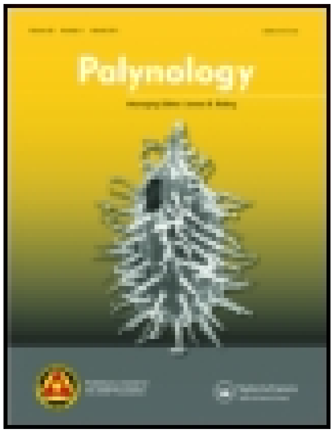

Palynology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tpal20

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Published online: 09 Jun 2015.

To cite this article: Dafna Langgut, Eli Yannai, Itamar Taxel, Amotz Agnon & Shmuel Marco (2015): Resolving a historical earthquake date at Tel Yavneh (central Israel) using pollen seasonality, Palynology, DOI: 10.1080/01916122.2015.1035405

To link to this article: http://dx.doi.org/10.1080/01916122.2015.1035405

Palynology, 2015
http://dx.doi.org/10.1080/01916122.2015.1035405

Resolving a historical earthquake date at Tel Yavneh (central Israel) using pollen seasonality

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The identification of historical events by geological and archaeological evidence is often ambiguous and conflicting, undermining the enormous potential for sub-annual precision in dating. The ruin of one of the largest pottery factories in the Middle East during Byzantine times, recently excavated in Yavneh (central Israel), exemplifies this: aligned fallen walls and columns and a kiln that collapsed while still in operation, with dozens of ceramic storage jars in articulation. Archaeological dating, which limits the time of the collapse to the seventh century CE, cannot distinguish between two large documented earthquakes that occurred during this century. By using pollen grains trapped by the collapse, we were able to distinguish, for the first time, between the two candidate earthquakes: September 634 CE and early June 659 CE. The pollen was extracted from the dust captured on the floor of the kiln during the cooling process of the vessels. The dust was collected only from below *in situ* whole vessels, and based on our reconstruction had been accumulated for about several days (after the heating process ended and before the collapse). Since the palynological assemblages included spring-blooming plants (such as *Olea europaea* and *Sarcopoterium spinosum*) and no common regional autumn bloomers (e.g. *Artemisia*), it is proposed that the kiln went out of use due to the early June 659 CE earthquake. We also propose that the recovery of the Yavneh workshops was no longer economically worthwhile, maybe in part due to changes in economic and political conditions in the region following the Muslim conquest.

Keywords: pollen seasonality; palynological archaeology; archaeoseismology; historical earthquakes; Yavneh; Israel; commercial pottery containers

1. Introduction

The high value of historical earthquake records is marred by copying mistakes, ambiguities, uncertain dates, biased reports and the use of unknown names and terms (e.g. Guidoboni et al. 1994; Guidoboni 1996; Baumgarten 2001). These issues can cause, for example, the amalgamation of several events into one (e.g. Ambraseys 2005), or the assignment of the wrong earthquake magnitude (e.g. Ambraseys & Karcz 1992). At times, though, physical evidence provides independent tests for historical accounts. Here, we address the two strong seventh-century CE earthquakes that affected the Middle East, in September 634 CE and in early June 659 CE, by applying for the first time the power of palynological analyses to resolve seasons in archaeoseismology.

Previous palynological investigation in the region which shed light on chronological uncertainties dealt with a different time-scale: Horowitz (2001) used pollen to determine the age of the Dead Sea Rift Valley. Farther away, along coastal areas (e.g. the Gulf of Mexico), pollen assemblages have been used to determine the time and intensity of hurricanes (Liu & Fearn 2000; Liu 2007). Bryant (1974) was among the first palynologists to use pollen in order to reveal seasonality: by extracting and identifying pollen grains from human coprolites retrieved from southwest Texas, he was able not only to reconstruct the ancient human diet but also to estimate the specific periods of seasonal site occupancy. Palynological studies are also involved in predicting the season of ancient building construction or renovation by extracting pollen from the outer layer of plaster and mud bricks (Langgut et al. 2013 and references therein).

In this study, pollen seasonality investigation was conducted in order to distinguish between two candidate earthquakes which occurred, based on written sources (see more below), during the seventh century CE at different seasons (autumn 634 CE and spring 659 CE). One of these earthquakes was most probably linked to the abandonment of one of the largest ceramic factories in the Middle East during Byzantine times, which was recently exposed near Tel Yavneh, a major ancient site located in the southern Levantine Coastal Plain (Figure 1; see Fischer & Taxel 2007). Since Yavneh is located about 70 km west of the Dead

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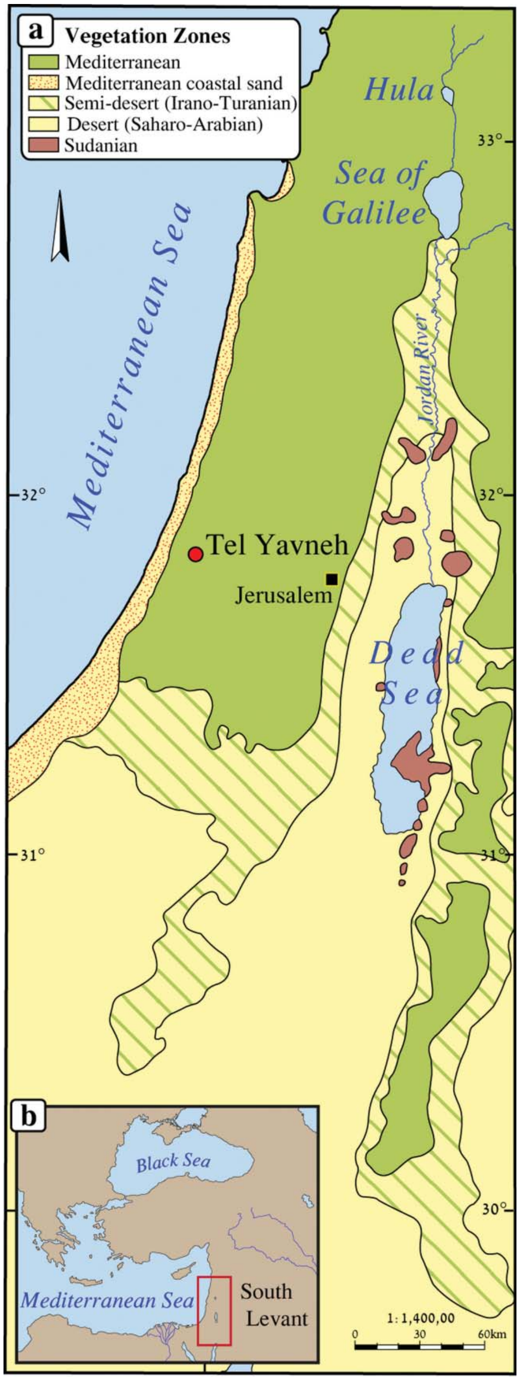

Figure 1. (a) The phytogeographic zones characterising the southern Levant region (after Danin 2004). (b) The position of the southern Levant in the Eastern Mediterranean.

Sea Fault (DSF), the latter is considered *a priori* the prime suspect source fault (Figure 2). This huge pottery workshop specialised in the production of commercial containers of two main types: the so-called Gaza amphora and the southern/coastal Palestinian bag-shaped jar (Figures 3 and 4 respectively; see more below). The vast geographical horizon of these ceramic containers in submerged shipwrecks across the Mediterranean Sea and the presence of these containers abroad (e.g. Egypt, Spain, Romania) attest to the importance of the southern Levantine region in the international Mediterranean commerce network during the Byzantine period (e.g. Parker 1992; Oked 2001 and references therein). After the seventh century, during the Early Islamic period, the distribution of these containers was mainly restricted to the local/regional markets.

Additionally in the attempt to decide between the two seventh-century CE candidate earthquakes by pollen seasonality, this paper will also try to shed light on possible links between the collapse of the factory in Yavneh and the decline of the commercial production of wine and wine containers during the transition from the Byzantine to the Early Islamic period.

