The contribution of POSL and PXRF to the discussion on sedimentary and site formation processes in archaeological contexts of the southern Levant and the interpretation of Biblical strata at Tel Burna

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Highlights:

Elemental stratigraphic gradients correlate with chronology (Ca, P, K, Mn, Zn).

Human activities revealed by Cu, P, K, Zn, and Mn.

Geochemistry could be used as a pseudo-dating method (K content).

Higher content of Ca in younger phases/topsoil is probably due to aeolian deposition.

Abstract

Site formation processes at ancient tells in the southern Levant have been the focus of several micromorphological studies, contributing to the differentiation of anthropogenic remains from long-term natural sedimentation, occurring post-abandonment. This paper discusses how the study of sedimentary processes and chemical compositions of sediments can be used within the context of an ongoing archaeological project, and how they can contribute to archaeological, historical and geomorphological interpretations. Sedimentary processes were studied implementing POSL, granulometry and PXRF as part of the archaeological research at Tel Burna, Israel. Focusing on the area along the north western fortification walls (Area B2), data was collected from multiple strata inside and outside the casemate fortifications dating from the Late Bronze Age to the Late Iron Age.

The gradual increase of OSL values obtained inside the casemate wall, indicate accumulation of sediment during a long period of time. Whereas similar values along the entire profile outside the casemate wall indicate sediment accumulation in one-time event. This might be related to defensive preparations, allegedly in response to advances made by Sennacherib's army in 701 BCE. In addition, results from the PXRF studies demonstrated correlation between human activities and the Cu, P, K, Zn, Mn values. Specifically, it was found that as K content increased from younger to older periods, it can be used as a pseudo-dating element. Ca content decreased as sampling descended from the tell's surface, suggesting its origin in long-term aeolian processes. The results show that the use of POSL and PXRF on archaeological contexts are useful for determining sedimentary processes. Furthermore, chemical content enabled pseudo-dating of strata and facilitated the distinction between natural and anthropogenic processes in archaeological sites and landscape.

1. Introduction

An ancient tell is a multi-period archaeological site, compiled from the remains of subsequent periods of human occupation, abandonment and reoccupation. Geomorphologically, a tell is not merely the result of a single historical event, rather it is the product of complex interactions between anthropogenic remains and natural formation processes amassed over time. It is during the course of these processes that sediment accumulation occurs, and a spatial matrix is formed (Rosen, 1986; Sapir, 2016; Luria, 2020). Depositional pathways retain evidence for these processes and can be studied to identify and differentiate these various processes and their characteristics.

The importance of natural and anthropogenic processes in archaeology has been thoroughly described in many geoarchaeological studies (e.g. Rosen, 1986; Goldberg and Macphail, 2006; Rapp and Hill, 2006; Shahack-Gross et al., 2014). Pedological activities are one of the natural processes reported in several studies from the area of East Europe and East Mediterranean. However, there is no unified methodology and research area. For example, Amadio's (2019) research on post-depositional processes conducted in Cyprus focused primarily on the micromorphological data. In an area closer to the study region, Itkin et al. (2018) carried out micromorphological research inspired by former studies (e.g. Matthews et al. 1997, Rosen 1986, Sedov et al. 2017). Itkin et al. described the pedological processes at several tells in Israel, concluding that the dominant soil-forming processes in tells are disintegration and dissolution of archaeological materials (inorganic, organic), pedoturbation, aggregation and redistribution of calcium carbonate. Whereas, studies by Lucke et al. (2019a,b) concluded that ancient ruins serve as a trap for aeolian sediments which affected the site sediments content.

Research on site formation processes can be divided into two perspectives. The one is focused primarily on pedological contexts and sedimentology (e.g. Itkin et al., 2018; Lucke et al. 2019a,b; Porat et al., 2018, 2019) and the other perspective is focused on environmental factors within archaeological contexts (e.g. Goldberg, 1979; Jelinek et al., 1973; Rosen 1986; Shahack-Gross, 2007, 2017). This paper aims to combine both perspectives and to evaluate the results in reference to the methodological diversity of these studies.

The selected site, Tel Burna, is a perfect candidate for this research as it was abandoned in the mid-first millennium BCE, and never resettled (Uziel and Shai 2010). From that time onward it has mainly undergone natural processes. This enables the differentiation between the human occupation and the following abandonment periods.

