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Pedology of archaeological soils in tells of the Judean foothills, Israel

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ABSTRACT

Tells (archaeological mounds) predominantly consist of poorly consolidated to unconsolidated sediments, and soils that are highly anthropogenic. This study examines pedogenic processes related to carbonate mobilization in tells in comparison with their peripheral soils (reference soil profiles). The key objective of this study is to test the hypothesis that tell deposits evolve through concurrent processes of sedimentation and pedogenesis (synlithogenic pedogenesis), and further explain it. Case studies are presented from three tells in semi-arid and Mediterranean climatic zones of the Levant. The methods applied included field survey, analyses of particle size distribution, pH, %$CaCO_3$ and organic carbon content, and soil micromorphology. Soils of the tells contain miscellaneous cultural materials that derive mainly from degraded mud bricks, pottery and burnt wood. Chemical data show basic pH values, high $CaCO_3$ content, and minor amounts of organic carbon. Field observations and lab analyses both indicate high similarity amongst the tells and their reference soil profiles. Buried tell soils show same characteristics as near-surface soils. However, the reference soil profiles show incipient horizonation, slightly darker colours, and more developed structure. Micromorphology of both the tells and the reference profiles show cohesively welded peds in a vughy microstructure, groundmass with an open porphyric c/f-related distribution, and discontinuous carbonate recrystallization. Relative rates of soil formation in the tells can be estimated when archaeological records are established. Contrary to the tells, the reference soil profiles show lower porosity and only minor remnants related to earth construction materials. We classify the soils of the studied tells as archaeological Calcareous Anthraltic Xerorthents. The correlative WRB classification would be Calcic Urbic Technosols (Archaic). The anthropogenic materials are as calcareous as the natural soils, but due to human action, carbonates in the tells are distributed differently. Based on these observations, ancient human actions and the dry climate have led to very little mobilization and accumulation of carbonates. The information provided in this study adds to the pedological understanding of archaeological environments. Specifically, it can be useful for the study of site formation processes of tells.

1. Introduction

The evolution of tells involves repeated human occupation of sites that built-up as a result of deposition and erosion processes of cultural materials (Davidson, 1976; Butzer, 1982, p.77–97; Rosen, 1986; Wilkinson, 2003, p. 100–127; Matthews, 2017). Tells etymologize from the Semitic language of Akkadian (Tillu; *tēlu*, meaning mound, ruin heap; Sokoloff, 2002). The occurrence of tells is abundant in western Asia, southeastern Europe and North Africa (Matthews, 2017). The characteristic composition of many tells is either calcareous or gypsiferous (e.g., Matthews et al., 1994; Beach and Luzzadder-Beach, 2008; Pustovoytov et al., 2011; Love, 2012; Benz et al., 2015; Riehl et al., 2015; Ackermann et al., 2017a), indicating that tells commonly form under arid to temperate (Mediterranean) climatic conditions. Apparently, pedogenesis in tells occur simultaneously with sedimentation (Sedov et al., 2017). Different from the classic (gradual) pathways of soil forming processes (Schaetzl and Anderson, 2005, pp. 347–461; Blume et al., 2016, pp. 285–316), soil formation that is associated with concurrent sedimentation is regarded as "synlithogenic pedogenesis" (Khokhlova et al., 2001; Targulian and Goryachkin, 2004; Shishov et al., 2005).

Recently, Sedov et al. (2017) added a new pedo-archaeological approach to the study of tell formation processes by considering synlithogenic pedogenesis as having a key role in the formation and

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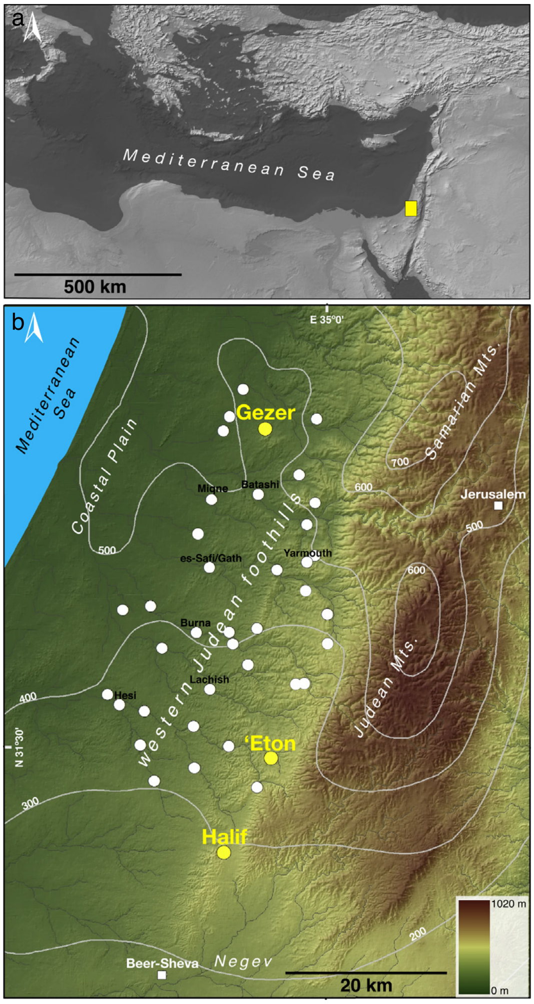

Fig. 1. (a) Map of the Eastern Mediterranean, showing the location of the study area (yellow rectangle). (b) Study area, showing locations of recognized tells (white dots) and sites of case studies (yellow dots). Names of other sites that are mentioned in the text are indicated in black. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

stratigraphical development of tells. By inspecting deposits of two tells in northern Thrace (Bulgaria) and southeastern Anatolia (Turkey), Sedov et al. (2017) concluded that contrary to natural soils, soils in tells form in a synlithogenic manner and could be classified as Urbic Technosols. However, despite these advances, several knowledge gaps remain in our understanding of pedogenesis of tells, such as: 1) What are the dominant processes of synlithogenic pedogenesis in tells? 2) What pedogenic properties and processes control the composition and structure of tells? 3) Can synlithogenic soils of tells be further classified and mapped? To address these knowledge gaps we investigated three tells in the Judean foothills, Israel (Fig. 1). The goals of this study are to: 1) Provide new insights on pedogenesis of near-surface calcareous deposits of tells, 2) Examine the possible pedogenetic relations between tells and their peripheral soils, 3) Assess the extent by which pedogenic properties influence the morphology and preservation of tells, 4) Further classify tell soils, 5) Raise implications for pedological and (geo) archaeological research of tells.

Tells are commonly distributed in the western Judean foothills (also known as the Shephelah; Fig. 1). The first geoarchaeological studies of tells in the Judean foothills started in the late 20th century (Bullard, 1970; Goldberg, 1979; Rosen, 1986). Here we examine three tells from this region: Gezer, 'Eton and Halif (Fig. 1). As a result of previous excavations (Ortiz and Wolff, 2012; Faust, 2013; Sapir, 2016; Borowski, 2017) a large area is exposed in the three tells. The examination of these specific sites enables us to observe hundreds of square metres of open profiles with no need for further excavations. While most of this study refers to the upper 1–2 m of the studied tells, a large excavation space in Tell Gezer (> 10 m deep, 20 × 20 m wide), and the detailed work of Sapir (2016) at Tell 'Eton, provide us with a view and a reference to large portions of soil that could not be inspected in this study. The available archaeological records of the three tells (Ortiz and Wolff, 2012; Faust, 2013; Sapir, 2016; Borowski, 2017) enable to assess the maximum age boundaries for the formation time of the studied profiles. A combination of field survey, particle size distribution (PSD), pH, $CaCO_3$ content, and organic carbon (OC) content has been applied in order to explore the nature of the groundmass of the tells and compare them with soils from their proximity. Soil micromorphology, that was proved to be most efficient for studies of tell soils (Stoops and Nijs, 1986; Matthews, 1995; Courty and Coqueugniot, 2013; Maghsoudi et al., 2014; Sedov et al., 2017) is taken as our main method. It is, however, accentuated that soil micromorphology is applied here as a tool for interpreting pedogenic features, rather than cultural materials. As opposed to the intense study of anthropogenic effects on soils in modern times (Howard, 2017), this study sheds light on a rarely discussed topic - the influence of humans on soil forming processes in history.

2. Background and previous studies

Early studies that described cultural mounds did not refer to their geoarchaeological features (Warren and Conder, 1884; Clermont-Ganneau, 1896; Rassam, 1897; Hilprecht, 1903, p.17). Such reference came only in the second half of the 20th century (Lloyd, 1963; Davidson, 1973, 1976; Liebowitz and Folk, 1980; Butzer, 1982, p.77–97), with the molding of geoarchaeology (Davidson and Shackley, 1976; Shahack-Gross, 2017). Further on, a milestone in the study of tells has been achieved with Rosen's (1986) seminal book “Cities of Clay: The Geoarchaeology of Tells”. Since then, marked efforts have been conducted in exploring various (geoarchaeological) materials and properties of tells (Albert et al., 2008; Matthews, 2010; Love, 2012; Maghsoudi et al., 2014; Regev et al., 2015; Sapir et al., 2016; Shahack-Gross et al., 2018), whereas only scarce studies focused on pedological processes in tells (Stoops and Nijs, 1986; Ryan et al., 2009), and not a much higher number of studies present a more holistic view on tell formation processes (Matthews et al., 1997; Davidson et al., 2010; Sapir, 2016; Sedov et al., 2017). Inspecting site formation processes is usually performed in the scope of ethnoarchaeological studies, mainly for the purpose of reconstructing past human activities (Schiffer, 1987; Weiss et al., 1993; Stein, 2001; Shahack-Gross et al., 2005; Matthews, 2010; Davidson et al., 2010; Riehl et al., 2015). Here, however, the terminology of “tell formation process” is discussed in a pedological context.

Tells are amongst the most outstanding archaeological landforms of the Judean foothills (Fig. 1). Located in the southwestern area of the Fertile Crescent (Lev-Yadun et al., 2000), since prehistoric times this part of the Levant has attracted many civilizations (Stern and Urman, 1988; Dagan, 2000, 2011), as inferred from the dense distribution and distinctive appearance of tells across the landscapes of this region. As shown in previous studies (Khalaily and Marder, 2010; Marder et al., 2011; Zaidner et al., 2018) the earliest prehistoric sites known so far in the Judean foothills are related to the Lower Palaeolithic (Late Acheulean culture). The cultural peaks in this region occurred during the Late Bronze (1550–1200 BCE) and Iron ages (1200–586 BCE; Koch, 2017; Maeir and Lipschits, 2017), and later, during the Byzantine period (324–638 CE; Bar, 2004). The youngest finds are attributed to the Ottoman period (20th century CE; e.g., Dagan, 2011).

Archaeological excavations of tells in the Judean foothills initiated in 1890 with an expedition to Tell el-Hesi (Hesi in Fig. 1; Bliss, 1894, p.77), and a decade later by excavating Tell Gezer (Macalister, 1925, p.64-73). However, geoarchaeological studies of tells in this region began only in the late 1960s. Bullard (1970), linked the sources of geological materials with human actions at Tell Gezer. Goldberg (1979) took a similar approach by identifying the source of mud brick materials at Tell Lachish (Fig. 1) and inspecting possible post-depositional alterations in those bricks. Broader examination of local tells and their formation processes was conducted by Rosen (1986) who focused on Tell Lachish, while adding reference data from Tell Batashi and Tell Miqne (as well as other tells outside this area). By providing a model for the development and erosion of tells, Rosen (1986) argued that tells are anthropogenic landforms that evolve through cultural and environmental interactions between humans and their natural surroundings. Rosen (1986) also emphasized the importance of implementing "microarchaeology" (other than soil micromorphology) in the study of tells.

Namdar et al. (2011) studied degradation-accumulation processes of a destruction layer at Tell es-Safi/Gath, and assessed the timeframe of these processes. By interpreting their observations with different post-depositional processes and production practices, Namdar et al. (2011) have reconstructed a cultural layer in this tell. Sapir (2016) inspected the formation processes of Tell 'Eton with relation to its surroundings and strongly related the development of the tell with both *in situ* and peripheral natural and cultural processes. By doing so he reconstructed a major destruction layer in that tell. Related to the study of Sapir (2016), Sapir and Faust (2016) argued that mole-rats (*Spalax ehrenbergi*) actions are a highly important agent of bioturbation in tells, and Sapir et al. (2016) reconstructed ancient architecture and production methods by analyzing mud brick composition. Studying concentrations of nutrients in Tell Burna, enabled Smejda et al. (2017a, 2017b) to reconstruct the longterm influences of human actions on topsoils, and later map them. By examining the slopes and periphery of Tell es-Safi/Gath, Ackermann et al. (2004, 2015, 2017a) reconstructed palaeoenvironmental conditions and past anthropogenic influences on the soils and landscape of this tell. Additionally, Paz et al. (2017) found that an ancient agricultural field in the proximity of Tell Yarmouth (Fig. 1) was anthropogenically constructed and agriculturally managed. However, while the above studies contributed much to the understanding of different ways by which humans have affected soils, they hardly discuss any actual pedogenic processes in tell soils. Moreover, Goldberg (2004) stressed that same as was argued by Liebowitz and Folk (1980), modified cultural material from Tell Lachish lack signs of pedogenesis, although he concluded by encouraging further study that might verify what pedological processes act on relicts of mud bricks.

3. The study area

The study area is situated in the Eastern Mediterranean and includes the western Judean foothills, Israel (Fig. 1). This region is characterized by westward descending mild hills with an elevation of ~90–500 m a.s.l. (Bar et al., 2016). This hilly landscape is truncated by four main channels and is bounded in the north and south by alluvial valleys (Ayalon and Beer Sheba valleys, respectively). The western Judean foothills juxtapose the Judean Mountains to the east, and the coastal plain of the Mediterranean Sea to the west. The bedrock is predominantly composed of Upper Cretaceous and Eocene carbonate rocks (mostly chalk, and to a lesser degree limestone and marl) with some Quaternary alluvium and clastic sedimentary rocks (Sneh et al., 1998; Bar et al., 2016). Most of the exposed bedrock is capped with late Cenozoic calcrete, locally known as 'nari' (Itkin et al., 2012). The climate is mostly temperate (Csa; Peel et al., 2007; Mediterranean) with arid (BSh; Peel et al., 2007) conditions in its southern part (Goldreich, 2003, p.12–17). The mean annual precipitation is 530–200 mm/yr, declining southwards (Israel Meteorological Service, 2018). Generally, these climatic conditions have prevailed during, at least, the last 5000 yrs. (Wiesl et al., 1986; Bar-Matthews et al., 1998).