1.1. *The Yavneh pottery workshop and the earthquake indicators*

In 2010–2011, a large-scale salvage excavation was conducted on behalf of the Israel Antiquities Authority at the eastern foot of Tel Yavneh (permission number A-6025/2010). This large artificial mound formed the core of the ancient settlement throughout its history, including during the Byzantine period, when it reached its territorial zenith (Fischer & Taxel 2007, p. 230–239). In the northern part of the excavation, a sophisticated and unique complex of pottery kilns was exposed (Figure 5a). The complex and its surrounding buildings, erected during the Byzantine period and continuing in use into the beginning of the Early Islamic period (until the mid-seventh century CE), were in a rare state of preservation and were only partially excavated due to planning considerations that precluded the excavation of the entire facility. The complex consists of six kilns connected by barrel-shaped tunnels with a common entrance. The kilns were built in two clusters of three kilns per cluster. Based on the finds at Yavneh, the six kilns were of the updraft type (Sklowski 1985/6, p. 14; pl. 20a–b, fig. 14), and the vessels were fired inside them without using a mud-brick dome.

Four peripheral buildings were constructed around the clusters of kilns, enclosing them from all directions and constituting an integral part of the complex. On the western side of the complex, cylindrical columns were arranged in two parallel rows along a colonnade street or a long rectangular building. They consisted of a square pedestal, 2–3 drums and a square capital, all made of a soft limestone apparently quarried in the lower foothills to the east of Yavneh. The height from the base to the top of the capital is 3.10 m and the

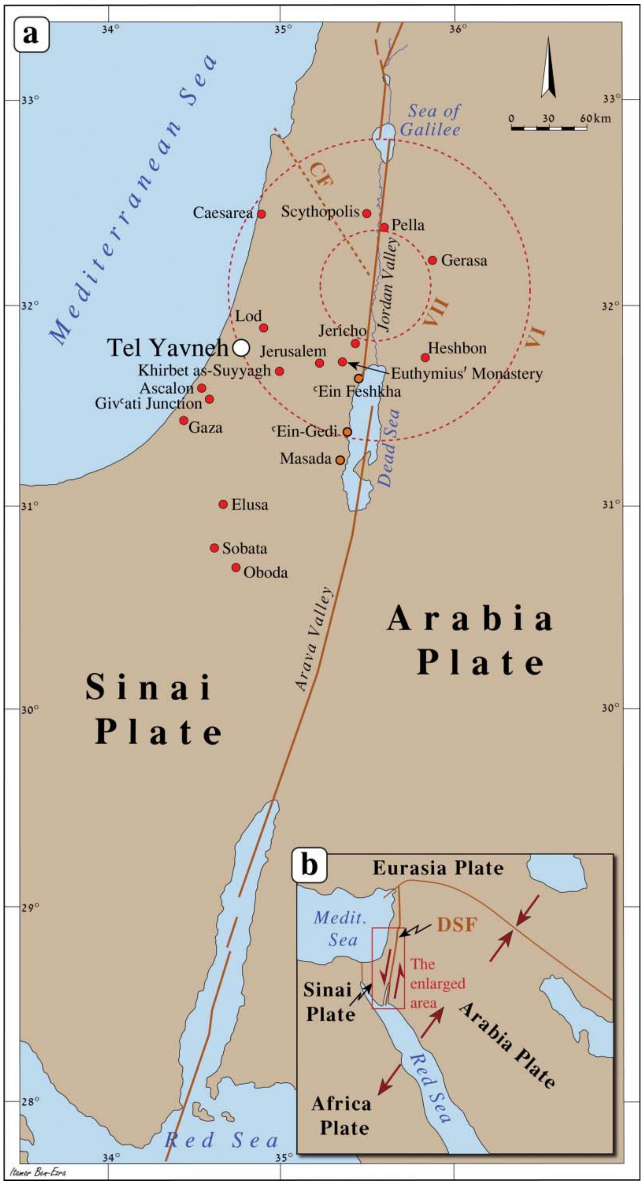

Figure 2. (a) The location of Tel Yavneh with other sites mentioned in the text. Continuous lines mark signets of the Dead Sea fault system; the Carmel fault (CF) is marked by a dashed line. Dashed circles mark calculated isoseismals for a hypothetical M6 earthquake rupturing ~6 km around the branching area between the main Dead Sea fault system and the Carmel fault. (b) Plate tectonic setting of the Middle East.

diameter is 0.40 m. Five such columns were found lying on the building's floor, all paralleling an east–west orientation (Figure 5a and 5b). Judging by the manner of their position as found, there is no doubt that the columns collapsed at the same time during a strong earthquake (Yannai 2012, 2014). The collapse of the kilns, or at least the fully excavated one, which contains whole vessels in articulation (Figure 5c), occurred while loaded with already-baked vessels.

1.2. *Candidate earthquakes*

The archaeological dating of the destruction limits the period to one in which two candidate earthquakes could have caused the destruction, one in September 634 CE and the other in June 659 CE. The historical records of both earthquakes are summarised by Guidoboni et al. (1994) and Ambraseys (2009). The 634 CE earthquake was mentioned in association with the appearance of a comet, which was reported by Chinese and Japanese astronomers as well (Guidoboni et al. 1994; Anbraseys 2009). Damage was reported in Jerusalem and surrounding towns, and minor damage was reported in Scythopolis (Beth She'an; Russel 1985). Debatable evidence of earthquake damage was also reported in Gerasa (Jerash) and Pella in Jordan, and possibly in Caesarea Maritima. Guidoboni et al. (1994) and Ambraseys (2009) are in agreement on the date but Russell (1985) dates the earthquake to September 633 CE.

Guidoboni et al. (1994) cite a Syrian source that reports the 659 CE earthquake "at the second hour on a Friday in the month of Haziran" (= June). They also mention the possibility of April as the month of the earthquake. A date of end May–early June 659 CE is concluded by other earthquake catalogues (e.g. Russell 1985; Ambraseys 2009). The 659 CE earthquake is reported to have affected 'most of Palestine'. The church of St. John the Baptist by the Jordan River near Jericho, and the monastery of Aba Euthymius 15 km east of Jerusalem, collapsed. Finally, Russell (1985) interprets damage to the Byzantine towns of Gerasa and Pella as a possible effect of the 659 CE earthquake (and see above).

Archaeological evidence for severe damage caused by an earthquake during the seventh century CE, usually associated with the 659 CE earthquake, was reported from several excavated sites in Israel and Jordan. These include mainly inland settlements, such as Scythopolis (Beth She'an; Bar-Nathan & Atrash 2011, p. 8, 153–154, table 4.4), Heshbon (Walker & LaBianca 2003, p. 453–454), Pella (Walmsley 2007, p. 129), the Monastery of Euthymius (Hirschfeld 1993, p. 357) and the monastery of Khirbet es-Suyyagh (Taxel 2009); the main exception thus far is the coastal city of Caesarea Maritima, where the destruction of a building was tentatively attributed to the 659 CE earthquake only in one location (Raban et al. 1993, p. 59–61). Evidence for destruction by an earthquake in the seventh century CE has also been reported from the large Negev sites of Sobata/Shivta (Korjenkov & Mazor 1999a),

Figure 3. The so-called Gaza amphora (LRA 4).

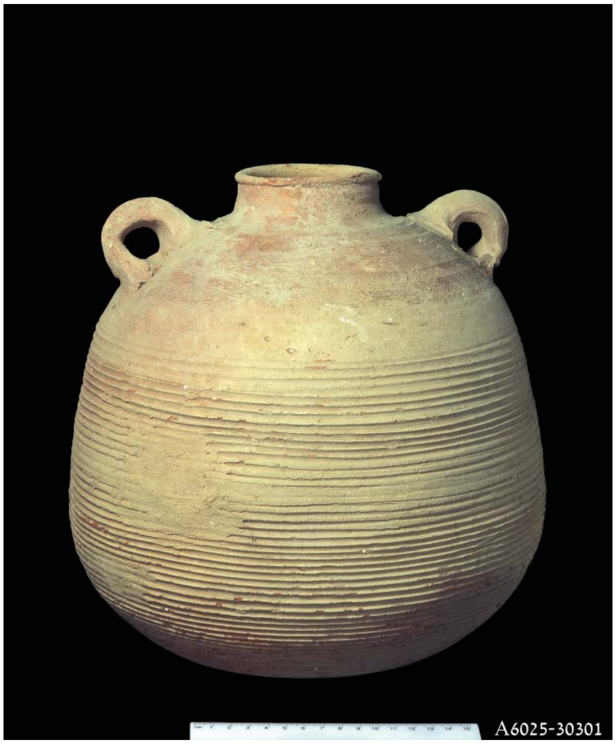

Figure 4. The southern/coastal Palestinian bag-shaped jar (LRA 5/6).