The aims of this paper are: i) visually uniform stratum sediments determination; ii) the interpretation of past human activities based on the PXRF and POSL results; iii) the determination of aeolian deposition by Ca content at the top of archaeological sediments and its interpretation.

2. Study area

2.1 Localisation and natural environment

Tel Burna is located in the Judaean low hills, also known as the Shephelah region, of central Israel (31.629659N, 34.873539E, Figure 1:a). This area is characterized by a Sub-humid to Semi-Arid climate with a mean annual temperature of 20°C and a mean annual precipitation of 401–500 mm (Israel Meteorological Service, 2019). Precipitation in this region is limited to the wintertime from October/November to April. The precipitation amount is sufficient for rain-fed agriculture during winter and spring (Zohary, 1962: Map 3, Figure 4). Notably, these climatic conditions have changed little since 6500 BP (Bar-Matthews et al., 1998).

The site (circa 10 ha) is situated on the northern bank of Nahal Guvrin ("Nahal" is the Hebrew term for "Wadi" in Arabic, i.e. for an ephemeral stream). The tell's bedrock consists mainly of Eocene chalk of the "Maresha" and "Bet-Guvrin" formations (Sneh, 2008). The chalk bedrock is covered by calcrete (calcium-rich duricrust), known locally as nāri (Wieder et al., 1994; Itkin et al., 2012). A Pliocene flood plain composed of gravel of the Ahuzam Conglomerate is located at the southwestern lower part of the tell's slopes (Sneh, 2008).

The pedological taxonomy is according to Israeli and EU Commission (Dan et al., 1976; Jones et al., 2005; Singer, 2007). Several types of rendzina soils are found in the area: Brown Rendzina soil (Calcisol) in soil pockets within Calcrete exposures; Pale Rendzina soil (calcareous Leptosol) on a soft chalk layer; and Dark Brown soil (Kastanozem) in the Nahal Guvrin flood plain area. The site consists of sediments ranging from poorly consolidated to unconsolidated and highly anthropogenic grey soils with mainly silty fraction size (Šmejda et al., 2017; 2018).

2.2 Archaeological and Geoarchaeological background

The ongoing Tel Burna excavations over the past decade (McKinny et al., 2020), have exposed strata dating to the Late Bronze Age (1550–1200 BCE – henceforth LB) and the Iron Age II (10th–6th century BCE - henceforth IA). The earliest occupation layer exposed (Figure 1:b), dates to LB, and consists of a fairly large public structure apparently dedicated to cultic activities (Area B1), located on the lower western saddle of the tell (Shai et al., 2015). At the summit, excavations have exposed the IA II fortification system (Areas A1, G and B2 Figure 1:b) (Shai et al., 2012) and some of the IA II buildings constructed within the fortification walls (Areas A1 and B2) (Shai et al., 2014; Riehl and Shai, 2015; Shai, 2017; McKinny et al., 2020).

In the middle of Area B2, located on the western slope of the tell, in squares D7-C7 and D6-C6, a casemate fortification was exposed. The term casemate fortification refers to a fortification constructed of an inner and an outer city wall, containing chambers with transverse walls referred to as the casemates. Tel Burna casemate's external wall (W65120) has been preserved to a height of approx. 2.5 meters. The fills outside and inside the casemate wall contained material with many large LB pottery sherds, as well as finds associated with metallurgical activities (e.g. crucibles, slags, copper fragments, Figure 2). The excavators presume that this fill had been brought intentionally from a nearby LB context, and dumped next to the fortification walls. They tentatively date this event, based on the small amount of IA sherds found in the fill, to sometime in the IA IIA or IIB (McKinny, Tavger and Shai 2019; Shai and McKinny 2020, 11–12). Outside of the fortification, below the aforementioned fill (Square B6), the archaeologists revealed a destruction layer with *in situ* smashed vessels, dating to the early IA IIA.

Geoarchaeological studies have demonstrated the impact of past human occupation on the archaeological sediments at Tel Burna (Šmejda et al. 2017; 2018). These studies have focused on the surface situation and have demonstrated the contemporary chemical status of the tell's soils and sediments after a long history of occupation and abandonment, as demonstrated a high value of various elements (e.g. P, K, Ca, Zn, Cu). The current research tests the chemical status of the tell's subsurface soils and sediments to get a vertical view of the layers below the surface.