The soil distribution (Soil Survey Staff, 2014, followed by IUSS Working Group WRB, 2015 in parentheses) includes: Mollisols (Leptosols, Phaeozems), Alfisols (Luvisols), Entisols (Regosols, Fluvisols), Vertisols, Inceptisols (Cambisols), and Aridisols (Calcisols). The latter, only in the southern part of this area (Dan, 1988a, 1988b). Soils have a xeric moisture regime and a thermic temperature regime (Soil Survey Staff, 2014; Israel Meteorological Service, 2018). The soils of this area are human-disturbed and severely degraded since, at least, the Early Bronze Age, due to influences such as overgrazing and poor agriculture practices (Naveh and Dan, 1973; Dan, 1988a). Desert loess is a major constituent of the Luvisols (Alfisols) and Vertisols (Dan, 1988a). These soils, that are located mainly in the valleys and truncated hill tops, are fertile and being cultivated for growing a range of cereal crops and deciduous fruit trees (Soil and Pasture Survey Staff, 1983). Buried soils are also found in the Judean foothills (Soil and Pasture Survey Staff, 1983; Weiner-Bloch, 1989), some of which are highly human induced (Ackermann et al., 2004, 2017b).

The phytogeographical conditions are predominantly Mediterranean (Sapir, 1977; Danin, 1988). The vegetation is mostly of an open park forest with carob trees (*Ceratonia siliqua* L.), interspersed in a mosaic with patches of planted pine forests (*Pinus halepensis Mill.*), and olive orchards (*Olea europaea* L.), associated with *Pistacia lentiscus* and *Sarcopoterium spinosum* shrubs and annual plants (Sapir, 1977; Danin, 1988). The arid part of the area exhibit sparse vegetation, predominated by annual plants. Because of this sparsity of vegetation, erosion of the soil is markedly higher in the arid area (Dan, 1988a).

The three tells studied here are located along a climatic gradient that includes Mediterranean (Gezer) and semi-arid climates ('Eton and Halif). Tell Gezer is located at the northern part of the study area, 230 m a.s.l., where the Judean foothills coincide with the Samarian foothills (Figs. 1, 2; supplementary material). The length and width of this tell are 890 m by 250 m, respectively, and its height above the surroundings is 25 m. Gezer was initially occupied around 3500 BCE, and during the Middle Bronze Age IIC (~2000–1500 BCE) it became a fortified city (Ortiz and Wolff, 2012). The latest and highest layer of Gezer is related to the Hellenistic period (167–63 BCE; Ortiz and Wolff, 2017). Situated on a major ancient crossroad, Gezer is considered as one of the most important Iron Age cities of the southern Levant, as indicated by its archaeological assemblage as well as its references in biblical, Egyptian, and Assyrian sources (Ortiz and Wolff, 2012). The stratigraphy of Gezer includes five destruction layers (Ortiz and Wolff, 2017). In what might be referred to as a sixth destruction layer, a large area of this tell has been excavated and refilled by Stewart Macalister during the first decade of the 20th century (Ortiz and Wolff, 2017).

Tell 'Eton is located at the southeastern part of the study area, 400 m a.s.l., at the footslopes of the Judean Mountains western flank (Figs. 1, 2; supplementary material). It is 560 m by 190 m and its height above the surroundings is 15 m. This tell was first inhabited during the Early Bronze Age, reached its cultural and economic peak at the Iron Age II, and experienced a destruction at the end of the 8th century BCE, apparently amongst few other destruction events throughout its history (Faust and Katz, 2015). The proximity of this tell to the city of Hebron (to the east) and easy access to the coastal plain (to the west), suggests that it served as a major crossroad (Faust and Katz, 2015). Tell 'Eton was resettled during the late Persian-early Hellenistic periods (roughly 4th–3rd centuries BCE), and was reused for agricultural purposes from at least the Byzantine period, when terraces were apparently constructed on it (Faust, 2013; Sapir, 2016).

Tell Halif is located at the southernmost part of the study area, 490 m a.s.l., bordering with the arid climatic zone of the northern Negev (Figs. 1, 2; supplementary material). The size of this tell is 270 m by 160 m and its height above the surroundings is 10 m. Tell Halif was first inhabited during the Early Bronze Age or even earlier than that (2600–2500 BCE; Borowski, 2017). Including at least three destruction layers in its archaeological record, the latest strata on the tell is related to the Persian (500–300 BCE) and Hellenistic (300–100 BCE) periods.

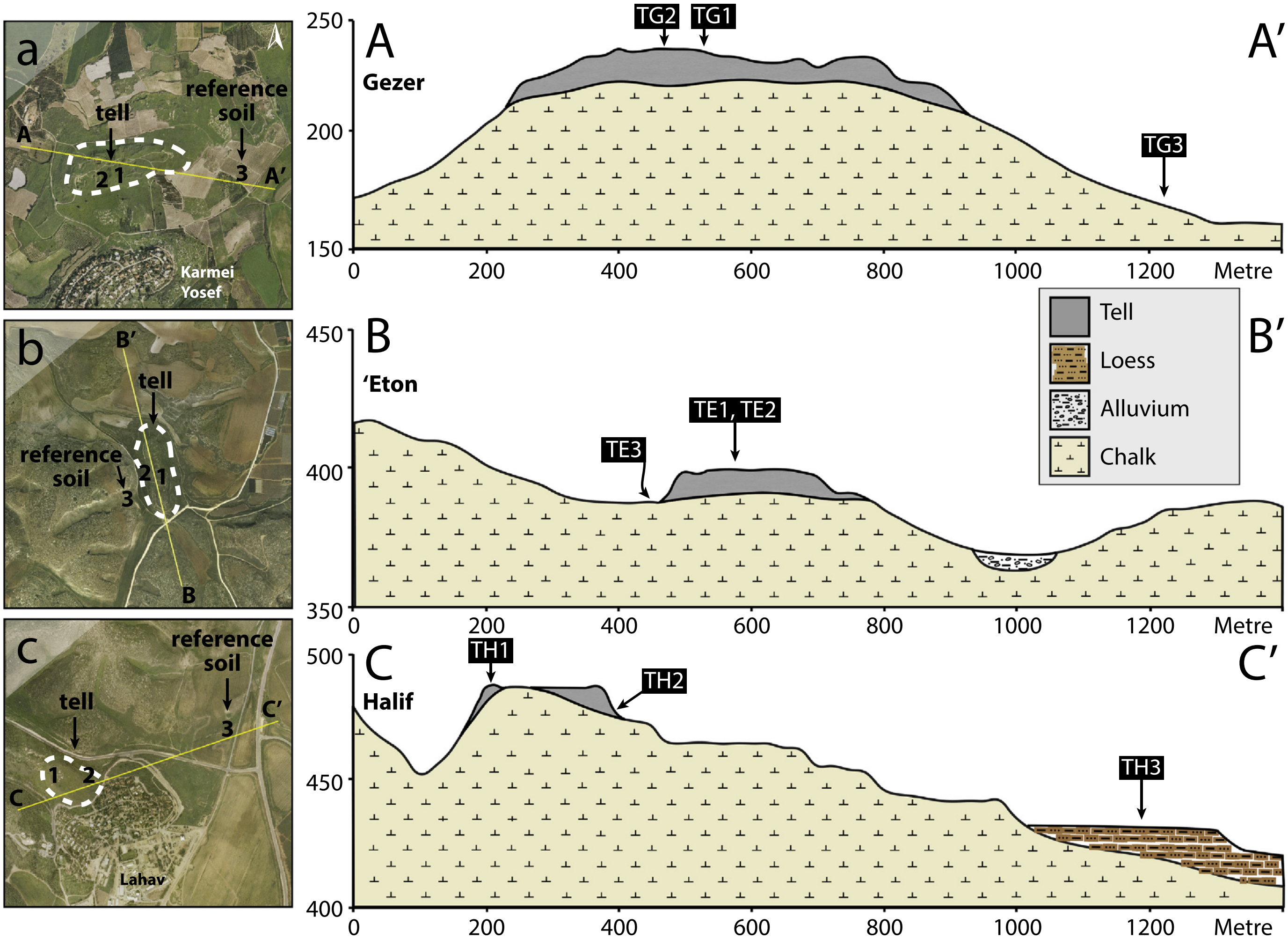

Fig. 2. Aerial photos (left) and schematic cross-sections (right) of the case-study tells. Abbreviations: TG - Tell Gezer, TE - Tell 'Eton, TH - Tell Halif (profiles are indicated by numbers, e.g., TG1, TG2, TG3). White dashed lines denote the area of the tells. Calcrete and soils are not indicated in the cross-sections. All aerial photos are oriented with north pointing up. Numbers 1, 2, 3 mark the sampling localities. Some of the locations that are marked in the aerial photos are projected in the cross sections (TG1, TG2, TE3).

Later, during the Roman/Byzantine periods (200–600 CE) the tell was barely occupied, and then resettled and abandoned in the Early Arab period (approx. 700 CE; Borowski, 2017).

4. Methods

The methods applied in this study include: 1) Remote sensing using Google Earth images, 2) Field survey, including observations and field analyses of colour (Munsell Color, 1990), texture estimation, and $CaCO_3$ effervescence (dilute hydrochloric acid), 3) PSD, 4) Chemistry analyses; pH, %$CaCO_3$, OC, and 5) Soil micromorphology. The field survey was based on relevant topics in the guidelines of Schoeneberger et al. (2012) for describing and sampling soils. Our sampling strategy included the following stages: 1) Forty tells were mapped across the western Judean foothills (Fig. 1), 2) Three tells were selected for closer examination: Gezer, 'Eton, and Halif (Figs. 1, 2), 3) The surfaces of the examined tells and their vicinity were carefully observed, first by a dji phantom (3 pro) drone and then on foot, 4) Two representative soil profiles were sampled per tell, in its summit and backslope, 5) A third profile (reference profile) was studied and sampled at the footslope or toeslope outside each tell, in order to confirm whether soils outside the tells are genetically related to their cultural deposits, 6) Each soil profile was sampled in three depths, 7) Undisturbed samples for micromorphology were extracted by applying the "selective sampling" method (Courty et al., 1989, p. 40–43). Namely, samples were retrieved according to specific considerations in each profile (archaeological record and length of profile), 8) Special attention was taken to avoid from inspecting modernly disturbed groundmass of previous archaeological excavations (e.g., the early 1900s excavations of Macalister; Wolff, 2017), 9) Soil classification was made according to the USDA Soil Taxonomy (Soil Survey Staff, 2014, 2015).

A few exceptions in our sampling procedure were made in the field: 1) Profile TG1 (Gezer) was extracted from the shoulder of the tell (instead of its summit), 2) Despite efforts to avoid from inspecting modernly disturbed material, in Tell Gezer it is nearly impossible to find such near-surface profiles. Therefore, profiles TG1 and sample TG2a (Gezer), were extracted from zones that have been anthroturbated during the early 1900s excavation of Macalister (Eli Yannai, pers. comm.), 3) Profile TH1 was sampled in four locations, rather than three, due to a suspected different material in its lower part (sample TH1d).

An overall of thirty-nine soil samples were analyzed: Twenty-five disturbed samples were extracted for soil analyses of PSD, pH, $CaCO_3$ content and OC, and fourteen undisturbed and oriented samples were taken for soil micromorphology. Twenty-one thin sections and twelve scanning electron microscopy (SEM) samples were produced out of the undisturbed samples. The exposed profiles enabled sampling to a depth of 100–200 cm. Profile TG2 (Gezer) was sampled to a depth of 445 cm.

All disturbed samples were air dried, sieved (< 2 mm) and split for further analyses. PSD analysis was performed with Malvern MS-2000 laser diffraction over the particle-size range of 0.02 to 2000 μm. Measurement procedure included dispersion (using sodium hexametaphosphate solution), stirring for 5 min, and ultrasonication for 30 s. Three to six replicate specimens of each sample were then subjected to three consecutive 5 s runs at a pump speed of 1800 RPM. The laser diffraction raw values were transformed into PSD using the Mie scattering model, with optical parameters of RI = 1.52 and A = 0.1. Here, we present the full PSD results and also calculate the clay/silt/sand fractions using thresholds of 6 μm and 63 μm, respectively. We chose 6 μm as the upper clay fraction threshold since several studies had demonstrated that it is equivalent to the mostly used 2 μm threshold when using the sedimentation technique (e.g., Miller and Schaetzl, 2012; Fisher et al., 2017). Soil pH_{H2O} (1:1 water/soil) followed the protocol of Burt (2014). Carbonate content was estimated using the pressure calcimeter method (Evangelou et al., 1984), OC was estimated using the modified Walkley-Black titration method (Gelman et al., 2012). Samples for carbonate content and OC were crushed before analyses.

Soil micromorphology was performed with polarizing light microscopy and scanning electron microscopy. The preparation of the thin sections (after drying, impregnating, grinding etc.) was produced with 2.5 × 7.5 cm slides according to Gottlieb (2015, p.13–28). The samples were observed using an Olympus BX53 polarizing microscope and photographed using an Olympus DP23 digital camera mounted on the microscope. The micromorphological descriptions were made according to Stoops (2003). The SEM samples were observed using a SEM model FEI Quanta 450, in a presentation mode of a secondary electron image, which displays surface texture, morphology and surface roughness.