Figure 5. (a) An aerial photo of one of the clusters of the unique pottery kiln complex. The kilns were connected by barrel-shaped and covered tunnels with a common entrance. (b) Fallen columns . (c) *In situ* bag-shaped jars that were placed on the kiln's floor.

Oboda/Avdat (Fabian et al. 1996; Korjenkov & Mazor 1999b) and Elusa/Halutza (Mazor & Korjenkov 2001, p. 133). In the case of Oboda, the destruction was attributed to the 633 (634) CE earthquake, a chronology adopted also in the cases of the earthquake destruction at Sobata and Elusa. However, in neither of these sites was the basis for this dating given, so for the time being it should be considered conjecture. According to T. Erickson-Gini (Israel Antiquities Authority), who recently carried out excavations at Oboda and Sobata, the discussed earthquake evidence in these sites can only be generally dated to the early seventh century CE based on the archaeological finds (Erickson-Gini, personal communication, July 2014), which tentatively precludes the possibility of the 659 CE earthquake as the cause.

Given the various data retrieved from the Yavneh pottery workshop, it can be assumed that at least some of the other contemporaneous pottery workshops which existed along the southern coast of Israel were also destroyed and abandoned due to an earthquake during the seventh century CE. One possible example is a pottery kiln excavated at the Giv'ati Junction (near the site of Khirbet 'Ajjis er-Ras), where many fired LRA (Late Roman Amphora) 4 jars (all are of the late variant, similar to those found at Yavneh) were found inside the kiln's collapsed firing chamber. The site was later covered by a thick layer of wind-blown sand. The excavator suggested that the kiln was destroyed during operation, possibly due to some technical fault, and was consequently abandoned (Baumgarten 2001). We argue that it is equally possible that this kiln was destroyed by an earthquake.

2. Research area

The Yavneh pottery workshop is located in the Levantine southern Coastal Plain (Figure 1). Extensive surveys and excavations over the last two decades have shown that during the Byzantine period, this area had become one of the most densely populated areas in the region. The Yavneh workshop is one of dozens of similar (though smaller) industrial facilities excavated and surveyed in various locations along the Levantine southern Coastal Plain, from the Gaza region in the south to the Lod region in the north (e.g. Israel 1993; Baumgarten 2001, table 1; Gophna et al. 2007), including in Yavneh and its vicinity (e.g. Gadot & Tepper 2003; Fischer & Taxel 2007). The occurrence of ceramic vessels which were produced in this coastal region in many other excavations in the southern Levant, and even abroad, testify to the international economic importance of the region.

2.1. Yavneh pottery workshop: ceramic and regional context

This pottery factory specialised in the production of two main types of well-known ceramic containers – the so-called Gaza amphora (LRA 4; Figure 3) and the southern/coastal Palestinian bag-shaped jar (LRA 5/6; Figure 4). Both vessel forms are represented, in the contexts attributed to the kiln complex proper, by their latest variants only. These are dated to between the late sixth/seventh to eighth centuries CE (Pieri 2005, p. 106–107), with the latter apparently continuing somewhat later than the LRA 4. It is commonly accepted that the LRA 5/6 was a multi-purpose container designated for both local and regional/international commerce (notably for transporting wine and olive oil), as well as for a variety of domestic and daily uses. In contrast, the LRA 4 was a typical commercial container, whose elongated shape made it most convenient for long-distance maritime and overland transport, first and foremost with relation to the trade in the famous wines produced in and around Gaza and Ascalon, and the other cities located along the southern Palestinian coast (Figure 1; Mayerson 1992; Pieri 2005, p. 110–114; 2012, p. 36–39).

The Yavneh pottery workshop and other similar workshops, which were exposed in nearby areas, manufactured industrial quantities of LRA 4 (and sometimes LRA 5/6 as well), and the majority of these workshops functioned during the sixth to seventh centuries CE. The Yavneh workshop, though, is the largest among them, with an estimated weekly output of about 450 LRA 4 jars, and probably a larger number of LRA 5/6 jars, for each of its six documented kilns (every firing cycle is calculated as five working days based on ethnographic parallels; Yannai 2012). This workshop was therefore able to produce an immense number of commercial containers, which were no doubt designated first and foremost for marketing the products of the intensive wine industry of Yavneh and its rural hinterland.

2.2. Regional settings

The site is located in the eastern outskirts of Tel Yavneh, several km east of the Mediterranean coast, inside a topographical trough rich in alluvial soil (Karmon 1971). The area receives 500–600 mm of annual rainfall and is part of the Mediterranean vegetation zone (Figure 1). The area's geographical setting determined its role as part of the famous international highway known today as the *Via Maris* or 'Way of the Sea' (e.g. Aharoni 1967). The highway circumvented the sand dunes of the western Coastal Plain and the limestone hills to the east, and used the natural topographical trough, making it the preferred route for travelers. The

Table 1. Pollen assemblage of the floor dust sample (no. 1).

		Blooming: calendar month[a]											
Pollen taxon	Pollen grains in absolute numbers	1	2	3	4	5	6	7	8	9	10	11	12
Pinus halepensis	3												
Asteraceae Asteroideae	1												
Asteraceae Cichorioideae	5												
Carthamus	3												
Polygonaceae	1												
Degraded (charred) palynomorphs	214												
Lycopodium	154												
Weight (g)	3.62												
Palynomorph concentration values (g/sediment)	7566												

[a]Grey bars represent the flowering season.

geographical advantages of the site also derive from the immediate proximity to the Soreq stream and the Yavneh tributary.

According to archaeobotanical remains from many excavations as well as pollen data, the primary vegetation in this region was Mediterranean maquis/forest, dominated by evergreen oak (*Quercus calliprinos*), olive (*Olea europaea*) and terebinth (*Pistacia palaestina*) (Gophna et al. 1986; Liphschitz et al. 1987; Langgut et al. 2011). Mount Tabor oak (*Quercus ithaburensis*), which existed not far to the north of Yavneh during the nineteenth century CE (Eig 1933), was probably only a secondary constituent in antiquity (Liphschitz et al. 1987). Since the Chalcolithic period, man's activity has caused significant changes to the vegetational landscape in this area (Gophna et al. 1986) as well as in other nearby regions in the southern Levant (e.g. Baruch 1990; Lev-Yadun 1997; Langgut et al. 2014). Today, due to the extensive exploitation of the *Quercus ithaburensis* forest, the area is characterised by degraded vegetation, consisting mainly of herbaceous and shrubby plants, ever since (Zohary 1962; Gophna et al. 1986).

Table 2. Pollen assemblage of the floor dust sample (no. 2).

		Blooming: calendar month[a]											
Pollen taxon	Pollen grains in absolute numbers	1	2	3	4	5	6	7	8	9	10	11	12
Sarcopoterium spinosum	1												
Asteraceae Asteroideae	1												
Asteraceae Cichorioideae	3												
Atriplex type	1												
Rosaceae	1												
Degraded (charred) palynomorphs	102												
Spores	5												
Lycopodium	281												
Weight (g)	3.0												
Palynomorph concentration values (g/sediment)	2513												

[a]Grey bars represent the flowering season.

Table 3. Pollen assemblage of the floor dust sample (no. 3).

Pollen taxon	Pollen grains in absolute numbers	Blooming: calendar month[a]											
		1	2	3	4	5	6	7	8	9	10	11	12
Pinus halepensis	1			■	■								
Olea europaea	1				■	■							
Poaceae	1		■	■	■	■	■	■	■	■	■		
Asteraceae Cichorioideae	1			■	■	■	■	■	■	■	■		
Carthamus	3				■	■	■	■	■	■			
Dipsacus laciniatus L.	1					■	■	■					
Atriplex type	1	■	■	■	■	■	■	■	■	■	■	■	■
Brassicaceae	2	■	■	■	■	■	■	■					
Degraded (charred) palynomorphs	10												
Lycopodium	96												
Weight (g)	0.62												
Palynomorph concentration values (g/sediment)	6556												

[a]Grey bars represent the flowering season.