3. Methodology

3.1 Sampling strategy

The selected Area B2 (Figure 1:c) is situated along the western slope of the tell just below the edge of the summit plateau, offering an opportunity to study interesting sedimentation dynamics (Squares B6, B7, C6, C7 D6, D7). The area is associated with the construction of the fortifications. To the west of it, in Square B7, a destruction layer was revealed which is dated to the 10th century BCE. These were both connected to the dynamic sedimentation changes on the site and to the presumably dynamic geochemical changes. The inner part of the fortification wall (Squares C6-C7) was filled with soil and artifacts, redeposited here from a yet unknown place of older, primary deposition. Samples were collected here, implementing two sampling strategies: one in a horizontal grid (for PXRF analysis) and one with vertical profiles (for granulometry and POSL analysis).

3.2 Granulometry and POSL sampling

The soil profiles were sampled for POSL (Portable OSL reader) analysis in two squares – D6 and C7 (Table 1, S1, Figure 3). Thirteen soil samples were collected in the southern profile of Square D6 from the depth of 0 to 180 centimetres; and 9 samples from the northern profile of Square C7 from the depth of 0 to 220 centimetres. Those two squares have been selected based on the archaeological interpretation during the excavation of Square D6, which recorded a more continuous sedimentary record than Square C7. The situation showcased the contrast of the sedimentary situation in both squares.

3.3 XRF sampling

A collection of 211 soil/sediment samples was taken from Area B2 during the 2018 excavation season. The position of each sample was entered into PlanGrid software (for use of this application in archaeology see McKinny and Shai, 2018). The final database contains information about each sample's location within the area, square, locus, and the elevation in m a.s.l.

Notably, in this study, the description of strata is as follows: Early IA IIA – IA IIA/B fill – IA IIB – IA IIC. As LB pottery sherds were discovered in the stratum IA IIA/B fill, this sedimentary material was the oldest by its origin, even though this fill had been redeposited secondarily in a later period. Therefore, the chronological sequence was followed in this order: IA IIA/B fill->Early IA IIA->IA IIB->IA IIC.

The numbers of samples taken by squares are as follows: B6 (41 samples), B7 (46 samples), C6 (55 samples), D6 (60 samples), and D7 (9 samples). If possible, chronological stratum was also added to the samples as follows: Early IA IIA (87 samples), IA IIA/B fill (60 samples), IA IIB (55 samples), and IA IIC (9 samples). The samples were taken in a regular horizontal grid from the following altitudes: B6 (251.7 – 252.16 m a.s.l.), B7 (251.66 – 252.13 m a.s.l.), C6 (253.05 – 253.47 m a.s.l.), D6 and D7 (254.13 – 254.68 m a.s.l.).

3.4 Analytical methods

3.4.1 Grain size analyses

Grain size analysis (granulometry) of the fine material (<2 mm) of the pedosediment samples was measured by the hydrometer sedimentation column method. Prior to measurement, the sample splits were dispersed using Calgon (powdered sodium hexametaphosphate) solutions (Wright, 1939; Klute, 1986).

3.4.2 Portable luminescence profiling

Over the past decade POSL has been increasingly implemented in geomorphological, archaeological and sedimentological investigations (e.g. Portenga and Bishop, 2016; Porat et al., 2019; Roskin et al., 2019; Schmitt et al., 2020). In Area B2, in order to understand the fill deposition processes on the two casemate wall sides, two vertical portable luminescence (POSL) profiles were sampled. One, inside the casemate (Square D6) and the other outside of it (Square C7). The assumption was that natural fill had accumulated over a long time period and the OSL signal would decrease gradually from the bottom to the top of the profile. While anthropogenic fill had occurred in a short time period and the POSL signal would be quite similar along the entire part of the profile (Itach et al., 2019).