5. Results

5.1. Tells: field observations and lab analyses

The first and most straightforward field observation is that all tells have a secluded appearance in the landscape and a flat summit. Different from the way occasionally described in geological maps (e.g., Sneh and Avni, 2008) all three tells are situated on preexisting natural hills of Eocene chalk (at least partly altered by calcrete). The tells are composed of archaeological materials and erosional deposits, with no allochthonous input of soils or sediments (excluding a minor contribution of aeolian dust). Occasionally, remnants of ancient agricultural terraces are observed along the slopes. The surface of the tells show a mosaic of Mediterranean shrubs and annual plants, vast number of potsherds, dozens of recent mole-rats' mounds, frequent cm-scale burrows, as well as many ant (common: *Messor ebeninus*) nests and trails. One exceptional landform is a small bedrock outcrop at the summit of Tell Halif (Fig. 2).

The results show homogeneity in the soil profiles of each tell and high similarity amongst all three of them (Table 1). The soils of the three tells show a massive weak structure when peds are not disturbed and a single grain weak to moderate structure, or granular in some discrete domains, when peds are slightly put under pressure by hand (Table 1). Carbonate in the observed profiles show strong effervescence throughout, with no (field) expression of induration. The dry colour of all samples (not indicated in Table 1) is similar to their moist colour. The moisture status of the profiles is dry, except for slightly moist buried soils in the lower part of profile TG2 (TG2b and TG2c; Tell Gezer). It should be noted that the buried soil samples TG2b and TG2c have similar characteristics as all other samples, except for TG2c which has a slightly darker colour and slightly less $CaCO_3$ content (Table 1). Although not sampled, we documented an observation of a 700 cm deep profile in Tell 'Eton (situated between profiles TE1 and TE2) that highly resembles profiles TE1 and TE2 in its homogeneity of colour, texture and structure, throughout.

All profiles are embedded with variable quantities of miscellaneous material, mostly fragments that includes pottery coated with thin calcareous accumulations (Fig. 3), mud bricks, charred wood and carbonate rock, mostly chalk. Occasionally, earthworm channels, shales of land snails and fragments of bones are also observed. The tells are canopied by annual plants. The rhizosphere of the annual plants extends to a depth of ~20 cm below the surface. Shrub roots reaches a depth of 1 m and more in a few places. The most pronounced field differences amongst the profiles of the three tells concerns the cultural context and quantity of artifacts in each (not specified in this study). The soils of the three tells show similar PSD characteristics (Table 1; Fig. 4a). All are characterized by a bi-modal distribution with modes at the coarse silt fraction (30–50 μm) and at the clay fraction (~1 μm). The main grain fraction is silt (60–70%), followed by clay (15–30%) and sand (5–15%).

5.2. Tells: micromorphological observations

The groundmass of the studied tells share high similarity but show different soil fabric, mainly in the quantity and size of common constituents. All tell profiles include the following fabric elements, unless otherwise indicated: Vughy microstructure with open porphyric coarse/fine(c/f)-related distribution ($c/f_{4\mu m}$ limit), and porous crumb peds ("peds" as alternatively to "aggregates"; Stoops, 2003, p. 58). Peds are partly welded and composed of micrite, small amounts of Fe-stained clay, charred particles (wood ash), and minor content of other organic matter. The groundmass shows discontinuous carbonate recrystallization (Figs. 5, 6, 7). Different from the observed contact between peds, most of the micrite grains that compose the peds are not welded, i.e., they are held mainly by cohesion (only slightly cemented or not at all). That implies that the slight precipitation of calcium carbonate is (still) not sufficient for indurating the tell soils. The formation of vughs is apparently disturbed by bioturbation and anthroturbation. A massive microstructure is occasionally observed (e.g., Tell Halif; TH1). Commonly observed are angular to sub-angular reddish/brownish blocky peds with massive microstructure and moldic voids, interpreted as degraded earth construction materials (e.g., Friesem et al., 2017), and vesicle voids, related to faunal activity. The calcitic fine material show interference colours that indicate a micritic crystallitic birefringence (b-fabric). This expresses the calcareous nature of the groundmass.

The groundmass includes fragments of varied species of angular and sub-angular carbonate rocks. Fragments of chalk are identified by their dense micritic micromass and embedded foraminifera while fragments of nari-calcrete are identified by a heterogeneous micromass and impregnated pedofeatures. Also observed in the groundmass are quartz grains (mostly silt) and other fine siliceous constituents (possibly phytoliths), potsherds, mud brick material, discrete iron-rich material, bones, shells, well-rounded calcium carbonate spherulites (interpreted as faunal excrements), plant residues and root remains with different degree of preservation, and organic fine material (Figs. 5, 6, 7). Much of the organic components are calcified, meaning that they have gone through decomposition and calcification. The occurrence of organic material is related to the influence of biota on the groundmass, unnecessarily associated with human action. Accumulations of needle fibre calcite are infrequently observed. As explained by Verrecchia and Verrecchia (1994), such needle-like features are related to a biogenic source. The observed intensity of micritic hypo-coatings and infillings, which is common in cracks of rock fragments (Fig. 7j) is related to incipient calcium carbonate cementation of the groundmass. These micritic features are also interpreted as early diagenesis in the rock fragments.

It is worthwhile to stress two issues regarding the thin sections of this study: 1) Peds and some calcified pedofeatures show calcitic rims that highly resembles micrite hypo-coatings (e.g., Fig. 5i). Described as "wedging effects" (Stoops, 2003, p.15–17), or "edge effects" (Murphy

Table 1
Results of soil analyses. Initials and abbreviations: TG - Tell Gezer, TE - Tell 'Eton, TH - Tell Halif. Ref. Prof. - reference profile, SL - silt loam, SCL - silty clay loam, M - massive, SG - single grain, Gr - granular, B - blocky, W - wedge, Pr - prismatic, OC - organic carbon. Parenthesis in the structure column indicates a structure that has a limited presence in parts of the profile. Structure types appear in a rightwards manner according to their dominance in the profile, e.g., M-SG-(Gr) means that profile shows massive (i.e., M), structure that turns into single grain (SG) when hand-crushed, and includes discrete domains of granular (i.e., Gr) structure.

Site	Profile & Sample	Horizon	Location	Archaeological stratigraphy	Thickness of horizon (cm)	Depth of sample (cm)	Clay (<6 μm) (%)	Silt (6-63 μm) (%)	Sand (63-2000 μm) (%)	Texture	Structure	Coarse fragments (>2 mm; wt. %)	Colour (moist)	pH_{H2O}	$\%CaCO_3$	%OC
Gezer	TG1 a					10	23.3	64.9	11.8			49.0	10YR 3/3	8.2	49.3	1.0
	TG1 b	Apuk	southern shoulder	early 1900s	170	50	21.0	69.6	9.4	SL	M-SG-(Gr)	36.8	10YR 4/2	8.3	50.7	0.4
	TG1 c					150	21.5	70.7	7.8			37.7	10YR 3/3	7.9	46.7	0.3
	TG2 a	Apuk		early 1900s		75	15.0	69.1	15.9			28.3	7.5YR 4/4	8.5	42.0	0.2
	TG2 b	Abuk	interior of tell	M. Bronze IIB	450	180	21.7	65.6	12.7	SL	M-SG-(Gr)	18.2	10YR 4/2	8.4	42.4	0.5
	TG2 c	Abuk		M. Bronze IIB		445	24.9	65.0	10.1			15.9	10YR 2/1	8.4	33.3	0.9
Ref.prof.	TG3 a	Apuk1	nearby field	modern	25	15	28.7	63.0	8.3	SL	Gr-B	68.8	10YR 3/3	7.9	49.1	1.3
	TG3 b	Apuk2			35	45	30.0	64.9	5.1	SL	Gr-B	55.6	10YR 3/2	8.2	52.2	1.0
'Eton	TE1 a					10	26.4	65.5	8.1			39.6	7.5YR 5/3	8.4	41.4	0.7
	TE1 b	Apuk	summit	Iron II	80	45	21.9	69.3	8.8	SL	M-SG-(Gr)	27.2	10YR 4/4	7.9	46.5	0.4
	TE1 c					70	25.1	67.5	7.4			35.1	10YR 4/4	8.4	41.0	0.4
	TE2 a					20	27.1	63.2	9.7			30.1	10YR 5/4	8.0	41.6	1.1
	TE2 b	Apuk	western slope	Iron II	140	50	29.2	64.4	6.4	SL	M-SG-(Gr)	51.7	10YR 4/4	7.4	46.4	0.5
	TE2 c					110	29.2	64.4	6.4			55.0	10YR 4/4	7.9	43.0	0.5
Ref.prof.	TE3 a	Apuk1	nearby field	modern	25	15	29.9	62.8	7.3	SL	Gr-B	22.2	7.5YR 4/3	8.2	50.3	1.0
	TE3 b	Apuk2			30	40	41.3	51.6	7.1	SL	Gr-B	30.7	7.5YR 4/4	8.4	55.2	0.5
Halif	TH1 a					10	33.3	55.5	11.2			39.5	10YR 3/4	8.0	33.5	0.4
	TH1 b	Apuk	summit	(late) Iron II	130	50	22.9	62.8	14.3	SL	M-SG-(Gr)	23.9	10YR 3/4	8.2	27.9	0.9
	TH1 c					85	28.8	63.7	7.5			38.1	10YR 3/4	8.1	31.4	0.4
	TH1 d					130	18.4	66.1	15.5			33.6	10YR 4/2	8.2	24.5	0.5
	TH2 a					10	24.9	63.9	11.2			31.0	10YR 4/4	9.2	27.9	0.3
	TH2 b	Apuk	north-eastern slope	Late Bronze	160	70	22.8	64.6	12.6	SL	M-SG-(Gr)	23.3	10YR 3/4	9.2	24.5	0.3
	TH2 c					130	21.5	67.1	11.4			23.2	10YR 3/3	8.1	25.0	0.7
Ref.prof.	TH3 a	Apuk	nearby field	modern	60	25	21.9	63.4	14.7	SL	M-Gr	10.2	10YR 3/4	8.1	24.7	0.6
	TH3 b	Btbss			160	110	50.1	43.3	6.6	SCL	W-Pr	6.7	5YR 4/4	8.3	27.0	0.2

Fig. 3. Example of a partly exposed potsherd coated with thin grayish accumulation of calcium carbonate (left) compare to a potsherd that was found exposed on the surface (right; Tell 'Eton). Surfaces of such embedded potsherds in alkaline environments acts as a substrate of calcite nucleation (Itkin et al., 2016).

and Kemp, 1984), these are in fact not pedogenic coatings but rather an apparent (pseudo-) coatings that are related to the production process of the thin sections. 2) Some photographs show slightly different colours compare to others due to the use of different light filters and (transmitted) light intensity during photography (Figs. 5, 6, 7).

The SEM results show variable quantities of micrite cement, quartz grains (most of which are silt size and show rounded surfaces), biogenic filaments, needle fibre calcite, fecal spherulites, calcified rhizospheric filament, charred particles, Eocene micro fauna, including foraminifera (species not identified) and coccolithopore (*Umbilicosphaera* sp. and *Chiasmolithus* sp.; e.g., Fig. 8). SEM observations were not sufficient to determine the associated clay minerals. However, the clay fraction in the study area is mostly of interstratified illite-smectite composition (Sandler, 2013).

5.3. Reference profiles: field observations and lab analyses

The land cover of the reference profiles is characterized by a heterogeneity of artifacts, rock fragments and a mosaic of shrubs and annual plants. Also evident at the surface are signs of human presence (agriculture and architecture), various tracks of animals, mounds of mole-rats, and ant nests. The reference profiles differ from the soils of the tells by their slightly darker and/or redder colours, granular to blocky moderate structure, and the occurrence of incipient horizonation (excluding profile TH3a; Table 1). The reference profiles have a dry moisture status and identifiable secondary carbonates. Apart from profile TH3b, all reference profiles are 60–100 cm and includes either one or two Apuk horizon(s) which are embedded with sparse amounts of calcareous rock fragments, archaeological artifacts, shales of land

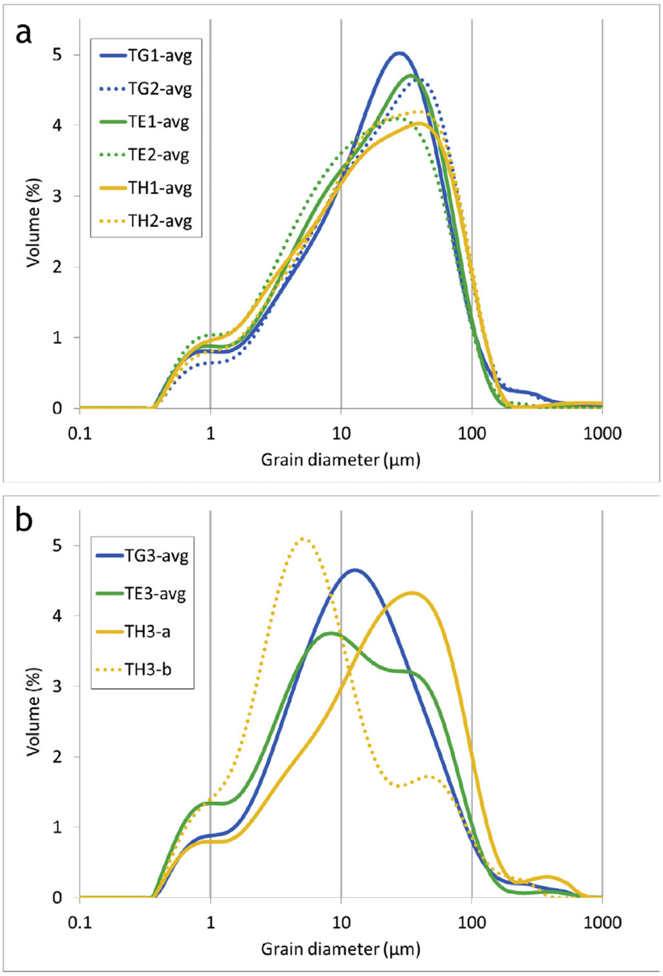

Fig. 4. Average PSD of the tell soil profiles (a), and the reference profiles (b). Note that PSD of reference profile TH3 is not presented as an average as this sequence consists of two distinct soil profiles that developed within different parent materials.

snails, occasionally charcoal, and fine roots throughout. The parent rock is calcrete (nari). Most reference soils have a silt loam texture, moderate pH values (7.9–8.4), and a minor content (0.5–1.3%) of OC (Table 1).