3. Methods: palynological analyses

The analysis of the archaeological data (especially pottery) cannot provide the resolution needed to distinguish between two earthquakes that could have affected the Yavneh pottery workshop in the seventh century CE. We therefore have to rely on the historical accounts, according to which the 659 CE earthquake happened in the spring and the 634 CE earthquake in autumn, and try to use palynological analyses in order to identify the season and hence the year of the destruction.

3.1. Sampling

Due to excavation limitations, we were only able to retrieve four *in situ* sealed dust samples (Tables 1–3), which were collected underneath unbroken ceramic vessels (Figures 5c and 6). These samples represent the dust which was captured on the floor of the kiln during the cooling process of the vessels and is archaeologically considered undisturbed material. Though we collected all the dusty material which accumulated below the vessels, the weight of the samples was low. Another sample was collected 2–3 cm above the kiln's floor (Table 4) and is serving as a control sample. A recent pollen sample, which was taken 30 m south of the site, during the excavation in May 2012, serves also as a control sample (Table 5). Sampling strategies and techniques followed the recommendations of Bryant & Holloway (1983, p. 199–200).

3.2. Laboratory procedure and pollen identification

Pollen extraction followed a chemical preparation procedure: one *Lycopodium* spore tablet was added to each sample (batch number 1031, with an average of 18,853 *Lycopodium* spores per tablet), in order to calculate pollen concentrations (Stockmarr 1971). Next, samples were immersed in hydrochloric acid (HCl) to remove the calcium carbonates, and then a density

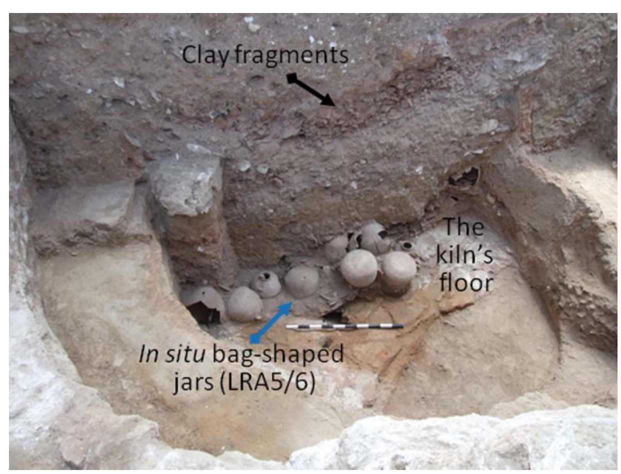

Figure 6. The kiln during the excavation. We were able to collect four *in situ* sealed dust samples for palynological investigation from the kiln's floor, underneath unbroken ceramic vessels. An additional sample was collected 2–3 cm above the kiln's floor. The black arrow points to the debris/clay fragments (which were used to cover the kiln during the heating process) and were deposited after the earthquake.

Table 4. Pollen assemblage 2–3 cm above the kiln's floor (sample no. 5 = control).

		Blooming: calendar month[a]											
Pollen taxon	Pollen grains in absolute numbers	1	2	3	4	5	6	7	8	9	10	11	12
Plantago lanceolata	1		■	■	■	■	■	■	■	■	■		
Poaceae	1		■	■	■	■	■	■	■	■	■		
Asteraceae Asteroideae	12			■	■	■	■	■	■	■	■		
Asteraceae Cichorioideae	48			■	■	■	■	■	■	■	■		
Achillea/Matricaria	1		■	■	■	■	■	■	■	■	■		
Xanthium	2					■	■	■	■	■			
Carthamus	19				■	■	■	■	■	■			
Artemisia	1									■	■	■	■
Scabiosa	1				■	■	■	■	■	■			
Atriplex type	1	■	■	■	■	■	■	■	■	■	■	■	■
Caryophyllaceae	1	■	■	■	■	■	■	■	■	■	■	■	■
Lycopodium	221												
Weight (g)	2.3												
Palynomorph concentration values (g/sediment)	3217												

[a]Grey bars represent the flowering season.

Table 5. Pollen assemblage of the recent control sample (no. 6).

		Blooming: calendar month[a]											
Pollen taxon	Pollen grains in absolute numbers	1	2	3	4	5	6	7	8	9	10	11	12
Pinus	3			■	■	■							
Poaceae	27		■	■	■	■	■	■	■	■	■		
Cereal	6		■	■	■	■	■	■	■	■	■		
Bunium	2			■	■	■	■	■	■	■			
Asteraceae Asteroideae	3			■	■	■	■	■	■	■	■		
Asteraceae Cichorioideae	6			■	■	■	■	■	■	■	■		
Carduus	1			■	■	■							
Achillea/Matricaria	136		■	■	■	■	■	■	■	■	■		
Polygonaceae	1	■	■	■	■	■	■	■	■	■	■	■	■
Brassicaceae	12	■	■	■	■	■	■	■					
Theligonum cynocrambe	1	■	■	■	■	■							
Atriplex type	2	■	■	■	■	■	■	■	■	■	■	■	■
Mercurialis	2	■	■	■	■	■	■						■
Ephedra	2	■	■	■	■	■	■	■	■				
spores	5												
Lycopodium	35												
Weight (g)	5.5												
Palynomorph concentration values (g/sediment)	20368												

[a]Grey bars represent the flowering season.

separation was carried out using zinc bromide ($ZnBr_2$) solution (with a specific gravity of 1.95) in order to float the organic material, together with sieving (150-μm mesh screen). After acetolysis, unstained residues were homogenised and mounted onto microscopic slides using glycerin (Faegri & Iversen 1989).

Pollen grains were identified under a light microscope, with magnifications of 200×, 400× and 1000× (oil immersion). In each sample, all the extracted pollen grains were counted and identified. Palynomorph concentrations per gram were calculated as follows: total of counted palynomorphs times the number of *Lycopodium* spores added to the full sample (18,583). Then, the ratio between this value and the weight of the sample times the number of counted *Lycopodium* spores gave the palynomorph concentration. Pollen grains were identified to the maximum accuracy possible systematic level. For pollen identification, a comparative reference collection of Israel pollen flora of Tel Aviv University (Steinhardt Museum of Natural History) was used, in addition to pollen atlases (e.g. Reille 1995, 1998, 1999; Beug 2004).

4. Results

Pollen results are presented in absolute numbers (Tables 1–5). The calendar blooming months for each taxon are marked by grey bars. The weight (in g) of the dust samples from the floor (nos. 1–4) is relatively low due to their archaeological context (0.62–3.62 g). These samples are also characterised by relatively low palynomorph concentration values (2513.0–7566.5 palynomorphs per g/sediment), while the recent sample is characterised by higher concentrations (20,368.9 palynomorphs per g/sediment). In total, 21 families/genera/species or pollen types were identified (Tables 1–5). Although in each of the dust samples only several pollen grains were identifiable, some of them clearly belong to spring-blooming plants (e.g. *Pinus halepensis*, *Sarcopoterium spinosum* and *Olea europaea*; Tables 1–3). On the contrary, the pollen spectra of the control sample taken 2–3 cm above of the kiln's floor included autumn bloomers (e.g. *Artemisia*) and was lacking in pollen of spring bloomers. The pollen assemblage of the recent control sample, which was collected in May, is indeed indicative of the spring.

Since Yavneh is located about 70 km west of the DSF, this fault is considered *a priori* the prime suspect source of the seismic event (Figure 2). Other posible sources and the estimated size of this event are discussed in section 5.5.