The samples were collected under a lightproof cloth and delivered to the lab in black lightproof plastic bags to avoid exposure to sunlight. In the lab, the sediments were air-dried and sieved using a 2 mm mesh sieve. Each bulk sediment sample of 5 grams was measured twice by the POSL reader. The reader measures the bulk OSL signal of quartz via blue LEDs and the IRSL signal of feldspar (K-rich) minerals via IR LEDs (protocol after Sanderson and Murphy, 2010).

3.4.3 PXRF

A portable ED-XRF (PXRF) analyser Delta Professional by Olympus InnovX with the Soil Geochem mode was used to analyse the soil samples from horizontal sampling (for applications of XRF spectrometry, see Šmejda et al., 2017; for critical discussion see Rouillon and Taylor, 2016). The samples were measured *in situ* during the archaeological excavation. They were irradiated sequentially with two different beams for one minute – 30 seconds of the 10-kV beam and 30 seconds of the 40-kV beam. The quality of the device results was successfully tested by BAS Rudice Ltd. Company (https://www.bas.cz/) on 55 reference materials (e.g. SRM 2709a, 2710a, 2711a, OREAS 161, 164, 166, RTC 405, 408). The reliability of PXRF data has been tested at Tel Burna in previous seasons comparing PXRF data with ICP-OES data (samples were extracted in Aqua regia; Šmejda et al., 2017; 2018).

3.5 Data analysis

Granulometry data were used without any transformation or statistical pre-processing. During the POSL analysis, every sample was measured twice and averaged for further analysis. Due to the PXRF construction design, not all the elements reached the limit of detection in all of the samples. Elements with more than 10% of unmeasured values were excluded from the dataset. The soil geochemical data obtained by PXRF have a compositional character, which means they provide a relative proportion to the whole (percentage, ppm, etc.). The compositional data do not vary independently, for this reason, it is not recommended to work with plain concentration or content of the element in soil (Aitchison, 1982; Reimann et al., 2012). For this reason, ilr-transformed data were used in the principal component analysis (PCA) (Reimann et al., 2008). This transformation enabled the evaluation of all the determined elements together in R version 3.6.3 (R Core Team, 2019). R with package robCompositions was used to transform the data (Templ et al., 2011).

4. Results

4.1 Granulometry results

Granulometric data obtained from selected soil samples in the profiles at Squares C7 and D6 (Table 1), indicate that the Square C7 profile was composed of loam to clay loam sediments. Whereas the Square D6 profile was composed of clay loam sediments from the topsoil to depth of 60 cm, sandy loam sediments from 60-130 cm and clay loam from 130-180 cm depth.

4.2 POSL results

The Square C7 profile (Figure 3) shows lower values at the top section (50 cm depths) than the bottom section (220 cm depths), showing photon counts from 83,464 to 172,536 respectively.

From the depth of 110 to 190 cm the values are higher, ranging from 218,595 to 248,456 photons counts. The Square D6 profile (Figure 3) shows gradual increasing values from the surface to the depths of 90 cm, ranging from 37,366 to 125,388 photons counts. From the depth of 100 to 180 centimetres the values have higher values, which are quite similar along this part of the profile, ranging from 124,642 to 170,171 photons counts.

4.3 PXRF results – the content of elements

The elements reached expected values, i.e. they were higher than the values measured in previous seasons around the site due to the anthropogenic impact. The sources of the used reference median values were published in studies by Šmejda et al. (2017, 2018). The median and maximum values of P (the most frequently analysed element in archaeology) were approx. four times higher than reference control field values. Cu was the only element with extremely high content, compared to the reference value. The median value was approximately three times higher; the maximum value was approximately fifty times higher than the values recorded off-site.

4.4 PXRF – PCA results

The ilr-transformed PCA extracted 12 components in total (Table 3), only components 1 to 6 are presented and commented (as comp., Figure 4). The first comp. explained 78% of variability, the first three comps. explained over 90% of the variability. The comp. 1 was strongly connected to Cu (positively). The comp. 2 was moderately connected to K (positively) and weakly connected to P (positively), to Ca and Cu (negatively). The comp. 3 was weakly connected to Al, Si, P (positively), to K and LE (negatively). The comp. 4 was weakly connected to P, Ca, Sr (positively) and to Ti, Mn, Fe, Zr (negatively). The comp. 5 was moderately connected to P (negatively), weakly connected to Mn, Zn (negatively) and Al, K (positively). The comp. 6 was strongly connected to Mn (positively) and weakly to P, Ti and Zr (negatively).