The reference soil profile of Tell Gezer was exposed to a depth of 60 cm (out of ~100 cm, due to technical difficulties at the time of sampling). This profile is located on a moderate toeslope of a south-eastern aspect along the untilled margins of an active agricultural field, ~680 m east of Gezer (Figs. 2, 5). Two horizons were identified in this profile. The upper horizon (TG3a; 25 cm) has a very dark grayish brown colour and the lower horizon (TG3b; only 35 cm exposed) is very dark brown (Table 1). The reference soil of Gezer exhibit bi-modal PSD that is similar to the tell, but with smaller coarse mode (~15 µm; Fig. 4b). This profile is interpreted as Anthropic Calcic Haploxerepts (Anthric Calcaric Cambisols).

The reference soil profile of Tell 'Eton is located on a moderate footslope of an eastern aspect at the margins of an ancient agricultural terrace, ~200 m west of the tell (Figs. 2, 6). The profile includes two horizons. The upper horizon (TE3a; 25 cm) has a (grayish) dark brown colour and the lower horizon (TE3b; 30 cm) is dark brown (Table 1). Alike Gezer, the PSD of the reference profile of 'Eton is also finer than the tell soils, but exhibit a tri-modal PSD, with an additional mode at ~8 µm. This profile is interpreted as Anthropic Calcic Haploxerepts (Calcaric Irragric Anthrosols).

The reference soil profile of Tell Halif is located on a moderate toeslope of an eastern aspect and is a part of an erosion gully wall, ~950 m east of the tell (Figs. 2, 7). This profile has a stratigraphy of two soil units; an upper unit (TH3a; 60 cm) overlying a thick buried unit (TH3b; only 160 cm exposed). The upper unit has a dark yellowish brown colour, lack of horizonation and is embedded with noticeable amount of angular carbonate rock fragments, sized 2–5 cm. The boundary between the two units has an abrupt distinctness and smooth topography. The upper soil unit correspond to Calcareous Anthraltic Haploxerepts (Anthric Calcaric Cambisols). The buried soil has a reddish brown colour, a wedge to prismatic strong structure with vertical cracks, a silty clay loam texture, high content of secondary carbonate accumulations, slickensides, clay coatings, and is embedded with sparse rock fragments (Table 1; Fig. 7). The upper reference soil at Halif presents similar PSD to the tell, whereas the lower reference soil exhibit a tri-modal PSD that is different from all other samples. Thus we refer to the upper soil unit of this profile when comparing it to the soil at Tell Halif. The parent material of the lower unit is loess, as indicated by the content and morphology of its silt quarts grains and PSD (Figs. 4b, 7l). The lower soil unit includes three horizons: Bkbss1, Btbss (Jahn et al., 2006; Btbi horizon) and Bkbss3, and it is interpreted as a buried Chromic Calcixererts (Calcic Chromic Vertisols).

5.4. Reference profiles: micromorphological observations

Except for profile TH3b, all reference profiles show complex, mainly vughy, microstructure with open porphyric c/f-related distribution (c/$f_{4\mu m}$ limit), and moderately separated sub-angular and angular peds, occasionally including few vesicle voids. The groundmass includes fragments of chalk, ferric material, silt and scarcely also sand quartz grains, shells of land snails, potsherd and organic matter. More frequently observed than in the tells are micritic hypo-coatings and infillings. The Vertisols (TH3b) show sub-angular blocky microstructure with accommodated to partly accommodated planes, moderately to highly separated peds, groundmass with chalk fragments and silt quartz grains. Pedofeatures include micritic infillings and micritic hypo-coatings. Slickensides are probably masked by calcium carbonate. Organic material includes rounded calcium carbonate spherulites, plant residues and root remains, with different degrees of preservation. Organic fine material is also observed but less than in the other reference profiles (Figs. 5, 6, 7).

Summarizing the results, the main observations are as follows: Comparison of the thin sections show that the content of silt quartz grains increases southwards. It also seems that pore systems are more developed in the northern part of the study area than in its southern part (Figs. 5, 6, 7). The reference soil profiles are similar compared to each other by their properties of texture, structure, colour, pH, $CaCO_3$ content and OC, excluding profile TH3b (Tell Halif; Table 1). Besides differences in colour, horizonation and nature of coarse material (more natural fragments vs. more artifacts in the tells), the reference soils are highly similar to the profiles of the tells (Table 1). Further data regarding the soils in the study area can be found in previous studies (Dan et al., 1972; Marish and Hetzroni, 1983; Dan, 1988a; Koyumdjisky et al., 1988; Singer, 2007, p.86-123; Sapir, 2016).

6. Discussion

Explaining synlithogenic pedogenesis requires evidence for soil formation that acts in concert with sedimentation (Khokhlova et al., 2001; Targulian and Goryachkin, 2004; Shishov et al., 2005; Sedov et al., 2017). Our results show that rocks and mud bricks are the main parent materials in the tells, and that their related fragments are either altered by early diagenesis or aggregated with fine material and organic matter (Figs. 5, 6, 7).

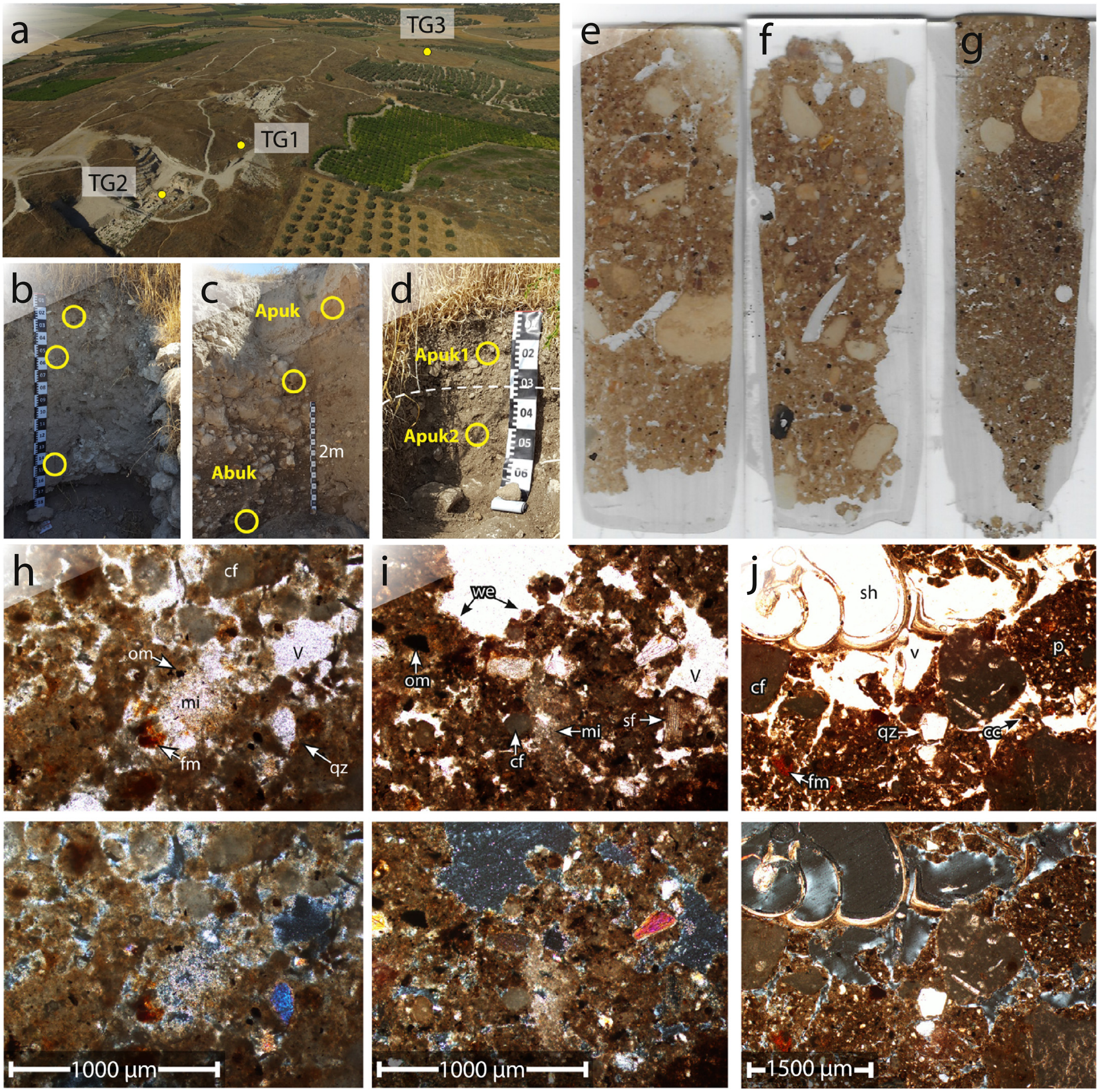

Fig. 5. (a) Drone photo of the Tell Gezer, showing locations of the studied profiles. Field photos: (b) Tell profile TG1. (c) Tell profile TG2. (d) Reference profile TG3 (sampling locations are indicated by yellow circles). Thin section scans: (e) Tell profile TG1. (f) Tell profile TG2. (g) Reference profile TG3 (slides are 2.5 × 7.5 cm). Thin sections photographs, PPL above the same in XPL: Material from Tell Gezer showing (h) TG1 and (i) TG2 (buried soil); discontinuous carbonate recrystallization in the groundmass: Vughy microstructure (a vugh is indicated by v); groundmass with calcitic (micritic) crystallitic b-fabric, chalk fragment (cf), iron-rich material (fm), quartz grain (qz), shell fragment (sf), and charred organic matter (om); micritic infillings (mi). Wedging effect (we) resembles calcite coatings. (j) Material from the Apuk2 horizon of reference profile TG3. Complex (mainly vughy) microstructure (a vugh is indicated by v) and moderately separated sub-angular and angular peds (p); groundmass with chalk fragment (cf), iron-rich material (fm), silt and sand quartz grains (qz), and a shell (sh); micritic hypo-coatings (cc). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

6.1. Evidence of sedimentation

Two main processes are responsible for the high content of carbonate rock fragments: 1) Degradation of earth construction materials associated with dispersal of their coarse calcareous components, possibly with additional contribution of tempers from degraded potsherds, and 2) Disintegration of carbonate rocks, mainly chalk, e.g., the microfauna in the tell soils includes addition of materials from rock weathering (Fig. 8). The mud bricks and rocks must have been subjected to external forces in order to become fragmentized. The human related causes could be architectural and industrial works, midden disposal, and/or violent destruction (Bullard, 1970; Butzer, 1982, p. 89–90; Rosen, 1986, p. 10–15). The main natural causes are most probably rain (that can initiate runoff and mass movement) and

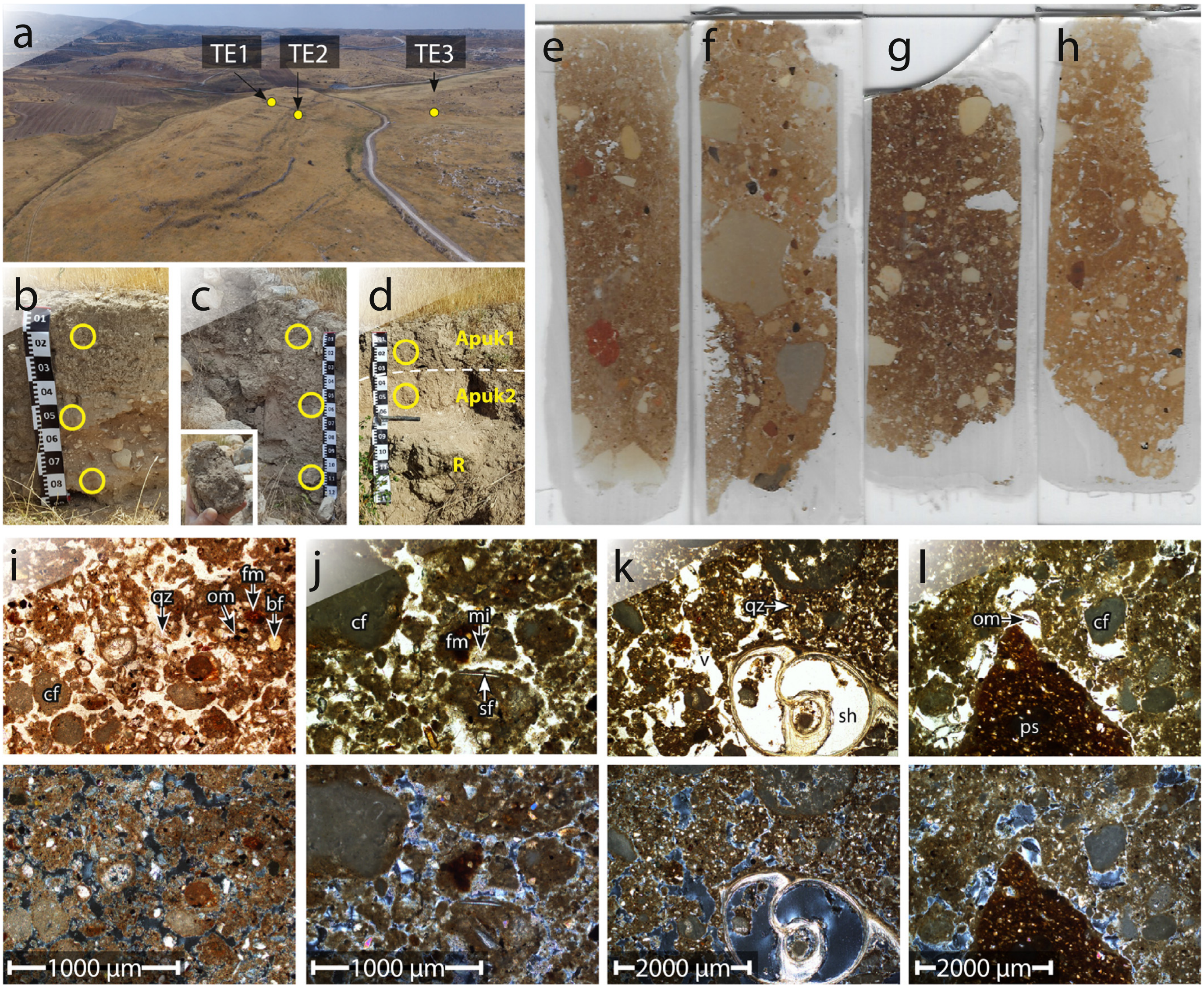

Fig. 6. (a) Drone photo of the Tell 'Eton, showing locations of the studied profiles. Field photos: (b) Tell profile TE1. (c) Tell profile TE2, showing a hand specimen (small box). (d) Reference profile TE3 (sampling locations are indicated by yellow circles). Thin section scans: (e) Tell profile TE1. (f) Tell profile TE2, (g) Reference profile TE3a. (h) Reference profile TE3b (slides are 2.5 × 7.5 cm). Thin sections photographs, PPL above the same in XPL: Material from Tell 'Eton showing (i) TE1 and (j) TE2; carbonate recrystallization of the groundmass: Vughy microstructure; groundmass with calcitic (micritic) crystallitic b-fabric, chalk fragment (cf), iron-rich material (fm), quartz grain (qz; noticeably higher content than in Tell Gezer), shell fragment (sf), bone fragment (bf) and organic matter (om); micritic infilling (mi). (k) TE3a: Material from the Apuk1 horizon of the reference profile of Tell 'Eton; Vughy microstructure (a vugh is indicated by 'v'); groundmass with silt quartz grains (qz), and a shell (sh; of a land snail). (l) Material from the Apuk2 horizon of reference profile TE3b: Complex microstructure; groundmass with chalk fragment (cf), potsherd (ps) and organic matter (om). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

earthquakes (Schiffer, 1987; Friesem et al., 2011, 2014). Records of local earthquakes history extends to the Iron Age IIB (760–750 BCE; Zohar et al., 2017). Today, humans are the main cause of tell erosion in the Judean foothills, mainly through excavations but also through destruction of plant canopies.

