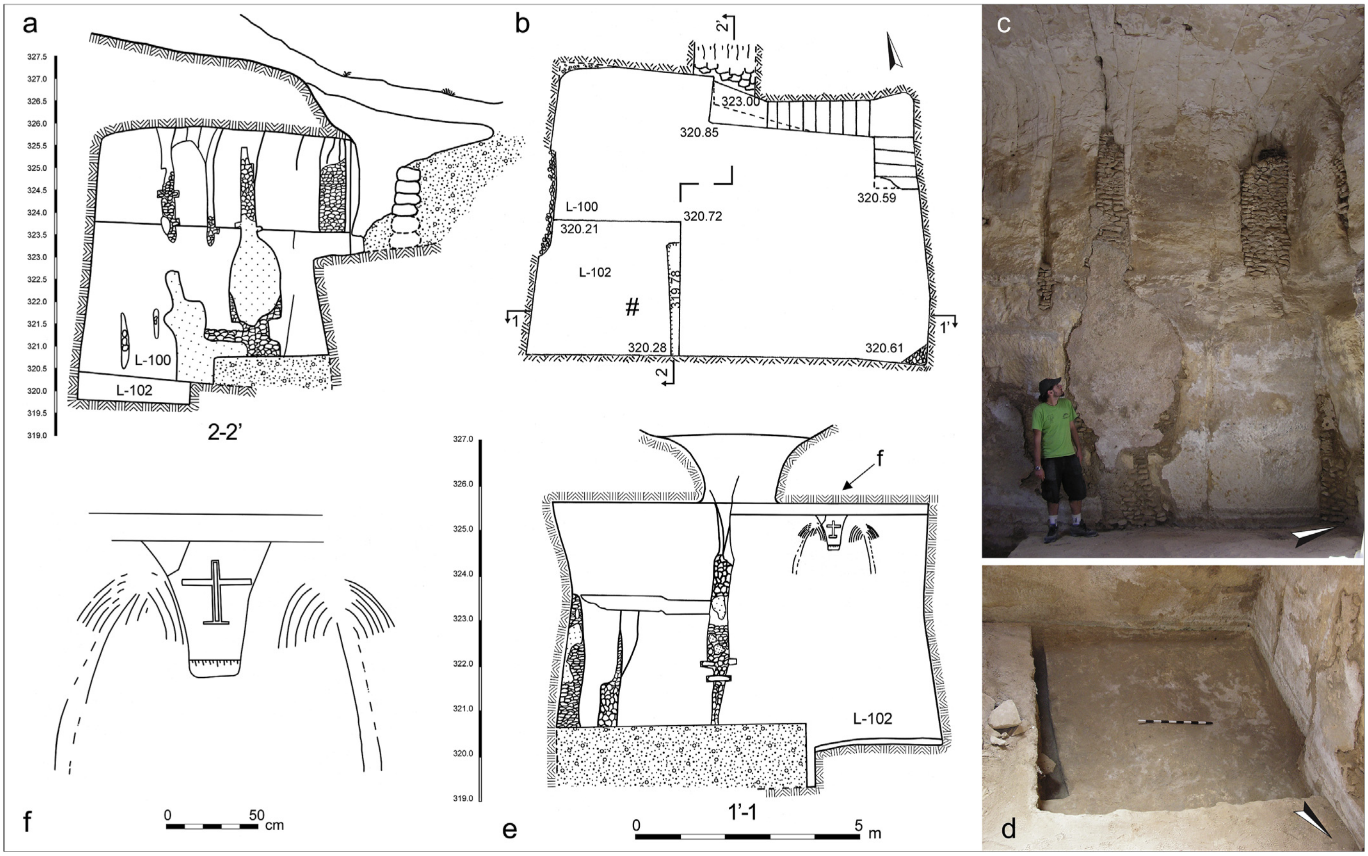

Fig. 19. Plan and sections of the cistern (a–b, e), excavation probe and western wall of the cistern (c–d), incised cross and date palms on the western wall (e–f; photo: Yotam Tepper; plan: Avi Blumenkrantz).