5. Discussion

5.1. The palynological spectrum

The four dust samples collected from the kiln's floor underneath unbroken ceramic vessels (Figure 6) contained mainly degraded palynomorphs as well as some well-preserved pollen grains (samples 1–5, Tables 1–4). The degraded group represents damaged palynomorphs, which are unidentifiable mainly due to obliterated surface ornamentation. The obliterated surface is interpreted as the result of deposition on a hot floor that caused thermal alternation (= charred palynomorphs). Most of sample no. 4 is composed of degraded palynomorphs and *Lycopodium* spores. Only one well-preserved pollen grain was identified – *Olea europaea* (and therefore it is not presented in a table). *O. europaea* blooms during the spring (April–May), though Keynan et al. (1991) showed the presence of aerial samples of *Olea* pollen on the Israeli coast from February to June. The three other floor samples included some more identifiable pollen grains, some of them belong to spring-blooming plants such as *Pinus halepensis*, *Sarcopoterium spinosum* and *Olea europaea*. Additionally, these samples were lacking common autumn bloomers of the studied region, such as *Artemisia*. On the contrary, the control sample taken a 2-3 centimetres above the kiln's floor (sample no. 5) did not include any of those spring-blooming plants, while *Artemisia* pollen was present. It seems more likely that this control sample was deposited during the autumn (*Artemisia* species are palynologically indistinguishable; two *Artemisia* species – *A. monosperma* and *A. herba-alba* – grow in the studied area and bloom from September to December).

The high frequencies of Asteraceae Cichorioideae pollen type (its different species bloom through almost the entire year) identified in this control sample may be an indicator of selective preservation (Havinga 1984). High values of Cichorioideae pollen type were found only in this sample, and therefore may suggest that the sediments which accumulated in the kiln after it went out of use were subjected to diagnosis processes to a larger extent than the sealed samples recovered from the kiln's floor. Consequently, this pollen type is supposedly over-represented, e.g. in pollen spectra from archaeological sites (Bottema 1975), although more recent studies on the oxidation of different pollen types underline that oxidation might not be the only taphonomical process involved: Cichorioideae pollen do not appear to be more resistant than other experimentally tested pollen types (Lebreton et al. 2010). Lebreton et al. (2010) pointed out that, due to their unique morphology, pollen of Cichorioideae are simply less prone to confusion with other pollen types even after alteration (for further discussion see Bryant 1988; Bryant et al. 1993; Neumann et al. 2014).

The intersection in flowering months of all the identifiable pollen taxa (samples 1–4) is April and May. According to the flowering months of the recent pollen sample (sample no. 6, Table 5), it seems that its palynological spectra represent palynomorphs which flourished and then were embedded during March–May. However, *Theligonum cynocrambe* usually blooms until the end of April. Since the recent control sample was collected on 23 May (2012), it is possible that this wind-pollinated species flowered late that year, possibly because of the relatively rainy spring. *Pinus* was identified only to the genus level in the recent pollen spectrum, unlike in the archaeological pollen assemblages (samples 1–5). This is because *Pinus halepensis* (Aleppo pine) is the only naturally occurring pine species in the southern Levant (Weinstein-Evron & Lev-Yadun 2000), while during the last several decades additional pine species were deliberately planted in Israel. While *Pinus halepensis* blooms in March–April, the other species also bloom during May. However, the long-distance transport ability of this bisaccate pollen should also be taken into consideration (e.g. Nichols et al. 1978). In any event, the different *Pinus* species are palynologically indistinguishable (e.g. Eastwood et al. 1998).

5.2. Kiln collapse and palynological constraints

The kiln collapsed during the cooling process of the vessels, probably when temperatures were already close to normal and therefore allowed for the accumulation of un-deformed pollen. Because the kiln was still full of vessels, we argue that the destruction took the operators by surprise. No weapons or other indications of violence such as arrow heads were found in the site. The plausible sequence of events in the kiln is illustrated in Figure 7. The preservation and penetration process of pollen grains into the kiln is reconstructed as follows: pollen grains which were present in the kiln during operation were destroyed since palynomorphs do not preserve in locations subjected to such intense heating (Bryant & Holloway 1983). Only after the end of the burning process (Figure 7c) and the removing of the kiln's covering, only when the vessel's cooling process began, did pollen penetrate the kiln (with the cooling air), and it was deposited on the floor. [Based on ethnographic parallels the kiln was probably covered by debris/clay fragments (Sklowski 1985/6); by removing the covering, a more efficient cooling process was conducted, which also allowed the penetration and deposition of pollen grains on the kiln's floor]. At the beginning of this cooling process, many of the arriving pollen grains were damaged due to the still-high temperatures (thermo-alternation), as evidenced by the group of degraded palynomorphs (it was still hot enough to char the pollen grains but not hot enough to burn them completely). Based on experimental studies of thermo-alteration of pollen and spores (Sengupta 1975; Ghosh et al. 2006), the charred grains identified in this study were deformed due to temperatures higher than 350°C. Only the pollen grains which were deposited on the kiln's floor when normal temperatures prevailed inside the kiln were well preserved (represented by the identifiable pollen grains of samples 1–4, and the entire palynological spectrum of sample 5). The palynological evidence therefore indicates that the kiln collapsed during the later phase of the cooling stage of the vessels (Figure 7d).

Based on the intersection of flowering months (April–May) of all the identifiable pollen taxa (samples 1–4), we suggest that the collapse of the kiln occurred during spring based on the presence of pollen of spring-flowering plants which were recovered from the dust collected from the kiln's floor below the vessels. The absence of pollen of common autumn bloomers (e.g. *Artemisia*) is in agreement with this assumption. This palynological evidence supports the attribution of this destruction to the earthquake of spring 659 CE.

5.3. Fallen columns

Slow deterioration of the colonnade is likely to result with columns falling in different directions. Aligned fallen columns are found in many earthquake-affected sites (Stiros 1996; Marco 2008; Hinzen et al. 2011; Rodríguez-Pascua et al. 2011; Sintubin 2011) and we propose that the same cause led to similar results in Yavneh. The colonnade's azimuth is 010°–190° and all the columns fell eastward (Figure 5b). The average azimuth of 31 column segments is 105 ± 16°. Simulations using strong-motion records of modern earthquakes show only little correlation between falling directions and back azimuth to the wave source (Hinzen 2009, 2011). This requires that the individual columns were connected, possibly with wooden beams that were not preserved, and unified the falling direction. We therefore regard the columns as evidence for earthquake as a trigger for the destruction of the site, but they cannot serve as a reliable indicator for determining the source location.

5.4. Economic-historical perspective

Our pollen results, suggesting the earthquake in the spring of 659 CE as the cause and date of the abandonment of the Yavneh pottery workshop (and presumably other similar facilities along the coast), may carry additional possible links to the broader issue of the decline in the Palestinian wine trade after the Byzantine domination. As this aspect will be discussed in detail elsewhere, only a brief outline is given here. As indicated by the archaeological evidence from sites outside the Levant and across the Mediterranean, the distribution of LRA 4 and LRA 5/6 jars sharply diminished