6.2. Evidence of pedogenesis

The occurrence of peds, discontinuous carbonate recrystallization, coatings and infillings, are the most prominent indication of pedogenesis in the studied tells. Pedoturbation is interpreted by poor aggregation of the groundmass that is indicated by the weakly welded porous crumb peds that form a vughy microstructure. We relate these features to the massive weak structure of the tell soils. The abundance of carbonate rock fragments in the groundmass with discontinuous recrystallization indicates a fairly low mobilization of $CaCO_3$. That implies that the calcification of tells is contributed mainly by disintegration of geogenic materials (rather than pedogenic). The chalk and calcrete fragments are therefore the main source of calcium carbonate in the soil system of the tells.

6.3. Role of biogenic agents

The dense rhizosphere and many signs of recent faunal activity implies that biogenic action might also influence pedogenic processes in tells. The plant canopies increase the stability of soil aggregates and reduce the erosion potential of slopes (Gyssels et al., 2005; Duran-Zuazo and Rodriguez-Plequezuelo, 2008; Erktan et al., 2015). Specifically, basic soil environments favour the interaction of species of the carbonic acid system (CO_2, HCO_3^-, CO_3^{2-}) and Ca ions, to produce calcium

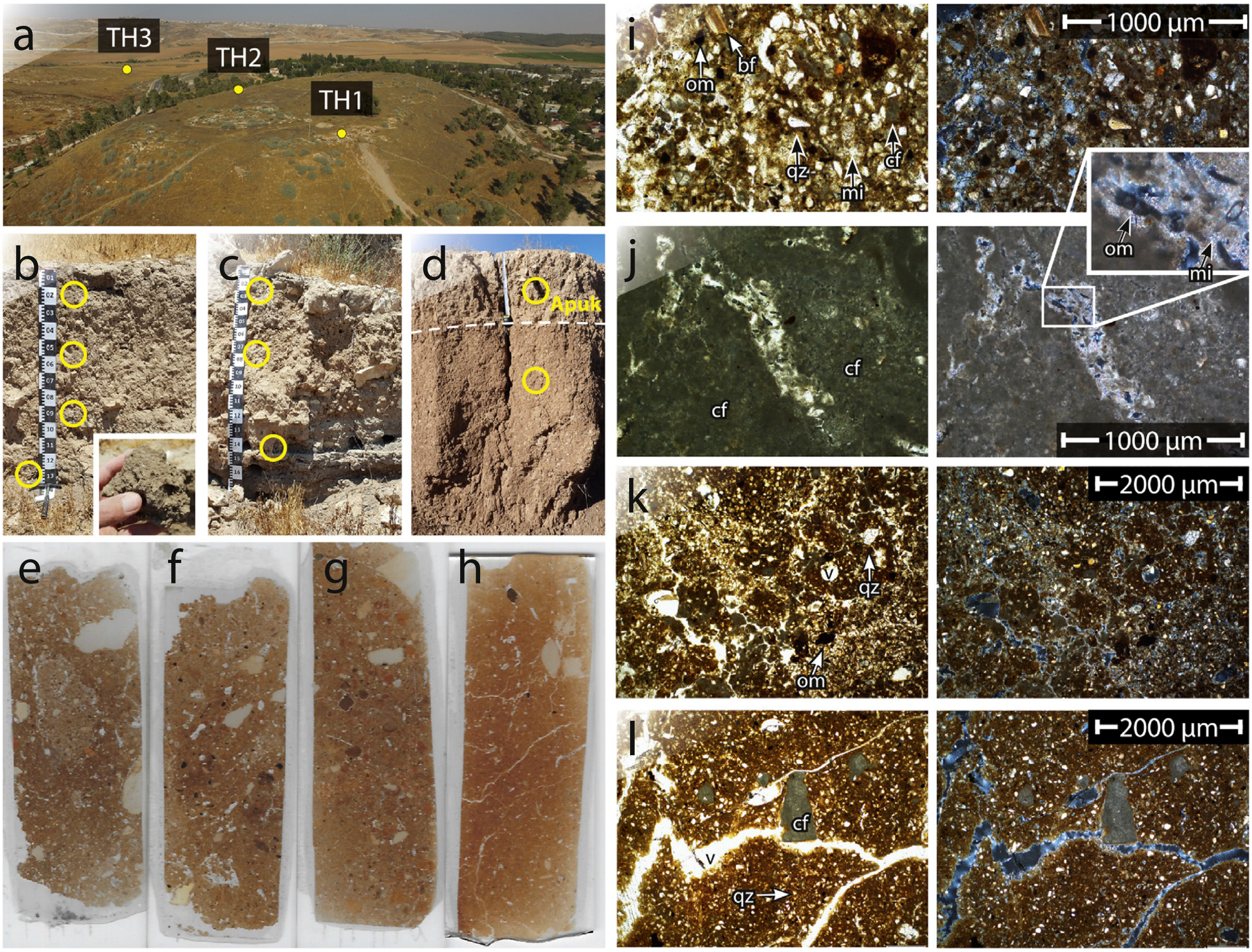

Fig. 7. (a) Drone photo of the Tell Halif, showing locations of the studied profiles. Field photos: (b) Tell profile TH1 showing a hand specimen (small box). (c) Tell profile TH2. (d) Reference profile TH3 (sampling locations are indicated by yellow circles). Thin section scans: (e) Tell profile TH1. (f) Tell profile TH2. (g) Reference profile TH3a. (h) Reference profile TH3b (slides are 2.5 × 7.5 cm). Thin sections photographs, PPL above the same in XPL: material from Tell Halif showing (i) TH1 and (j) TH2; discontinuous recrystallization of the groundmass: massive microstructure; groundmass with calcitic (micritic) crystallitic b-fabric, chalk fragment (cf), quartz grain (qz; noticeably higher content than in Tell Gezer), bone fragment (bf) and organic matter (om); micritic infillings (mi). Discontinuous micritic cementation in crack of an altered chalk fragment (j) shows groundmass that is very much alike sample TH1. (k) TH3a: material from the upper soil unit of the reference profile of Tell Halif; Vughy microstructure, including few vesicle voids (V); groundmass with calcitic crystallitic b-fabric, silt (and scarcely sand) quartz grains (qz) and organic material (om). (l) TH3b: material from the Btss horizon of the lower soil unit of the reference profile; sub-angular blocky microstructure with accommodated to partly accommodated planes (v), peds are moderately to highly separated; groundmass with chalk fragment (cf), silt quartz grains (qz). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

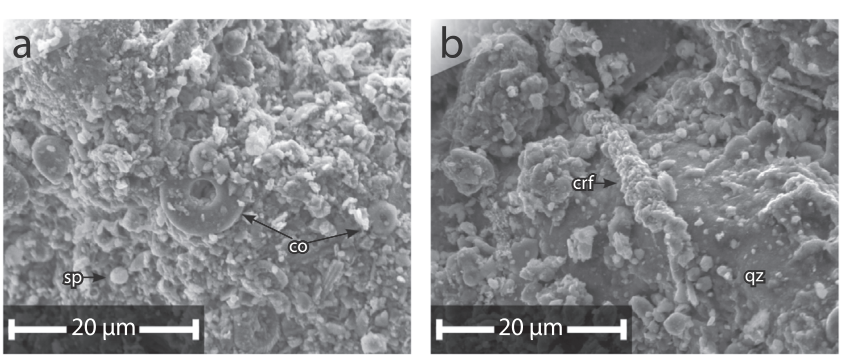

Fig. 8. Scanning electron microscope images. (a) Material from Tell 'Eton (sample TE1): Chalk fragment showing coccolithopore (co; *Umbilicosphaera* sp. and *Chiasmolithus* sp.), and spherulite (sp). (b) Material from Tell Halif (sample TH1): Rounded silt quartz (qz; > 40 µm sub-angular feature) and calcitic rhizospheric filament (crf).

carbonate (Monger and Wilding, 2017). Further related to calcification, components of anthropogenic wood ash can enter the soil system following the decomposing of calcium oxalate crystals (Liebowitz and Folk, 1980; Regev et al., 2010; Shahack-Gross and Ayalon, 2013). Ca ions can also derive from decomposition of bones (Shinomiya et al., 1998), plants and plant roots (Verrecchia et al., 1993; Franceschi and Nakata, 2005), fungi, and lichens (Verrecchia, 2000; Verrecchia, 2011). The occurrence of needle-fiber calcite indicate a near-surface biogenic influence (Verrecchia and Verrecchia, 1994). It is possible that Ca and $CaCO_3$ are also related to activity of microorganisms (Pentecost and Riding, 1986; Monger et al., 1991; Gadd, 2007), and that CO_2 derives from rhizospheric respiration (Monger and Martinez-Rios, 2000; Monger et al., 2009). Soil macro-organisms such as earthworms can also contribute as biogenic agents of calcium carbonate redistribution (Canti and Piearce, 2003; Hodson et al., 2015).

6.4. Synlithogenic pedogenesis in tells

It is interpreted from the micromorphological observations that the brownish colours of the tells (Table 1) are derived from the combination of rubefied (Fe-stained) clay and fine charred particles in a calcareous (greyish) groundmass (Figs. 5, 6, 7). Clay coatings and infillings are occasionally observed, suggesting dry moisture status and poor translocation of clay during pedogenesis. The strong flocculating (clay aggregation) power of Ca ions demands sufficient decalcification in order for clay particles to disperse and be transported by percolating water (Torrent, 2005). Thus we infer that clay rubefication formed outside the tell system and that they originated from desert dust. The major input of desert dust to soils in the Eastern Mediterranean occurred during the late Pleistocene (Yaalon, 1987; Crouvi et al., 2017). Locally, the content of silt quartz grains is higher in the southern tells 'Eton and Halif compared to Tell Gezer which is located 40–55 km respectively to the north (Fig. 1). This difference points to a proximal source of dust located south of the study area (Crouvi et al., 2008, 2017). Therefore, we argue that soils with strong influence of aeolian dust (Yaalon and Ganor, 1973; Fedoroff and Courty, 2013) in the western Judean foothills (Dan, 1988a) are the most likely source of rubefied clay in the tells. The source of charred particles is burnt wood that derive from degraded mud bricks, bonfire remnants and other sources of combusted ligneous matter. It is also possible that some of the charred particles are related to atmospheric aeroplasma processes rather than human actions (Courty and Coqueugniot, 2013; Courty and Martinez, 2015; Courty, 2017). The buried soils in Tell Gezer possess the same general characteristics as other tell profiles.

The dominant silt fraction is related to the high content of disintegrated chalk, quartz grains and charred particles. The minor variations in PSD throughout the profiles (Table 1; Fig. 4) are related to pedoturbation and incipient pedogenesis. The archaeology of the studied tells (Faust and Katz, 2015; Sapir, 2016; Borowski, 2017; Ortiz and Wolff, 2017) together with the field and micromorphological observations, suggest that bioturbation and anthroturbation are the two dominant mechanisms of pedoturbation. The causes of bioturbation are evident by mounds of mole-rats, earthworm channels, ants mounds, and rhizospheric action. The anthroturbation is related to both ancient (Ortiz and Wolff, 2012; Faust, 2013; Sapir, 2016; Borowski, 2017) and modern human actions (e.g., Macalister's 1900s excavations; Wolff, 2017).

The lack of horizonation and the rather uniform content of $CaCO_3$ in a groundmass of a silt loam texture, together with very low content of organic carbon, suggest a prolonged shortage of moisture in the soil system. This understanding is fortified by the fairly uniform pH values and the discontinuous carbonate recrystallization, both indicating dominance of solid-phase $CaCO_3$ in the groundmass and its low mobility in the soil solution. One exception is the high pH value found in the upper part of profile TH2 (Table 1; Tell Halif). Sodium has a strong influence on pH in alkali soil solutions (Robbins and Gavlak, 1989; Gupta and Abrol, 1990). It is therefore suggested that this pH value derives from high concentration of Na ions in the groundmass, probably from $NaCO_3$ and/or $NaHCO_3$ (Goffer, 2007, p.116, 368, 398; Rothenberg, 2014).