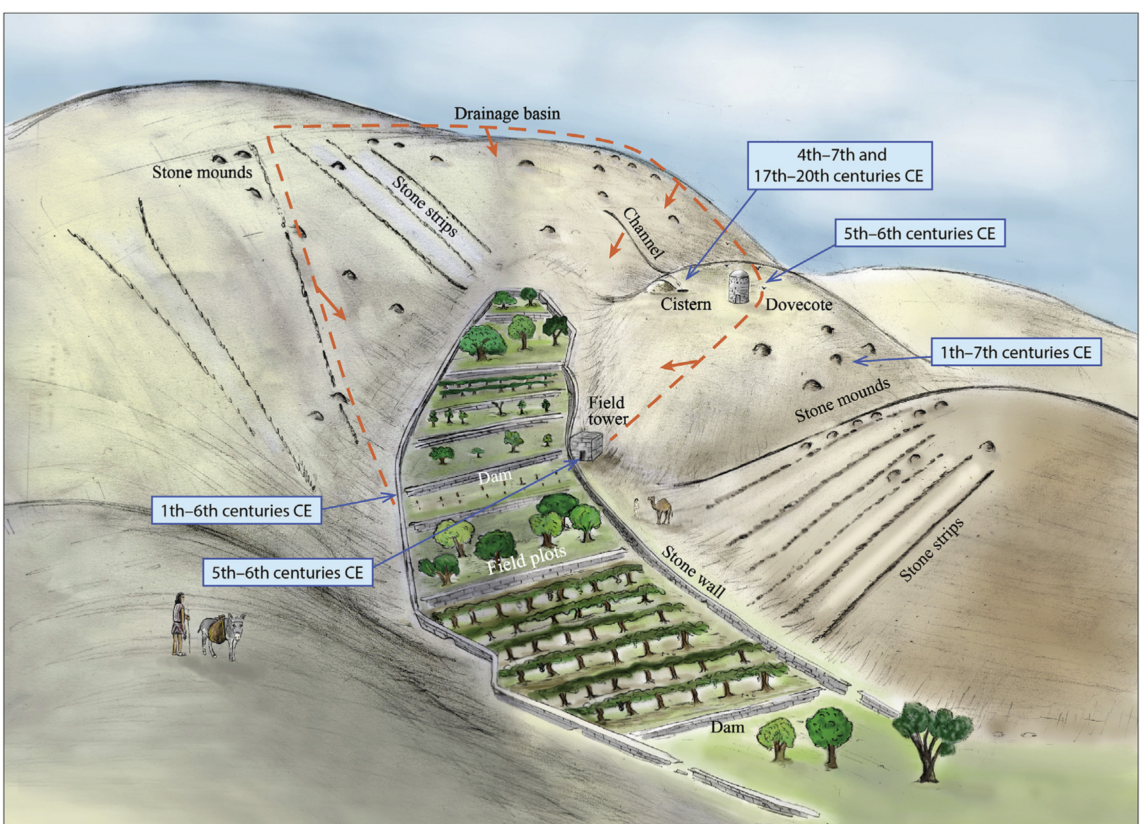

Fig. 20. Artist's reconstruction of the agricultural system near Shivta, facing south (drawing: Sapir Haad).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jaridenv.2020.104134.

References

Ackermann, O., Zhevelev, H.M., Svoray, T., 2019. Agricultural systems and terrace pattern distribution and preservation along climatic gradient: from sub-humid Mediterranean to arid conditions. Quat. Int. 502, 319–326.
Arjava, A., Buchholz, M., Gagos, T. (Eds.), 2007. The Petra Papyri III. ACOR Publications 5), Amman.
Ashkenazi, E., Avni, Y., Avni, G., 2012. A comprehensive characterization of ancient desert agricultural systems in the Negev Highlands of Israel. J. Arid Environ. 86, 55–64.
Avni, D., 1996. Nomads, Farmers, and Town-Dwellers: Pastoralist-Sedentist Interaction in the Negev Highlands. Sixth–Eighth Centuries CE, Jerusalem.
Avni, G., 2008. The Byzantine-Islamic transition in the Negev: an archaeological perspective. Jerus. Stud. Arabic Islam 35, 1–26.