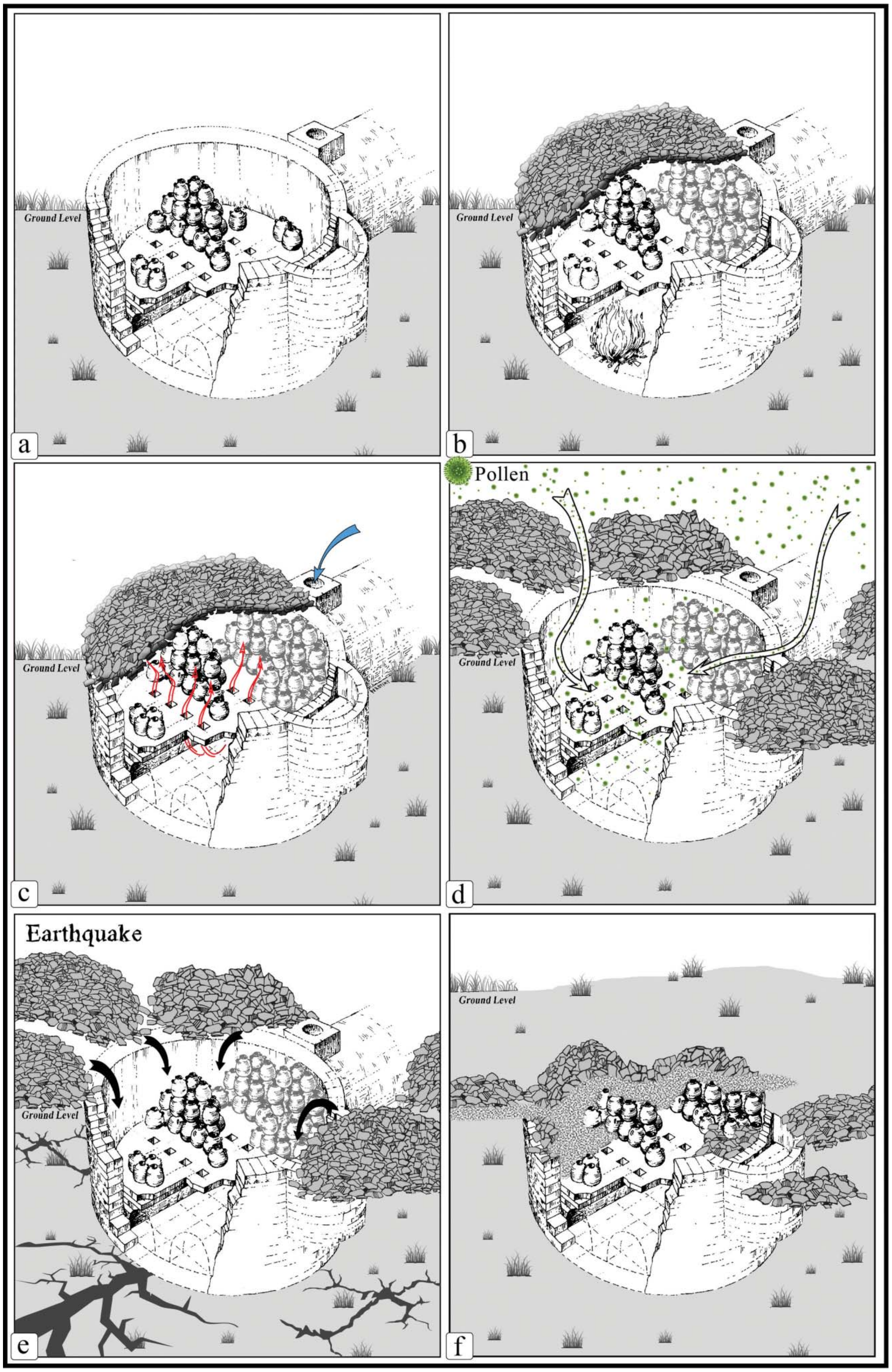

Figure 7. Possible sequence of events in the kiln. (a) Construction of the kiln; laying the freshly made pots at the bottom. (b) Covering with debris/clay fragments; igniting fire, heating. (c) End of burning process. (d) Removing debris/clay fragments; beginning of vessels' cooling process. Pollen penetrated the kiln (with the cooling air) and was deposited on the floor, but was partially damaged due to the still high temperatures (as evidenced by the group of degraded palynomorphs = charred pollen). Pollen (of spring bloomers) penetrated and was deposited on the kiln's floor when normal temperatures prevailed in the kiln (and was therefore well preserved). (e) An earthquake – the kiln collapsed. (f) The burial of the kiln: sediments were deposited covering the burnt material.

after the mid-seventh century CE, and their disappearance from foreign markets usually occurred before the end of the seventh century CE. Traditionally, this decline in the long-distance marketing of Palestinian products (notably wine stored in LRA 4 and LRA 5/6 jars) has been attributed to various short- and long-term aftermaths of the Muslim conquest of the Levant (634–640 CE), first and foremost the reorientation and temporal recession of eastern Mediterranean maritime trade during the late seventh and eighth centuries CE. As is commonly assumed, these changes gradually brought about a decline in local wine production, until its near disappearance by the late eighth or early ninth century CE, while the long-distance (especially seaborne) Palestinian wine trade ceased much earlier (see most recently Decker 2013).

Yet the combination of the ceramic, palynological, geophysical and historical evidence retrieved from the excavation of the Yavneh workshop, which suggests that the abandonment occurred as a result of the 659 CE earthquake, proposes that this seismic event might be another agent responsible for the sharp decline in the Palestinian wine industry. Although for the moment only a hypothesis, it is possible that this natural catastrophe, during times of an already changing socio-political and economic reality (especially along the coast; Taxel 2013), caused severe damage to many coastal (as well as inland) pottery workshops, since the jars they produced were largely designated for the international wine trade. Apparently, the recovery of these workshops was no longer economically worthwhile, or even possible, maybe in part due to changes in economic conditions and trends, and/or ideological aspects related to the new Muslim regime (as mentioned above, the production of wine and its associated ceramic containers continued on a smaller scale after the seventh century, though the distribution of these products was largely confined to local/regional markets). Thus, it may not be a coincidence that the quantity of Palestinian commercial ceramic containers documented in overseas locations after the mid-seventh century CE is often considerably smaller than those that originated in earlier contexts in the same places.

5.5. *Possible source location of the seismic event and its size*

Agnon (2014) discussed physical evidence for the seventh-century CE earthquakes in the Dead Sea. Careful microscopic examination of the laminated section from 'Ein Gedi core allows the correlation of historically documented shaking events and deformation layers termed 'intraclast breccia layers' or, more generally, 'seismites' (Migowski et al. 2004; Agnon et al. 2006) (originally termed 'mixed layers' by Marco & Agnon 1995) (Figure 2). An age model based on lamina-counting shows excellent agreement between a deformed layer and the 659/660 CE earthquake (Migowski et al. 2004). Kagan et al. (2011) found a similar result in 'Ein Feshkha with a Bayesian age-depth analysis based on dense sampling for radiocarbon. By contrast, the corresponding
section in Ze'elim creek (near Masada) shows undisturbed lamination (Kagan et al. 2011).

Considering the distance–magnitude systematics by Agnon (2014), and the 50-km distance of the two sites, a magnitude M~6 and an epicenter in the central Jordan Valley is a likely source (Agnon 2014, fig. 8.14). The two concentric circles on Figure 2 mark calculated isoseismals for local intensities VI and VII, respectively, assuming the attenuation relation inferred by Hough & Avni (2009/2010, equation 5). The sites for which historical and physical damage are documented lie between these two circles. A larger earthquake should have damaged Jerusalem to an extent that would likely be recorded historically; a smaller earthquake would not show such a broad distribution of damage. Yavneh experienced local intensities of 5–6 during the 1927 M~6.3 earthquake (Hough & Avni 2009/2010), hardly sufficient to account for demolition. Yet the pottery factory at Yavneh could have been more vulnerable to damage than typical sites at such an epicentral distance. Such an earthquake could be originated from a ~6-km rupture in the central Jordan Valley (Wells & Coppersmith 1994) at the branching point of the Carmel fault from the Dead Sea rift (Figure 2). Recently, Wechsler et al. (2014) assigned the source of a seventh-century CE event to surface ruptures documented north of the Sea of Galilee, some 85 km north of our inferred source. Our results imply that it was one of the 634 CE earthquakes that ruptured north of the Sea of Galilee. Another earthquake from that year could account for a rupture reported at the southern end of the Dead Sea (Haynes et al. 2006).

In summary, the new evidence for damage near Tel Yavneh, together with published historical documents and the sedimentological–chronological evidence from the Dead Sea, are best explained by a moderate magnitude (M~6) earthquake originating from the central Jordan Valley (Figure 2).

6. Conclusions

Palynology can add a new dimension to chronological studies of destruction layers, enabling us to decide between candidate historic events that fall within the range limited by other dating methods. Specifically, in the case of the Yavneh pottery workshop, palynological data have allowed us to refine the rather general seventh-century dating of the local earthquake destruction, as reflected by the artifactual – mainly ceramic – archaeological evidence, while allowing the attribution of this destruction to the earthquake in the spring of 659 CE rather than to that in the fall of 634 CE.

It is possible to distinguish palynologically with high certainty between these two earthquakes, based on a unique pollen sampling situation which resulted from the chain of events in the Yavneh pottery workshop: during the burning process in the kiln, no previously deposited pollen grains were preserved on the floor due to the high temperatures. Only when the covering of the kiln was removed did pollen traveling in the air penetrate the kiln with the air responsible for cooling, and it was deposited on the kiln floor together with other dusty particles. The collapse following the earthquake trapped the freshly arrived dust and the pollen below whole ceramic vessels which were in their cooling process, and allowed us, many centuries later, to identify the season in which the kiln complex went out of use. This rare situation from the palynological point of view is like a time capsule for scholars who are interested in refinement chronology of archaeological events and earthquake history.