All of the above processes can be put in timeframes. The archaeological record of the studied tells (Ortiz and Wolff, 2012; Faust, 2013; Sapir, 2016; Borowski, 2017) provides maximum age boundaries for the development of the inspected profiles (Table 1). These boundaries define our results with specific chronological context in each profile. The profiles in Tell Gezer, which have been harshly disturbed about 100 yrs. ago, prove that pedogenesis initiated rapidly. Assuming that pedogenesis in the Judean foothills maintained similar rates during the last 3500 yrs., suggests that it acted concurrently with the deposition of cultural materials in the tells, i.e., synlithogenically.

6.5. Pedogenetic relations between the tells and their peripheral soils

Comparing the soil fabric and groundmass of the tells with soils of the reference profiles shows that the pedogenic features of the tells are genetically related to those developed outside the tells (Table 1, Figs. 4, 5, 6, 7). However, the stronger structure, incipient horizonation and occasionally darker colours of the reference profiles indicate that the peripheral soils are older and more mature. This could support the broad understanding that tell soils are genetically related with their peripheral soils and that most of the earth materials which were used by ancient cultures, derived from proximal sources (Stoops and Nijs, 1986; Rosen, 1986; Goldberg, 2004; Goldberg and Macphail, 2006, p.227–235; Sapir, 2016; Matthews, 2017). Additionally to differences in pedogenic maturity between the tells and the reference soils, there is also a difference in the distribution of calcium carbonate. While the concentrations of $CaCO_3$ of the tells are very similar to the reference profiles (Table 1), it is evident that the occurrence of calcium carbonate in the tells is mainly in the form of carbonate fragments. Compared to the tells, the presence of calcium carbonate in the reference profiles is mainly in the form of micritic accumulations and calcified organic matter (Fig. 5, 6, 7).

6.6. Classification of the tell deposits

Asking whether cultural deposits are sediments or soils appear to be an issue of interest in geoarchaeology (Goldberg and Macphail, 2006, p.11–27, 33–71). Considering that tell deposits are soils, as we show in this study, they can be accordingly classified. Having said that, we argue that tell soils in the Judean foothills are classified as archaeological Calcareous Anthraltic Xerorthents ('archaeological' is currently informal in Soil Taxonomy). The correlative WRB classification would be Calcic Urbic Technosols (Archaic). Soils which are sufficiently classified can be marked on a map. It is therefore suggested that same as with the need of mapping modern anthropogenic soils (Lehmann and Stahr, 2007; Charzyński et al., 2017) tells will be considered as separate mapping units. This might change the situation with archaeological soils which are usually disregarded in soil distribution maps, even in highly dense archaeological environments (e.g., Marish and Soil Survey Staff, 1980; Marish and Hetzroni, 1983; Soil and Pasture Survey Staff, 1983; Crouvi et al., 2013). Currently, tells are being erroneously designated (even) in low-scale soil maps same as their surrounding soils (Marish and Hetzroni, 1983).

6.7. Highlighting the need for multidisciplinary cooperation

"Soils mean different things to different people" (Yaalon, 1993). Tell deposits are often being referred to as 'fill material' and are commonly being neglected during archaeological excavations. However, these deposits bear invaluable information for both the reconstruction of past cultural actions (Weiss et al., 1993; Matthews et al., 1997; Stein, 2001; Shillito and Matthews, 2013; Matthews, 2017) and human induced pedogenesis (Stoops and Nijs, 1986; Ryan et al., 2009; Sedov et al., 2017). It is therefore important to treat tell soils with knowledge of both archaeology and pedology. The necessity of performing multidisciplinary studies when exploring site formation processes has already been strongly underscored (Rapp 1975; Macphail et al., 2017). The sound wake-up call made by Shahack-Gross (2016) regarding the requisite to include basic geology in teaching programs of archaeology, should also be applied for soil scientists who seek to explore archaeological environments. Regarding the tools for studying tell deposits, soil micromorphology is found to be amongst the most important methods for analyzing cultural deposits (Courty et al., 1989; Macphail and Cruise, 2001; Tsatskin and Zaidner, 2014; Nicosia and Stoops, 2017; Macphail and Goldberg, 2017). Goren (2013) proved that a relatively low cost and simple micromorphological procedures can easily be applied during active excavations. In light of the above discussion, it would be interesting to correlate pedogenetic processes of Near Eastern tells with other archaeological landforms alike (e.g., Sherwood and Kidder, 2011).

7. Conclusions

Field observations and lab analyses of tell soils of the western Judean foothills show that they are genetically related with their peripheral soils and that they form in a multi-phased synlithogenic pedogenesis. The dominant soil forming processes in tells are disintegration and partial dissolution of archaeological materials, that are associated with pedoturbation, aggregation and limited occurrence of both calcium carbonate redistribution and organic matter accumulation. Buried tell soils are formed by the same synlithogenic pedogenic mechanism. Relative rates of soil formation in tells can be assessed when archaeological records are established. In this study, the tell profiles have formed in either 3500 yrs. to 3000 yrs. Pedogenesis of 100 yrs. has also been demonstrated and discussed, strengthening the hypothesis of synlithogenic pedogenesis. This study provides an example of how archaeological record and pedological characteristics allow the assessment of formation time. The main differences found amongst the soils of the tells and the reference soils are related to time of formation (the reference soils are more mature) and type of coarse material content. The colour and texture of tells is influenced by local disintegrated cultural geogenic materials, degraded mud brick material and charred particles. The overall (macro-scale) structure of tells is determined by the degree of their internal cohesiveness and state of their plant canopies, if present. Incipient cementation might also influence structure development of tells. Pore system of tells is controlled by the intensity of biogenic activity and rainfall. Tell soils are as calcareous as the natural soils, but due to human action, carbonates in the tells are distributed mostly as coarse material rather than in fine (micritic) masses. Synlithogenic soils in tells have been classified as archaeological Calcareous Anthraltic Xerorthents, and are therefore also mappable in suitable scales. The correlative WRB classification would be Calcic Urbic Technosols (Archaic). The scarcity of pedological studies of tells necessitates further study of this subject. These conclusions imply that pedological approach should also be put into practice in studies of other ancient anthropogenic landforms, such as agricultural terraces.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version, at https://doi.org/10.1016/j.catena.2018.03.014. These data include the Google maps of the most important areas described in this article.

References

Ackermann, O., Maeir, A.M., Bruins, H.J., 2004. Unique human-made catenary changes and their effect on soil and vegetation in the semi-arid Mediterranean zone: a case study on *Sarcopoterium* spinosum distribution near Tell eṣ-Ṣâfi/Gath, Israel. Catena 57, 309–330.

Ackermann, O., Greenbaum, N., Osband, M., Almogi-Labin, A., Ayalon, A., Bar-Matthews, A., Boaretto, E., Bruins, H.J., Cabanes, D., Horwitz, L.K., Neumann, F.H., Porat, N., Schilman, B., Weiss, E., Maeir, A.M., 2015. Soil and sediments as an archive of landscape history: a case study of Tell es-Safi/Gath, in the East Mediterranean. In: Lucke, B., Bäumler, R., Schmidt, M. (Eds.), Soils and Sediments as Archives of Environmental Change. Geoarchaeology and Landscape Change in the Subtropics and Tropics, pp. 281–294 (Erlangen (Erlanger Geographische Arbeiten Band 42), S).

Ackermann, O., Greenbaum, N., Bruins, H., Ayalon, A., Bar-Matthews, M., Cabanes, D., Horwitz, L.K., Neumann, F.H., Osband, M., Porat, N., Weiss, E., Maeir, M.A., 2017a. Ancient environment and human interaction at Tell eṣ-Ṣâfi/Gath. Near East. Archaeol. 80, 244–246.

Ackermann, O., Maeir, A.M., Frumin, S.S., Svoray, T., Weiss, E., Zhevelev, H.M., Horwitz, L.K., 2017b. The paleo-Anthropocene and the genesis of the current landscape of Israel. J. Landsc. Ecol. 10, 109–140.

Albert, R.M., Shahack-Gross, R., Cabanes, D., Gilboa, A., Lev-Yadun, S., Portillo, M., Sharon, I., Boaretto, E., Weiner, S., 2008. Phytolith-rich layers from the Late Bronze and Iron Ages at Tel Dor (Israel): mode of formation and archaeological significance. J. Archaeol. Sci. 35, 57–75.

Bar, D., 2004. Population, settlement and economy in Late Roman and Byzantine Palestine (70-641 AD). Bull. Sch. Orient. Afr. Stud. 67, 307–320.

Bar, O., Zilberman, E., Feinstein, S., Calvo, R., Gvirtzman, Z., 2016. The uplift history of the Arabian plateau as inferred from geomorphologic analysis of its northwestern edge. Tectonophysics 671, 9–23.

Bar-Matthews, M., Ayalon, A., Kaufman, A., 1998. Middle to late Holocene (6500 Yr. period) paleoclimate in the Eastern Mediterranean region from stable isotopic composition of speleothems from Soreq Cave, Israel. In: Issar, A.S., Brown, N. (Eds.), Water, Environment and Society in Times of Climatic Change. Kluwer Academic Publishers, Dordrecht, pp. 203–214.

Beach, T.P., Luzzadder-Beach, S., 2008. Geoarchaeology and aggradation around Kinet Höyük, an archaeological mound in the Eastern Mediterranean, Turkey. Geomorphology 101, 416–428.

Benz, M., Deckers, K., Rössner, C., Alexandrovskiy, K., Pustovoytov, M., Scheeres, M., Fecher, M., Coşkun, A., Riehl, S., Alt, K.W., Özkaya, V., 2015. Prelude to village life. Environmental data and building traditions of the Epipalaeolithic settlement at Körtik Tepe, Southeastern Turkey. Paléorient 41, 9–30.

Bliss, F.J., 1894. A Mound of Many Cities, or, Tell el Hesy Excavated. Macmillan & Co., New York and Londlon.

Blume, H.P., Brümmer, G.W., Fleige, H., Horn, R., Kandeler, E., Kögel-Knabner, I., Kretzschmar, R., Stahr, K., Wilke, B.M., 2016. Scheffer/Schachtschabel Soil Science. Springer-Verlag, Berlin Heidelberg, New York Dordrecht London.

Borowski, O., 2017. Tell Halif in the Late Bronze and Iron Age. In: Maeir, A.M., Lipschits, O. (Eds.), The Shephelah During the Iron Age: Recent Archaeological Studies. Eisenbrauns, Winona Lake, Indiana, pp. 103–114.

Bullard, R.G., 1970. Geological studies in field archaeology. Biblic. Archaeol. 33, 98–132.

Burt, R. (Ed.), 2014. Kellogg Soil Survey Laboratory Methods Manual. United States Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center, Kellogg Soil Survey Laboratory, Lincoln, Nebraska.

Butzer, K.W., 1982. Archaeology as Human Ecology: Method and Theory for a Contextual Approach. Cambridge University Press, New York.

Canti, M.G., Piearce, T.G., 2003. Morphology and dynamics of calcium carbonate granules produced by different earthworm species: The 7th International Symposium on Earthworm Ecology, Cardiff, Wales, 2002. Pedobiologia 47, 511–521.

Charzyński, P., Galbraith, J.M., Kabała, C., Kühn, D., Prokofeva, T.V., Vasenev, V., 2017. Classification of urban soils. In: Levin, M.J., Kim, K.H.J., Morel, J.L., Burghardt, W., Charzynski, P., Shaw, R.K. (Eds.), Soils Within Cities: Global Approaches to Their Sustainable Management-Composition, Properties, and Functions of Soils of the Urban Environment. GeoEcology essay, Schweizerbart and Borntraeger science publishers, Stuttgart, pp. 93–106.

Clermont-Ganneau, C., 1896. Archaeological Researches in Palestine During the Years 1873–1874 (Vol. 2): With Numerous Illustrations from Drawings Made on the Spot by A. Lecomte Du Noüy. Published for the Committee of the Palestine Exploration Fund, London.