Avni, G., 2014. The Byzantine–Islamic Transition in Palestine: an Archaeological Approach. Oxford.
Avni, G., Rosen, S.A., 1993. The edge of the empire: the archaeology of pastoral nomads in the southern Negev highlands in Late Antiquity. Biblic. Archaeol. 56, 189–199.
Avni, Y., Porat, N., Avni, G., 2012. Pre-farming environment and OSL chronology in the Negev highlands, Israel. J. Arid Environ. 86, 12–27.
Avni, G., Porat, N., Avni, Y., 2013. Byzantine-Early Islamic agricultural systems in the Negev Highlands: stages of development as interpreted through OSL dating. J. Field Archaeol. 38, 332–346.
Avni, Y., Porat, N., Plakht, J., Avni, G., 2006. Geomorphic changes leading to natural desertification versus anthropogenic land conservation in an arid environment: the Negev highlands, Israel. Geomorphology 82, 177–200.
Avni, Y., Porat, N., Avni, G., 2019. A review of the rise and fall of ancient desert runoff agriculture in the Negev highlands: a model for the southern Levant deserts. J. Arid Environ. 163, 127–137.
Avriel-Avni, N., Avni, Y., Babad, A., Meroz, A., 2019. Wisdom dwells in places: what can modern farmers learn from ancient agricultural systems in the desert of the southern Levant? J. Arid Environ. https://doi.org/10.1016/j.jaridenv.2018.11.009.
Barker, G., 2002. A tale of two deserts: contrasting desertification histories on Rome's desert frontiers. World Archaeol. 33, 488–507.
Bar-Oz, G., Weissbrod, L., Erickson-Gini, T., Tepper, Y., Malkinson, D., et al., 2019. Ancient trash mounds unravel urban collapse a century before the end of Byzantine hegemony in the southern Levant. Proc. Natl. Acad. Sci. U.S.A. https://doi.org/10.1073/pnas.1900233116.
Baumgarten, Y., 2004. *Excavation and Survey in Israel: Map of Shivta* (166). Jerusalem (Hebrew).
Bruins, H.J., 2012. Ancient desert agriculture in the Negev and climate-zone boundary changes during average, wet and drought years. J. Arid Environ. 86, 28–42. https://doi.org/10.1016/j.jaridenv.2012.01.015.
Bruins, H.J., Ore, G., 2008. Runoff from loess or bedrock? Hillslope geoarchaeology of ancient runoff farming systems at Horvat Haluqim and Har Eldad in the central Negev Desert. Isr. J. Earth Sci. 57, 231–247.
Bruins, H.J., Jongmans, A.G., 2012. Micromorphology of ancient agricultural terraces in the Negev Desert, Horvat Haluqim (Israel). In: Poch, R.M., Casamitjana, M., Francis, M.L. (Eds.), Proceedings of the 14th International Working Meeting on Soil Micromorphology. University of Lleida & International Union of Soil Sciences, Lleida, pp. 292–2955.
Bruins, H.J., Bithan-Guedj, H., Svoray, T., 2019. GIS-based hydrological modelling to assess runoff yields in ancient agricultural terraced wadi fields (central Negev desert). J. Arid Environ. https://doi.org/10.1016/j.jaridenv.2019.02.010.
Cameron, A., 2012. The Mediterranean World in Late Antiquity 395–700 AD. London.
Columella, L.J., 1926. De Re Rustica. Loeb Classical Library, London.
Colt, H.D., 1962. *Excavations at Nessana*, I. London.
Crouvi, O., Amit, R., Enzel, Y., Porat, N., Sandler, A., 2008. Sand dunes as a major proximal dust source for late Pleistocene loess in the Negev Desert, Israel. Quat. Res. 70, 275–282.
Decker, M.J., 2013. The end of the Holy Land wine trade. STRATA 31, 103–116.
Di Segni, L., 1997. Dated Greek Inscriptions from Palestine from the Roman and Byzantine Periods. Ph.D. dissertation. The Hebrew University of Jerusalem.
Dunseth, Z.C., Junge, A., Lomax, J., Boaretto, E., Finkelstein, I., Fuchs, M., Shahack-Gross, R., 2017. Dating archaeological sites in an arid environment: a multi-method case study in the Negev Highlands, Israel. J. Arid Environ. 144, 156–169.