This study therefore improves the chronology, while combining with the certain archaeological and economic context (namely, a huge pottery workshop which specialised in the production of commercial containers) and adds a new perspective to the complex issue of the decline of eastern Mediterranean commerce in general and Palestinian wine production in particular after the Muslim conquest; it is suggested in this study that the recovery of the Yavneh workshop (as well as other workshops along the coast) after the earthquake was no longer economically worthwhile, maybe in part due to changes in economic and political conditions in the region.

Acknowledgements

We wish to thank M. Kitin from the Israel Geological Survey for performing the pollen extraction procedure. I. Ben-Ezra, Y. Gottlieb and D. Porotsky are acknowledged for their help in drawing the figures. Pictures were made available thanks to the courtesy of the Israel Antiquities Authority (Photo C. Amit).

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

A. Agnon was supported by Israel Science Foundation grant no. 1181/12 and S. Marco was supported by Israel Science Foundation grant no. 1736/11.

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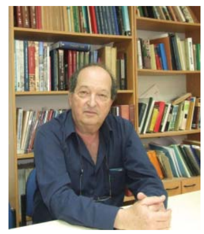

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References

Agnon A. 2014. Pre-instrumental earthquakes along the Dead Sea Rift, Dead Sea Transform Fault System: Reviews. Springer; p. 207–261.

Agnon A, Marco S, Migowski C. 2006. Intraclast breccia layers in laminated sequences reviewed: recorders of paleo-earthquakes. In: Enzel Y, Agnon A, Stein M, editors. New Frontiers in Dead Sea Paleoenvironmental Research. Geol Soc Amer Spec Paper 401:195–214.

Aharoni Y. 1967. The Land of the Bible: a historical geography. Philadelphia: Westminster Press.

Ambraseys N, Karcz I. 1992. The earthquake of 1546 in the Holy Land. Terra Nova 4:253–262.

Ambraseys NN. 2005. The seismic activity in Syria and Palestine during the middle of the 8^{th} Century; an amalgamation of historical earthquakes. J Seismol. 9:115–125.

Ambraseys NN. 2009. Earthquakes in the Mediterranean and Middle East: a multidisciplinary study of seismicity up to 1900. Cambridge: Cambridge University Press.

Bar-Nathan R, Atrash W. 2011. Bet She'an II, Baysān: the theater pottery workshop. Jerusaem: IAA Reports.

Baruch U. 1990. Palynogical evidence of human impact on the vegetation as recorded in late Holocene lake sediments in Israel. In: Bottema S, Entjes-Nieborg G, Van Zeist W, editors. Man's Role in Shaping of the Eastern Mediterranean Landscape. Rotterdam: A. A. Balkema; p. 283–293.

Baumgarten Y. 2001. A pottery kiln near the Giva'ti Junction. Atiqot. 42–43:323–324.

Beug HJ. 2004. Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete. München: Friedrich Pfeil.

Bottema S. 1975. The interpretation of pollen spectra from prehistoric settlements (with special attention to Cichorioideae). Palaeohistoria 17:17–35.

Bryant VM. 1974. Prehistoric diet in southwest Texas: the coprolite evidence. Am Antiquity 39:407–420.

Bryant VM. 1988. Preservation of biological remains from archaeological sites. In: Mathewson CC, editor. Interdisciplinary Workshop on the Physical-Chemical-Biological Processes Affecting Archaeological Sites. Vicksburg, U. S: Army Corps of Engineers Waterways Experiment Station; p. 85–115.

Bryant VM, Holloway BA. 1983. The role of palynology in archaeology. Adv Archaeol Method Th. 6:191–224.

Bryant VM, Holloway RG, Jones JG, Carlson DL. 1993. Pollen preservation in alkaline soils of the American Southwest. In: Traverse A, editor. Sedimentation of Organic Particles. Cambridge: Cambridge University Press; p. 47–58.

Danin A. 2004. Distribution Atlas of Plants in the Flora Palaestina Area. Jerusalem: Israel academy of sciences and humanities.

Decker M. 2013. The end of the holy land wine trade. Strata: Bulletin of the Anglo-Israel Archaeological Society 31:103–116.

Eastwood WJ, Roberts N, Lamb HF. 1998. Paleoecological and archaeological evidence for human occupancy in southwest Turkey: the Beysehir occupation phase. Anatolian Studies 48:69–86.

Eig A. 1933. Ecological and phytogeographical observations on Palestine plants. Beihefte Botanisches Centralblatt. 50:470–496.

Fabian K, Andreas K, Williams W, Heider F, Leibl T, Huber A. 1996. Three-dimensional micromagnetic calculations for magnetite using FFT. Geophys J Int. 124:89–104.

Faegri K, Iversen J. 1989. Textbook of Pollen Analysis (IV Edition). London: Blackburn Press.

Fischer M., Taxel I. 2007. Ancient Yavneh: its History and Archaeology. Tel Aviv 34:204–284.

Gadot Y, Tepper Y. 2003. A late Byzantine pottery workshop at Khirbet Baraqa. Tel Aviv 30:130–162.

Ghosh R, D'Rozario A, Bera S. 2006. Can palynomorphs occur in burnt ancient potsherds? An experimental proof J Archaeol Sci. 33:1445–1451.

Gophna R, Liphschitz N, Lev-Yadun S. 1986. Man's impact on the natural vegetation of the central coastal plain of Israel during the Chalcolithic period and the Bronze age. Tel Aviv 13–14:71–84.

Gophna R. Taxel I. Feldstein A. 2007. Kafr 'ana: a rural settlement in the Lod Valley. Salvage Excavation Reports 4:3–138.

Guidoboni E. 1996. Archaeology and historical seismology: the need for collaboration in the Mediterranean area. In: Stiros S, Jones RE, editors. Archaeoseismology. Athens: Institute of Geology & Mineral Exploration, and the British School at Athens; p. 7–13.

Guidoboni E, Comastri A, Traina G. 1994. Catalogue of Ancient Earthquakes in the Mediterranean Area up to the 10^{th} Century. Bologna: Istituto Nazionale di Geofisica.

Havinga AJ. 1984. A 20-year experimental investigation into the differential corrosion susceptibility of pollen and spores in various soil types. Pollen et Spores 26:541–58.

Haynes JM, Niemi TM, Atallah M. 2006. Evidence for ground-rupturing earthquakes on the northern Wadi Araba fault at the archaeological site of Qasr Tilah, Dead Sea Transform Fault System, Jordan. J Seismol. 10:415–430.

Hinzen K-G. 2009. Simulation of toppling columns in archaeoseismology. B Seismol Soc Am. 99:2855–2875.

Hinzen K-G. 2011. Sensitivity of earthquake toppled columns to small changes in ground motion and geometry. Israel J Earth Sci. 58:309–326.

Hinzen K-G, Fleischer C, Reamer SK, Schreiber S, Schütte S, Yerli B. 2011. Quantitative methods in archaeoseismology. Quatern Int. 242:31–41.

Hirschfeld Y. 1993. Euthymius and his monastery in the Judean Desert. Liber Annuus 43:339–371.

Horowitz A. 2001. The Jordan Rift Valley. Lisse: A.A. Balkema Publishers.

Hough SE, Avni R. 2009/2010. The 1170 and 1202 CE Dead Sea Rift earthquakes and long-term magnitude distribution of the Dead Sea Fault zone. Israel J Earth Sci. 58:295–308.

Israel Y. 1993. Survey of pottery workshops, Nahal Lakhish-Nahal Besor. Excavations Surv Israel 13:106–107.

Kagan E, Stein M, Agnon A, Neumann F. 2011. Intrabasin paleoearthquake and quiescence correlation of the late Holocene Dead Sea. J Geophys Res Sol Ea. 116:B4.

Karmon Y. 1971. Israel: a Regional Geography. London: John Wiley.

Keynan N, Waisel Y, Shomer-Ilan A, Goren A, Brener S. 1991. Annual variations of air-borne pollen in the coastal plain of Israel. Grana 30:477–480.