Color, Munsell, 1990. Munsell Soil Color Charts and Determination of Soil Color, from USDA Handbook 18-Soil Survey Manual. Kollmorgen Instruments Corp, Baltimore, MD.
Courty, M.A., 2017. Fuel origin and firing product preservation in archaeological occupation contexts. Quat. Int. 431, 116–130.
Courty, M.A., Coqueugniot, E., 2013. A microfacies toolkit for revealing linkages between cultural discontinuities and exceptional geogenic events: the Tell Da'de case study (NE Syria). J. Archaeol. Method Theory 20, 331–362.
Courty, M.A., Martinez, J.M., 2015. Terrestrial carbonaceous debris tracing atmospheric hypervelocity-shock aeroplasma processes. Procedia Eng. 103, 81–88.
Courty, M.A., Goldberg, P., Macphail, R. (Eds.), 1989. Soils and Micromorphology in Archaeology. Cambridge University Press, Cambridge.
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.
Crouvi, O., Zaidenberg, R., Shapiro, M., 2013. Soil resources of Israel. In: Yigini, Y., Panagos, P., Montanarella, L. (Eds.), Soil Resources of Mediterranean and Caucasus Countries Extension of the European Soil Database. European Commission, Joint Research Centre, Institute for Environment and Sustainability, Italy, pp. 113–132.
Crouvi, O., Amit, R., Ben Israel, M., Enzel, Y., 2017. Loess in the Negev Desert: sources, Loessial soils, Palaeosols, And Palaeoclimatic implications. In: Enzel, Y., Bar-Yosef, O. (Eds.), Quaternary of the Levant: Environments, Climate Change, and Humans. Cambridge University Press, Cambridge, pp. 471–482.
Dagan, Y., 2000. The Settlement in the Judean Shephelah in the Second and First Millennium B.C.: A Test-Case of Settlement Processes in a Geographic Region (Ph.D. Dissertation). Tel Aviv University, Tel Aviv (Hebrew).
Dagan, Y., 2011. The Ramat Bet Shemesh regional project: landscapes of settlement, from the Paleolithic to the Ottoman period. In: Israel Antiquities Authority, Reports: 47. Israel Antiquities Authority, Jerusalem.
Dan, J., 1988a. The soils of the southern Shefelah. In: Stern, E., Urman, D. (Eds.), Man and Environment in the Southern Shefelah-Stusies in Regional Geography and History. Massada, Ben-Gurion University of the Negev, Hebrew, pp. 50–58.
Dan, J., 1988b. The soils of the land of Israel. In: Yom-Tov, Y., Tchernov, E. (Eds.), The Zoogeography of Israel: The Distribution and Abundance at a Zoogeographical Crossroad. Dr. W. Junk Publishers, Dordrecht, pp. 95–128.
Dan, J., Yaalon, D.H., Koyumdjisky, H., 1972. Catenary soil relationships in Israel: II. The Bet Guvrin Catena on chalk and nari limestone crust in the Shefela. Isr. J. Earth Sci. 21, 99–118.
Danin, A., 1988. Flora and vegetation of Israel and adjacent areas. In: Yom-Tov, Y., Tchernov, E. (Eds.), The Zoogeography of Israel: The Distribution and Abundance at a Zoogeographical Crossroad. Dr. W. Junk Publications, Dordrecht, pp. 129–158.
Davidson, D., 1973. Particle size and phosphate analysis-evidence for the evolution of a tell. Archaeometry 15, 143–152.
Davidson, D.A., 1976. Processes of tell formation and erosion. In: Davidson, D.A., Shackley, M.L. (Eds.), Geoarchaeology: Earth Science and the Past. Westview Press, Boulder, Colorado, pp. 255–266.
Davidson, D.A., Shackley, M.L., 1976. Geoarchaeology: Earth Science and the Past. Westview Press, Boulder, Colorado.
Davidson, D.A., Wilson, C.A., Lemos, I.S., Theocharopoulos, S.P., 2010. Tell formation processes as indicated from geoarchaeological and geochemical investigations at Xeropolis, Euboea, Greece. J. Archaeol. Sci. 37, 1564–1571.
Duran-Zuazo, V.H., Rodriguez-Plequezuelo, C.R., 2008. Soil-erosion and runoff prevention by plants cover. A review. Agron. Sustain. Dev. 28, 65–86.
Erktan, A., Cécillon, L., Graf, F., Roumet, C., Legout, C., Rey, F., 2015. Increase in soil aggregate stability along a Mediterranean successional gradient in severely eroded gully bed ecosystems: combined effects of soil, root traits and plant community characteristics. Plant Soil 398, 121–137.
Evangelou, V.P., Whittig, L.D., Tanji, K.K., 1984. An automated manometric method for quantitative determination of calcite and dolomite. Soil Sci. Soc. Am. J. 48, 1236–1239.
Faust, A., 2013. The Shephelah in the Iron Age: A new look on the settlement of Judah. Palest. Explor. Q. 145, 203–219.
Faust, A., Katz, H., 2015. A Canaanite town, a Judahite center, and a Persian Period fort: excavating over two thousand years of history at Tel 'Eton. Near East. Archaeol. 78, 88–102.
Fedoroff, N., Courty, M.A., 2013. Revisiting the genesis of red Mediterranean soils. Turk. J. Earth Sci. 22, 359–375.
Fisher, P., Aumann, C., Chia, K., O'Halloran, N., Chandra, S., 2017. Adequacy of laser diffraction for soil particle size analysis. PLoS One 12. http://dx.doi.org/10.1371/journal.pone.0176510.
Franceschi, V.R., Nakata, P.A., 2005. Calcium oxalate in plants: formation and function. Annu. Rev. Plant Biol. 56, 41–71.
Friesem, D., Boaretto, E., Eliyahu-Behar, A., Shahack-Gross, R., 2011. Degradation of mud brick houses in an arid environment: a geoarchaeological model. J. Archaeol. Sci. 38, 1135–1147.
Friesem, D.E., Tsartsidou, G., Karkanas, P., Shahack-Gross, R., 2014. Where are the roofs? A geo-ethnoarchaeological study of mud brick structures and their collapse processes, focusing on the identification of roofs. Archaeol. Anthropol. Sci. 6, 73–92.
Friesem, D.E., Wattez, J., Onfray, M., 2017. Earth construction materials. In: Nicosia, C., Stoops, G. (Eds.), Archaeological Soil and Sediment Micromorphology. John Wiley & Sons, Chichester, pp. 99–110.
Gadd, G.M., 2007. Geomycology: biogeochemical transformations of rocks, minerals, metals and radionuclides by fungi, bioweathering and bioremediation. Mycol. Res. 111, 3–49.
Gelman, F., Binstock, R., Halicz, L., 2012. Application of the Walkley-Black titration for the organic carbon quantification in organic rich sedimentary rocks. Fuel 96, 608–610.
Goffer, Z., 2007. Archaeological Chemistry. John Wiley & Sons, Hoboken, New Jersey.
Goldberg, P., 1979. Geology of Late Bronze Age mudbrick from Tel Lachish. Tel Aviv J. Tel Aviv Inst. Archaeol. 6, 60–71.
Goldberg, P., 2004. Section F: the micromorphology of Late Bronze Age Mudbrick. In: Ussishkin, D. (Ed.), The Renewed Archaeological Excavations at Lachish (1973–1994), Volumes I–V, Appendix II. Emery and Claire Yass Publications in Archaeology, pp. 2593–2603.
Goldberg, P., Macphail, R.I., 2006. Practical and Theoretical Geoarchaeology. Blackwell Publishing, Oxford.
Goldreich, Y., 2003. The Climate of Israel: Observation, Research and Application. Springer Science + Business Media, New York.
Goren, Y., 2013. New design for a versatile field microscope. Microsc. Today 21, 26–29.
Gottlieb, J.J., 2015. Analysis of Ancient Mortars Employed in the Construction of Montfort Castle and their Modern Counterparts Used in its Conservation. University of Haifa, Faculty of Humanities, Department of Archaeology, Haifa (MA thesis).
Gupta, R.K., Abrol, I.P., 1990. Salt-affected soils: their reclamation and management for crop production. In: Lal, R., Stewart, B.A. (Eds.), Advances in Soil Science. Springer, New York, pp. 223–288.
Gyssels, G., Poesen, J., Bochet, E., Li, Y., 2005. Impact of plant roots on the resistance of soils to erosion by water: a review. Prog. Phys. Geogr. 29, 189–217.
Hilprecht, H.V., 1903. Explorations in Bible Lands During the 19th Century. A.J Holman and Company, Philadelphia.
Hodson, M.E., Benning, L.G., Demarchi, B., Penkman, K.E., Rodriguez-Blanco, J.D., Schofield, P.F., Versteegh, E.A., 2015. Biomineralisation by earthworms - an investigation into the stability and distribution of amorphous calcium carbonate. Geochem. Trans. 16, 1–16.
Howard, J., 2017. Anthropogenic Soils. Springer International Publishing, Gewerbestrasse.
Israel Meteorological Service, 2018. http://www.ims.gov.il/IMSEng/Tazpiot, Accessed date: January 2018.
Itkin, D., Geva-Kleinberger, A., Yaalon, D.H., Shaanan, U., Goldfus, H., 2012. Nāri in the Levant: historical and etymological aspects of a specific calcrete formation. Earth Sci. Hist. 31, 210–228.
Itkin, D., Goldfus, H., Monger, H.C., 2016. Human induced calcretisation in anthropogenic soils and sediments: field observations and micromorphology in a Mediterranean climatic zone, Israel. Catena 146, 48–61.
IUSS Working Group WRB, 2015. World reference base for soil resources 2014, update 2015 international soil classification system for naming soils and creating legends for soil maps. In: World Soil Resources Reports No. 106. FAO, Rome.
Jahn, R., Blume, H.P., Asio, V.B., Spaargaren, O., Schad, P., 2006. Guidelines for Soil Description. Food and Agriculture Organization of the United Nations, Rome.
Khalaily, H., Marder, O., 2010. Prehistoric investigations along the cross-Israel highway: state of research. Atiqot 64, 5–23.
Khokhlova, O.S., Voronin, K.V., Malashev, V.Yu., Golyeva, A.A., Khokhlov, A.A., 2001. Soil evolution and accumulation of loess-like material in the Chechen depression, Northern Caucasus, Russia. Quat. Int. 76/77, 103–112.
Koch, I., 2017. Settlements and Interactions in the Shephelah during the late second through early first Millennium BCE. In: Maeir, A.M., Lipschits, O. (Eds.), The Shephelah During the Iron Age: Recent Archaeological Studies. Eisenbrauns, Winona Lake, Indiana, pp. 181–207.
Koyumdjisky, H., Dan, J., Suriano, S., Nissim, S., 1988. Selected soil profiles from the soils of Eretz-Israel. In: Agricaltural Research Organization. The Institute for Soil and Water, Department of Pedology. Volcani Center, Bet-Dagan (Hebrew).
Lehmann, A., Stahr, K., 2007. Nature and significance of anthropogenic urban soils. J. Soils Sediments 7, 247–260.
Lev-Yadun, S., Gopher, A., Abbo, S., 2000. The cradle of agriculture. Science 288, 1602–1603.
Liebowitz, H., Folk, R.L., 1980. Archeological geology of Tel Yin'am, Galilee, Israel. J. F. Archaeol. 7, 23–42.
Lloyd, S., 1963. Mounds of the Near East. Edinburgh University Press, Edinburgh, Aldine Publishing Company, Chicago.
Love, S., 2012. The geoarchaeology of mudbricks in architecture: a methodological study from Çatalhöyük, Turkey. Geoarchaeology 27, 140–156.
Macalister, R.A.S., 1925. A Century of Excavation in Palestine. The Religious Tract Society, London.
Macphail, R.I., Cruise, G.M., 2001. The soil micromorphologist as team player: a multianalytical approach to the study of European microstratigraphy. In: Goldberg, P., Holliday, V.T., Ferring, C.R. (Eds.), Earth Sciences and Archaeology. Springer Science + Business Media, New York, pp. 241–268.
Macphail, R.I., Goldberg, P., 2017. Applied Soils and Micromorphology in Archaeology. Cambridge University Press, Cambridge.
Macphail, R.I., Bill, J., Crowther, J., Haită, C., Linderholm, J., Popovici, D., Rødsrud, C.L., 2017. European ancient settlements - a guide to their composition and morphology based on soil micromorphology and associated geoarchaeological techniques; introducing the contrasting sites of Chalcolithic Bordusani-Popina, Borcea River, Romania and Viking Age Heimdaljordet, Vestfold, Norway. Quat. Int. 460, 30–47.
Maeir, A.M., Lipschits, O., 2017. Introduction. In: Maeir, A.M., Lipschits, O. (Eds.), The Shephelah During the Iron Age: Recent Archaeological Studies. Eisenbrauns, Winona Lake, Indiana, pp. vii–x.
Maghsoudi, M., Simpson, I.A., Kourampas, N., Nashli, H.F., 2014. Archaeological sediments from settlement mounds of the Sagzabad Cluster, central Iran: human-induced deposition on an arid alluvial plain. Quat. Int. 324, 67–83.
Marder, O., Malinsky-Buller, A., Shahack-Gross, R., Ackermann, O., Ayalon, A., Bar-Matthews, M., Goldsmith, Y., Inbar, M., Rabinovich, R., Hovers, E., 2011. Archaeological horizons and fluvial processes at the Lower Paleolithic open-air site of