Erickson-Gini, T., 2012. Nabataean agriculture: myth and reality. J. Arid Environ. 86, 50–54.
Evenari, M., Shanan, L., Tadmor, N., 1982. The Negev: the Challenge of a Desert. Cambridge, MA.
Faershtein, G., Porat, N., Avni, Y., Matmon, A., 2016. Aggradation-incision transition in arid environments at the end of the Pleistocene: an example from the Negev highlands, southern Israel. Geomorphology 253, 289–304.
Frosen, J., Arjava, A., Lehtinen, M. (Eds.), 2002. *The Petra Papyri I* (ACOR Publications 4), Amman.
Fuks, D., Weiss, E., Tepper, Y., Bar-Oz, G., 2016. Seeds of collapse? Reconstructing the ancient agricultural economy at Shivta in the Negev. Antiq. Proj. Gallery 90. https://doi.org/10.15184/aqy.2016.167.
Goldreich, Y., 2003. The Climate of Israel: Observation, Research and Application. Kluwer Academic/Plenum Publishers, New York, NY.
Haiman, M., 1995. Agriculture and nomad: state relations in the Negev in the Byzantine and early Islamic periods. Bull. Am. Sch. Orient. Res. 297, 29–53.
Haiman, M., 2012. Dating the agricultural terraces in the southern Levantine deserts: the spatial-contextual argument. J. Arid Environ. 86, 43–50.
Hirschfeld, Y., 2003a. Social aspects of the late-antique village of Shivta. J. Rom. Archaeol. 16, 395–408.
Hirschfeld, Y., 2003b. Man and society in Byzantine Shivta. Qadmoniot 125, 2–17 (Hebrew).
Hirschfeld, Y., 2006. The crisis of the sixth century: climatic change, natural disasters and the plague. Mediterr. Archaeol. Archaeometry 6, 19–32.
Hirschfeld, Y., Tepper, Y., 2006. Columbarium towers and other structures in the environs of Shivta. Tel Aviv 33, 83–116.
Junge, A., Lomax, J., Shahack-Gross, R., Dunseth, C.Z., Finkelstein, I., 2016. OSL age determination of archaeological stone structures using trapped Aeolian sediments: a case study from the Negev highlands, Israel. Geoarchaeology 31, 550–563.
Junge, A., Lomax, J., Shahack-Gross, R., Finkelstein, I., Fuchs, M., 2018. Chronology of an ancient water reservoir and the history of human activity in the Negev Highlands, Israel. Geoarchaeology 33, 695–707. https://doi.org/10.1002/gea.21682.
Kedar, Y., 1957a. Water and soil from the desert: some ancient agricultural achievements in the Central Negev. Geogr. J. 123, 179–187.
Kedar, Y., 1957b. Ancient agriculture at Shivta in the Negev. Isr. Explor. J. 7, 178–189.
Kraemer, C.J., 1958. Excavations at Nessana, Non Literary Papyri, vol. III Princeton.
Lavee, H., Poesent, J., Yair, A., 1997. Evidence of high efficiency water-harvesting by ancient farmers in the Negev Desert, Israel. J. Arid Environ. 35, 341–348.
Magness, J., 2003. The Archaeology of the Early Islamic Settlement in Palestina. Winona Lake.
Marom, N., Rosen, B., Tepper, Y., Bar-Oz, G., 2018. Pigeons at the edge of the empire: Bioarchaeological evidences for extensive management of pigeons in a Byzantine desert settlement in the southern Levant. PloS One, e0193206. https://doi.org/10.1371/journal.pone.0193206.
Mayerson, P., 1955. Arid Zone Farming in Antiquity: A Study of Ancient Agricultural and Related Hydrological Practices in Southern Palestine. Ann Arbor.
Mayerson, P., 1959. Ancient agricultural remains in the central Negev: the Teleilat el-anab'. Bull. Am. Sch. Orient. Res. 153, 19–53.
Mayerson, P., 1960. The ancient agricultural remains of the central Negeb: methodology and dating criteria. Bull. Am. Sch. Orient. Res. 160, 27–37. https://doi.org/10.2307/1355645.