Korjenkov A, Mazor E. 1999a. Earthquake characteristics reconstructed from archeological damage patterns: Shivta, the Negev Desert, Israel. Isr J Earth Sci. 48:265–282.

Korjenkov A, Mazor E. 1999b. Seismogenic origin of the ancient Avdat ruins, Negev Desert, Israel. Nat Hazards 18:193–226.

Langgut D, Almogi-Labin A, Bar-Matthews M, Weinstein-Evron M. 2011. Vegetation and climate changes in the

South Eastern Mediterranean during the Last Glacial-Interglacial cycle (86 ka): new marine pollen record. Quaternary Sci Rev. 30:3960–3972.

Langgut D, Gadot Y, Porat N, Lipschits O. 2013. Fossil pollen reveals the secrets of royal Persian garden at Ramat Rahel (Jerusalem). Palynology 37:115–129.

Langgut D, Neumann FH, Stein M, Wagner A, Kagan EJ, Boaretto E, Finkelstein I. 2014. Dead Sea pollen record and history of human activity in the Judean Highlands (Israel) from the intermediate Bronze into the Iron Ages (~2500-500 BCE). Palynology 38:280–302.

Lebreton V, Messager E, Marquer L, Renault-Miskovsky J. 2010. A neotaphonomic experiment in pollen oxidation and its implications for archaeopalynology. Rev Palaeobot Palyno. 162:29–38.

Lev-Yadun S. 1997. Flora and Climate in Southern Samaria: Past and Present. In: Finkelstein I, Lederman Z, Bunimovitz S, editors. Highlands of Many Cultures I - the Sites. Tel Aviv: Monograph Series of the Institute of Archaeology; p. 85–102.

Liphschitz N, Lev-Yadun S, Gophna R. 1987. The Dominance of *Quercus calliprinos* (Kermes Oak) in the Central Coastal Plain in Antiquity. IEJ. 37:43–50.

Liu K-b. 2007. Uncovering Prehistoric Hurricane Activity Examination of the geological record reveals some surprising long-term trends. Am Sci. 95:126–133.

Liu K-b, Fearn ML. 2000. Reconstruction of prehistoric landfall frequencies of catastrophic hurricanes in northwestern Florida from lake sediment records. Quaternary Res. 54:238–245.

Marco S. 2008. Recognition of earthquake-related damage in archaeological sites: examples from the Dead Sea Fault zone. Tectonophysics 453:148–156.

Marco S, Agnon A. 1995. Prehistoric earthquake deformations near Masada, Dead Sea Graben. Geology 23:695–698.

Mayerson P. 1992. The Gaza Wine Jar (Gazition) and the 'lost' Ashkelon Jar (Ashkelonion). IEJ. 42:76–80.

Mazor E, Korjenkov A. 2001. Applied archaeoseismology: decoding earthquake parameters recorded in archaeological ruins: the Makhteshim country: a laboratory of nature—geological and ecological studies in the desert region of Israel; p. 423.

Migowski C, Agnon A, Bookman R, Negendank JFW, Stein M. 2004. Recurrence pattern of Holocene earthquakes along the Dead Sea Transform revealed by varve-counting and radiocarbon dating of lacustrine sediments. Earth Planet Sc Lett. 222:301–314.

Neumann FH, Zangenberg J, Shivti'el Y, Münger S. 2014. Galilee Blooming: First palynological and archaeological data from an Early Byzantine Cistern at Horvat Kur. Environ Archaeol. 19:39–54.

Nichols H, Kelly PM, Andrews JT. 1978. Holocene palaeowind evidence from palynology in Baffin Island. Nature 273:140–142.

Oked HS. 2001. "Gaza Jars": a chronicle, and economic overview. In: Sasson A, Safrai Z, Sagiv N, editors. Ashkelon: a City on the Seashore. Ashkelon: Ashkelon Academic Collage; p. 227–250 (Hebrew with an English Summary).

Parker JA. 1992. Ancient Shipwrecks of the Mediterranean and the Roman Provinces. BAR S.580. Oxford.

Pieri D. 2005. Le commerce du vin oriental à l'époque Byzantine (Ve-VIIe siècles): Le témoignage des amphores en Gaule. Beirut: Institut français du Proche-Orient.

Pieri D. 2012. Regional and Interregional Exchanges in the Eastern Mediterranean during the Early Byzantine Period. In: Morrisson C, editor. Trade and Markets in Byzantium. Washington D.C: Dumbarton Oaks Research Library and Collection; p. 27–49.

Raban A, Holum KG, Blakely JA. 1993. The combined Caesarea expeditions: field reports of the 1992 season. Haifa: University of Haifa.

Reille M. 1995. Pollen et Spores d'Europe et d'Afrique du Nord. Supplément 1. Marseille: Laboratoire de Botanique Historique et Palynologie.

Reille M. 1998. Pollen et Spores d'Europe et d'Afrique du Nord. Supplément 2. Marseille: Laboratoire de Botanique Historique et Palynologie.

Reille M. 1999. Pollen et Spores d'Europe et d'Afrique du Nord. Marseille: Laboratoire de Botanique Historique et Palynologie.

Rodríguez-Pascua MA, Pérez-López R, Giner-Robles JL, Silva PG, Garduño-Monroy VH, Reicherter K. 2011. A comprehensive classification of Earthquake Archaeological Effects (EAE) in archaeoseismology: application to ancient remains of Roman and Mesoamerican cultures. Quatern Int. 242:20–30.

Russell KE. 1985. The earthquake chronology of Palestine and Northwest Arabia from the 2nd through the Mid-8th Century A.D. BASOR. 260:37–60.

Sengupta S. 1975. Experimental alterations of the spores of *Lycopodium clavatum* as related to diagenesis. Rev Palaeobot Palyno. 19:173–192.

Sintubin M. 2011. Archaeoseismology: past, present and future. Quatern Int. 242:4–10.

Sklowski L. 1985/6. Pottery Firing Process. Hebrew University, Jerusalem.

Stiros SC. 1996. Identification of earthquakes from archaeological data: method- ology, criteria and limitations. Fitch Laboratory Occasional Paper 7. In: Stiros S, Jones R, editors. Archaeoseismology. Oxford: British School at Athens; p. 129–152.

Stockmarr J. 1971. Tablets with spores used in absolute pollen analysis. Pollen Spores 13:615–621.

Taxel I. 2009. Khirbet es-Suyyagh: a Byzantine monastery in the Judean Shephelah. Tel Aviv: Salvage Excavation Reports v. 6.

Taxel I. 2013. The Byzantine-early Islamic transition on the Palestinian Coastal Plain: a re-evaluation of the archaeological evidence. Semitica et Classica 6:73–106.

Walker BJ, LaBianca Ø. 2003. The Islamic Quṣūr of Tall ḥisbān: Preliminary Report on the 1998 and 2001 Seasons. Annu Department Antiquities Jordan 47:443–471.

Walmsley A. 2007. Early Islamic Syria: an archaeological assessment. London: Bloomsbury Publishing.

Wechsler N, Rockwell TK, Klinger Y, Štěpančíková P, Kanari M, Marco S, Agnon A. 2014. A Paleoseismic Record of Earthquakes for the Dead Sea Transform Fault between the First and Seventh Centuries Ce: nonperiodic behavior of a plate boundary fault. B Seismol Soc Am. 104:1329–1347.

Weinstein-Evron M, Lev-Yadun S. 2000. Palaeoecology of *Pinus halepensis* in Israel in the light of archaeobotanical data. In: Neeman G, Trabaud L, editors. Ecology, biogeography and management of *Pinus halepensis* and *Pinus brutia* forest ecosystems in the Mediterranean Basin. Leiden: Backhuys Publishers; p. 119–130.

Wells DL, Coppersmith KJ. 1994. New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. B Seismol Soc Am. 84:974–1002.
Yannai E. 2012. A Byzantine Pottery Kiln Complex at Yavne. Qadmoniot. 144:94–103 (Hebrew).
Yannai E. 2014. Excavations at Yavneh. Jerusalem: Hadashot Arkheologyot - Excavations and Surveys in Israel 126.
Zohary M. 1962. Plant life of Palestine, Israel and Jordan. New York: The Ronald Press Company.