Revadim (Israel). J. Hum. Evol. 60, 508–522.
Marish, M., Hetzroni, S., 1983. Lachish East, Soil Survey Report. Minsetry of Agriculture, Water Commissionership, The Department of Soil Conservation and Water Drainage, Hebrew.
Marish, S., Soil Survey Staff, 1980. Soil Survey Report. Minsetry of Agriculture, The Water Commissionership, Regional Concil Mate Yehuda, Hebrew.
Matthews, W., 1995. Micromorphological characterisation and interpretation of occupation deposits and microstratigraphic sequences at Abu Salabikh, Southern Iraq. In: Barham, A.J., Macphail, R.I. (Eds.), Archaeological Sediments and Soils: Analysis, Interpretation and Management. Institute of Archaeology, University College, London, pp. 41–76.
Matthews, W., 2010. Geoarchaeology and taphonomy of plant remains and microarchaeological residues in early urban environments in the Ancient Near East. Quat. Int. 214, 98–113.
Matthews, W., 2017. Tells. In: Gilbert, A.S., Goldberg, P., Holliday, V.T., Mandel, R.D., Sternberg, R.S. (Eds.), Encyclopedia of Geoarchaeology. Springer Science + Business Media Dordrecht, pp. 951–972.
Matthews, R.J., Matthews, W., McDonald, H., 1994. Excavations at Tell Brak, 1994. 56. British Institute for the Study of Iraq, Iraq, pp. 177–194.
Matthews, W., French, C.A.I., Lawrence, T., Cutler, D.F., Jones, M.K., 1997. Microstratigraphic traces of site formation processes and human activities. World Archaeol. 29, 281–308.
Miller, B.A., Schaetzl, R.J., 2012. Precision of soil particle size analysis using laser diffractometry. Soil Sci. Soc. Am. J. 76, 1719–1727.
Monger, H.C., Daugherty, L.A., Lindemann, W.C., Liddell, C.M., 1991. Microbial precipitation of pedogenic calcite. Geology 19, 997–1000.
Monger, H.C., Martinez-Rios, J.J., 2000. Inorganic carbon sequestration in grazing lands. In: Kimble, J.M., Lal, R. (Eds.), The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. Follett, R.F.CRC Press, LLC, Boca Raton, Florida, pp. 87–118.
Monger, H.C., Wilding, L.P., 2017. Inorganic carbon: Composition and formation. In: Lal, R. (Ed.), Encyclopedia of Soil Science. Taylor & Francis Group, Boca Raton, pp. 1199–1202.
Monger, H.C., Cole, D.R., Buck, B.J., Gallegos, R.A., 2009. Scale and the isotopic record of C4 plants in pedogenic carbonate: from the biome to the rhizosphere. Ecology 90, 1498–1511.
Murphy, C.P., Kemp, R.A., 1984. The over-estimation of clay and the under-estimation of pores in soil thin sections. Eur. J. Soil Sci. 35, 481–495.
Namdar, D., Zukerman, A., Maeir, A.M., Katz, J.C., Cabanes, D., Trueman, C., Shahack-Gross, R., Weiner, S., 2011. The 9th century BCE destruction layer at Tell es-Safi/Gath, Israel: integrating macro- and microarchaeology. J. Archaeol. Sci. 38, 3471–3482.
Naveh, Z., Dan, J., 1973. The human degradation of Mediterranean landscapes in Israel. In: Castri, F.D., Mooney, A. (Eds.), Mediterranean Type Ecosystems. Origin and Structure. Springer Verlag, Berlin & Heidelberg, pp. 373–390.
Nicosia, C., Stoops, G. (Eds.), 2017. Archaeological Soil and Sediment Micromorphology. John Wiley & Sons, Chichester.
Ortiz, S., Wolff, S., 2012. Guarding the border to Jerusalem: The Iron Age city of Gezer. Near East. Archaeol. 75, 4–19.
Ortiz, S.M., Wolff, S.R., 2017. Tel Gezer excavations 2006–2015: the transformation of a border city. In: Maeir, A.M., Lipschits, O. (Eds.), The Shephelah During the Iron Age: Recent Archaeological Studies. Eisenbrauns, Winona Lake, Indiana, pp. 61–102.
Paz, Y., Ackermann, O., Avni, Y., Ben-Hur, M., Birkenfeld, M., Langgut, D., Mizrahi, A.S., Weiss, E., Porat, N., 2017. An early bronze age fertilized agricultural plot discovered near Tel Yarmouth, Ramat Bet Shemesh, Israel. J. Archaeol. Sci. Rep. 15, 226–234.
Peel, M.C., Finlayson, B.L., McMahon, T.A., 2007. Updated world map of the Köppen-Geiger climate classification. Hydrol. Earth Syst. Sci. Discuss. 4, 439–473.
Pentecost, A., Riding, R., 1986. Calcification in cyanobacteria. In: Leadbeater, B.S.C., Riding, R. (Eds.), Biomineralization in lower plants and animals systematics association special volume. vol. 30. Oxford University Press, Oxford, pp. 73–90.
Pustovoytov, K., Deckers, K., Goldberg, P., 2011. Genesis, age and archaeological significance of a pedosediment in the depression around Tell Mozan, Syria. J. Archaeol. Sci. 38, 913–924.
Rapp Jr., G., 1975. The archaeological field staff: the geologist. J. Field Archaeol. 2, 229–237.
Rassam, H., 1897. Asshur and the Land of Nimrod. Curts & Jennings, Cincinnati.
Regev, L., Poduska, K.M., Addadi, L., Weiner, S., Boaretto, E., 2010. Distinguishing between calcites formed by different mechanisms using infrared spectrometry: archaeological applications. J. Archaeol. Sci. 37, 3022–3029.
Regev, L., Cabanes, D., Homsher, R., Kleiman, A., Weiner, S., Finkelstein, I., Shahack-Gross, R., 2015. Geoarchaeological investigation in a domestic Iron Age quarter, Tel Megiddo, Israel. Bull. Am. Sch. Orient. Res. 374, 135–157.
Riehl, S., Asouti, E., Karakaya, D., Starkovich, B.M., Zeidi, M., Conard, N.J., 2015. Resilience at the transition to agriculture: The long-term landscape and resource development at the Aceramic Neolithic Tell site of Chogha Golan (Iran). Biomed. Res. Int. http://dx.doi.org/10.1155/2015/532481.
Robbins, C.W., Gavlak, R.G., 1989. Salt-and sodium-affected soils. University of Idaho, College of Agriculture. Bull 703, 2–12.
Rosen, A.M., 1986. Cities of Clay: The Geoarchaeology of Tells. University of Chicago Press, Chicago.
Rothenberg, K., 2014. Chemical Survey of Archaeological sites. In: Smith, C. (Ed.), Encyclopedia of Global Archaeology. Springer Science + Business Media, New York, pp. 1379–1382.
Ryan, J., Kapur, S., Akça, E. (Eds.), 2009. Application of soil analyses as markers to characterize a Middle Eastern Chalcolithic-Late Bronze Age mounds. TÜBA-AR 12, 65–76.
Sandler, A., 2013. Clay distribution over the landscape of Israel: from the hyper-arid to the Mediterranean climate regimes. Catena 110, 119–132.
Sapir, G., 1977. Vegetation of the Southern Shephelah and the Relation Between Plant Groups Distribution and Habitat Factors. The Hebrew University of Jerusalem, Department of Botany, Jerusalem (MSc thesis; Hebrew).
Sapir, Y., 2016. Site Formation Processes at Tel 'Eton and Its Surrounding. Bar-Ilan University, The Martin (Szusz) Department of Land of Israel Studies and Archaeology, Ramat-Gan (PhD thesis; Hebrew with English abstract).
Sapir, Y., Faust, A., 2016. Utilizing mole-rat activity for archaeological survey: a case study and a proposal. Adv. Archaeol. Pract. 4, 55–70.
Sapir, Y., Avraham, A., Faust, A., 2016. Mud-brick composition, archeological phasing and pre-planning in Iron Age structures: Tel 'Eton (Israel) as a test-case. Archaeol. Anthropol. Sci. 1–14. http://dx.doi.org/10.1007/s12520-016-0350-z.
Schaetzl, R., Anderson, S., 2005. Soils: Genesis and Geomorphology. Cambridge University Press, New York.
Schiffer, M.B., 1987. Formation Processes of the Archaeological Record. University of Utah Press, Salt Lake City.
Schoeneberger, P.J., Wysocki, D.A., Benham, E.C., Soil Survey Staff, 2012. Field Book for Describing and Sampling Soils, Version 3.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.
Sedov, S.N., Aleksandrovskii, A.L., Benz, M., Balabina, V.I., Mishina, T.N., Shishkov, V.A., Şahin, F., Özkaya, V., 2017. Anthropogenic sediments and soils of tells of the Balkans and Anatolia: composition, genesis, and relationships with the history of landscape and human occupation. Eurasian Soil Sci. 50, 373–386.
Shahack-Gross, R., 2016. Archaeological micromorphology self-evaluation exercise. Geoarchaeology 31, 49–57.
Shahack-Gross, R., 2017. Archaeological formation theory and geoarchaeology: state-of-the-art in 2016. J. Archaeol. Sci. 79, 36–43.
Shahack-Gross, R., Ayalon, A., 2013. Stable carbon and oxygen isotopic compositions of wood ash: an experimental study with archaeological implications. J. Archaeol. Sci. 40, 570–578.
Shahack-Gross, R., Albert, R.M., Gilboa, A., Nagar-Hilman, O., Sharon, I., Weiner, S., 2005. Geoarchaeology in an urban context: the uses of space in a Phoenician monumental building at Tel Dor (Israel). J. Archaeol. Sci. 32, 1417–1431.
Shahack-Gross, R., Shaar, R., Hassul, E., Ebert, Y., Forget, M., Nowaczyk, N., Marco, S., Finkelstein, I., Agnon, A., 2018. Fire and collapse: untangling the formation of destruction layers using archaeomagnetism. Geoarchaeology 1-16.
Sherwood, S.C., Kidder, T.R., 2011. The DaVincis of dirt: geoarchaeological perspectives on Native American mound building in the Mississippi River basin. J. Anthropol. Archaeol. 30, 69–87.
Shillito, L.M., Matthews, W., 2013. Geoarchaeological investigations of midden-formation processes in the early to late ceramic Neolithic levels at Çatalhöyük, Turkey ca. 8550–8370 cal BP. Geoarchaeology 28, 25–49.
Shinomiya, T., Shinomiya, K., Orimoto, C., Minami, T., Tohno, Y., Yamada, M.O., 1998. In- and out-flows of elements in bones embedded in reference soils. Forensic Sci. Int. 98, 109–118.
Shishov, L.L., Tonkonogov, V.D., Gerasimova, M.I., Lebedeva, I.I., 2005. New classification system of Russian soils. Eurasian Soil Sci. 38, S35–S43.
Singer, A., 2007. The soils of Israel. Springer-Verlag, Berlin Heidelberg.
Smejda, L., Hejcman, M., Horak, J., Shai, I., 2017a. Ancient settlement activities as important sources of nutrients (P, K, S, Zn and Cu) in Eastern Mediterranean ecosystems - the case of biblical Tel Burna, Israel. Catena 156, 62–73.
Smejda, L., Hejcman, M., Horák, J., Shai, I., 2017b. Multi-element mapping of anthropogenically modified soils and sediments at the Bronze to Iron Ages site of Tel Burna in the southern Levant. Quat. Int. http://dx.doi.org/10.1016/j.quaint.2017.11.005. (in press).
Sneh, A., Avni, Y., 2008. Geological Map of Israel 1:50,000, Eshtemoa sheet 15-1. Ministry of Natl. Infrastructures. Geological Surv. of Israel, Jerusalem.
Sneh, A., Bartov, Y., Rosensaft, M., 1998. Geological Map of Israel 1:200000, Sheet 2. Ministry of Natl. Infrastructures, Geological Surv. of Israel, Jerusalem.
Soil and Pasture Survey Staff, 1983. Southern Hebron Mountains–Surveys Summery. Water Commissionership, The Department of Soil Conservation and Water Drainage, Hebrew.
Soil Survey Staff, 2014. Keys to Soil Taxonomy. In: United States Department of Agriculture, Natural Resources Conservation Service, 12th ed. National Soil Survey Center, Lincoln, Nebraska.
Soil Survey Staff, 2015. Illustrated Guide to Soil Taxonomy, Version 2. United States Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, Nebraska.
Sokoloff, M., 2002. A Dictionary of Jewish Babylonian Aramaic of the Talmudic and Geonic periods. vol. 3 JHU Press, Jerusalem.
Stein, J.K., 2001. A review of site formation processes and their relevance to geoarchaeology. In: Goldberg, P., Holliday, V.T., Ferring, C.R. (Eds.), Earth Sciences and Archaeology. Springer Science + Business Media, New York, pp. 37–51.
Stern, E., Urman, D. (Eds.), 1988. Man and Environment in the Southern Shefelah–Stusies in Regional Geography and History. Ben-Gurion University of the Negev, Massada.
Stoops, G., 2003. Guidelines for Analysis and Description of Soil and Regolith Thin Sections. Soil Science Society of America, Inc, Madison, Wisconsin.
Stoops, G., Nijs, R., 1986. Micromorphological characteristics of some tell materials from Mesopotamia. Pédologie 36, 329–335.
Targulian, V.O., Goryachkin, S.V., 2004. Soil memory: types of record, carriers, hierarchy and diversity. Rev. Mex. Cienc. Geol. 21, 1–8.
Torrent, J., 2005. Mediterranean soils. In: Hillel, D., Hatfield, J.L., Powlson, D.S., Rosenzweig, C., Scow, K.M., Singer, M.J., Sparks, D.L. (Eds.), Encyclopedia of Soils in the Environment. vol. 2. pp. 418–427.
Tsatskin, A., Zaidner, Y., 2014. Geoarchaeological context of the later phases of

Mousterian occupation (80–115 ka) at Nesher Ramla, Israel: soil erosion, deposition and pedogenic processes. Quat. Int. 331, 103–114.
Verrecchia, E.P., 2000. Fungi and sediments. In: Riding, R.E., Awramik, S.M. (Eds.), Microbial Sediments. Springer-Verlag, Berlin, Heidelberg, pp. 68–75.
Verrecchia, E.P., 2011. Pedogenic carbonates. In: Reitner, J., Thiel, V. (Eds.), Encyclopedia of Geobiology. Springer Science + Business Media B.V, Netherlands, pp. 721–725.
Verrecchia, E.P., Verrecchia, K.E., 1994. Needle-fiber calcite: a critical review and a proposed classification. J. Sediment. Res. 64, 650–664.
Verrecchia, E.P., Dumont, J.L., Verrecchia, K.E., 1993. Role of calcium oxalate biomineralization by fungi in the formation of calcretes: a case-study from Nazareth, Israel. J. Sediment. Petrol. 63, 1000–1006.
Warren, C., Conder, C.R., 1884. The Survey of Western Palestine: Jerusalem. Committee of the Palestine Exploration Fund, Adelphi, London.
Weiner-Bloch, S., 1989. Paleosols from the Bet Nir Formation (Late Miocene) in the Messilat Ziyyon Area. The Hebrew University of Jerusalem, Institute of Earth Sciences, Jerusalem (M.Sc. thesis; Hebrew with English abstract).
Weiss, H., Courty, M.A., Wetterstrom, W., Guichard, F., Senior, L., Meadow, R., Curnow, A., 1993. The genesis and collapse of third millennium north Mesopotamian civilization. Science 261, 995–1004.
Wiesl, Y., Liphschitz, Lev-Yadun, S., 1986. Flora in ancient Eretz-Israel. In: Kasher, A., Oppenheimer, A., Rappaport, U. (Eds.), Man and Land in Eretz-Israel in Antiquity. Yad Izhak Ben Zvi, Jerusalem, pp. 231–243 (Hebrew).
Wilkinson, T.J., 2003. Archaeological Landscapes of the Near East. University of Arizona Press, Arizona.
Wolff, S. (Ed.), 2017. Villain or Visionary?: RAS Macalister and the Archaeology of Palestine. Routledge, New York.
Yaalon, D.H., 1987. Saharan dust and desert loess: effect on surrounding soils. J. Afr. Earth Sci. 6, 569–571.
Yaalon, D.H., 1993. Soil science in the eyes of the beholder: better understanding of soil processes and pedology urged. Bull. Int. Soc. Soil Sci. 84, 13–14.
Yaalon, D.H., Ganor, E., 1973. The influence of dust on soils during the Quaternary. Soil Sci. 116, 146–155.
Zaidner, Y., Porat, N., Zilberman, E., Herzlinger, G., Almogi-Labin, A., Roskin, J., 2018. Geo-chronological context of the open-air Acheulian site at Nahal Hesi, northwestern Negev, Israel. Quat. Int. 464, 18–31.
Zohar, M., Salamon, A., Rubin, R., 2017. Earthquake damage history in Israel and its close surrounding-evaluation of spatial and temporal patterns. Tectonophysics 696, 1–13.