Mayerson, P., 1985. Wine and vineyards of Gaza in the Byzantine period. Bull. Am. Sch. Orient. Res. 257, 75–80.
Pliny the Elder, G.S. Natural History. Loeb Classical Library. London.
Porat, N., Rosen, S.A., Avni, Y., Boaretto, E., 2006. Dating the Ramat Saharonim late neolithic desert cult site. J. Archaeol. Sci. 33, 1341–1355.
Porat, N., Duller, G.A.T., Roberts, H.M., Piasetzky, E., Finkelstein, I., 2012. OSL dating in a multi-strata tel: Megiddo (Israel) as a case study. Quat. Geochronol. 10, 359–366.
Ramsay, J., Tepper, Y., Weinstein-Evron, M., Bratenkov, S., Marom, N., Bar-Oz, G., 2016. For the birds: an environmental archaeological analysis of Byzantine pigeon towers at Shivta (Negev desert, Israel). J. Archaeol. Sci. Rep. 9, 718–727.
Rubin, R., 1996. Urbanization, settlement and agriculture in the Negev Desert: the impact of the Roman-Byzantine empire on the frontier. Z. Dtsch. Paläst. Ver. 112, 49–60.
Segal, A., 1983. The Byzantine City of Shivta (Esbeita), Negev Desert, Israel (BAR International Series 179). Oxford.
Segal, A., 1988. *Architectural Decoration in Byzantine Shivta, Negev Desert, Israel* (BAR International Series 420). Oxford.
Shereshevski, J., 1991. Byzantine Urban Settlements in the Negev Desert. Beer-Sheva.
Tepper, Y., 2007. Soil improvement and agricultural pesticides in antiquity: examples from archaeological research in Israel. In: Conan, M. (Ed.), Middle East Garden Traditions: Unity and Diversity, pp. 41–52 Washington D.C.
Tepper, Y., Weissbord, L., Bar-Oz, G., 2015. Behind sealed doors: unravelling abandonment dynamics at the Byzantine site of Shivta in the Negev desert. Antiq. Proj. Gallery 348. http://antiquity.ac.uk/projgall/bar-oz348.
Tepper, Y., Rosen, B., Haber, A., Bar-Oz, G., 2017. Traces in the desert dust: soil tests characterize a pigeon tower structure near Byzantine Shivta, Israel. J. Arid Environ. 145, 81–89.
Tepper, Y., Erickson-Gini, T., Farhi, Y., Bar-Oz, G., 2018a. Probing the Byzantine/early Islamic transition in the Negev: the renewed Shivta excavations, 2015–2016. Tel Aviv 45, 120–152.
Tepper, Y., Weissbrod, L., Fried, T., Marom, N., Ramsay, J., Weinstein-Evron, M., Aharonovich, S., Liphschitz, N., Farhi, Y., Yan, Y., Boaretto, E., Bar-Oz, G., 2018b. Pigeon-raising and sustainable agriculture at the fringe of the desert: a view from the Byzantine village of Sa'adon, Negev, Israel. Levant. https://doi.org/10.1080/00758914.2018.1528532.
Tepper, Y., Bar-Oz, G., 2019. Mount Hotev, Nahal Zetan. *Hadashot Arkheologiyot Excavations and Surveys in Israel* 131 (Preliminary Report; 1-12-2019). . http://www.

hadashot-esi.org.il/Report_Detail_Eng.aspx?id=25643.
Varro, M.T. Rerum Rusticarum. Loeb Classical Library. Leipzig.
Wieler, N., Avni, Y., Rosensaft, M., 2016. The significance of the geological strata on desert runoff agriculture: indications for a stable desert environment over the last 1600 years in southern Israel. J. Arid Environ. 135, 147–163.
Wintle, A.G., 2008. Fifty years of luminescence dating. Archaeometry 50, 276–312.
Youtie, H.C., 1936. Ostraca from Sbeitah. Am. J. Archaeol. 40, 452–459.
Zohar, M., Salamon, A., Rubin, R., 2016. Reappraised list of historical earthquakes that affected Israel and its close surroundings. J. Seismol. 20, 971–981.