4.5 Results of PCA and elemental contents – general characteristics according to the archaeological stratigraphy and chronology

The P, Sr and LE, levels in Square B7, were very high and chronologically specified as stratum Early IA IIA (and defined as a destruction level). The values of Cu demonstrated a unique distribution of values (ratio of maximum to median was over 16; all other elements reached such values between 1.1 and 3.4). The maximum of Cu was measured in the Square C6 (stratum IA IIA/B fill). This enrichment is also manifested in the comp. 1 of ilr-transformed PCA in stratum IA IIA/B.

The next described characteristics pertained to the bimodality or multimodality of the data distribution, which could be indicative of combinations of different inputs into one category (e.g. the archaeological stratum/stratigraphic unit in our case). There are two examples of multimodality: the content of Cu in the Square C6 (stratum IA IIA/B fill) and the comp. 1 in stratum IA IIA/B fill (linked to Cu content). Bimodality was observed in cases of P content (Squares D6 and B7, stratum IA IIB, stratum Early IA IIA), LE content (Square B7, stratum Early IA IIA), the comp. 1 (Square C6) and the comp. 5 (Square B7, stratum Early IA IIA; component linked to P content) of ilr-transformed PCA.

Another pattern observable in the data was the trend of changing values in time (strata from the oldest to the most recent phases IA IIA/B fill->Early IA IIA->IA IIB->IA IIC). All elements showed no change between the first and the second phase (Figures 5 and 6). The most notable changes were observed between the second and the third phase. Ca was the only element, which had a higher content in sediments, retaining increased values in the last phase. Most other elements showed a decreasing trend between the second and the third phase (K, Mn, Zn, P, the comp. 1 and the comp. 2). Only K and P retained decreased values in the last phase, contrary to Mn, Zn and the comp. 1 and the comp. 2 show increased values in the last phase.

5. Discussion

5.1 Interpretation of granulometry and POSL results

The POSL results appear to indicate the sedimentation processes of profiles Squares D6 and C7. The results of the Square D6 profile, the casemate wall fill, suggest a quick fill in 90 to 180 cm depth and a continuous and gradual accumulation of sediments from 90 cm to the topsoil.

The fill from a depth of 180 cm up to 90 cm occurred during the IA IIA/B (10-9th/8th centuries BCE) and seems to be anthropogenic fill, intended to strengthen the casemate wall. The gradual fill from 90 cm to the topsoil might be related to natural fill. The fill from 90 cm up to 20 cm, occurred during the IA C (7th century BCE), a period with less human activity at the site and from 20 cm to the topsoil, following the abandonment of the site.

The results from the Square C7 profile suggest a different trend, as the values are quite similar through the entire profile. It seems that the sedimentary fill in this profile would have occurred in a relatively short time. The values of profile C7 are higher than in the bottom of profile D6, and the ceramic finds in Square C7 date to the IA IIB. It would be expected that the values would have been similar to the bottom of C6. This seems to indicate that the material, which was collected at some point in the Iron Age, in fact predates the Iron Age and was deposited relatively quickly, presumably as part of preparations for the Assyrian siege by Sennacherib's army in the late 8th century BCE (2 Kgs 19:8-9).

The topsoil of both profiles seems to be a natural fill, mostly silty, with similar OSL values, which is most-likely the accumulation of dust that sealed the profile following the abandonment of the site (Lucke et al., 2019a,b).

5.2 Interpretation of PXRF results

There are two groups of maximum values of interest. The first consists of Cu and the second consists of P, K, Sr, and LE. The content of Cu reached maximum values in Square C6. High values of Cu were interpreted as material originating from the area of metallurgical activity (see also McKinny, Tavger and Shai, 2019 and Shai and McKinny, 2020 for a suggestion that this material was originally from Area B1). This is not based only on the high Cu values but also on the presence of artefacts typically associated with metallurgy, such as crucibles, tuyeres and slags (Šmejda et al., 2018). This interpretation is supported by the POSL data of the Square C7, which is archaeologically similar to C6. The second group of elements (P, K, Sr, LE) reached maximum values in the Squares B6 and B7. The fill of these squares was archaeologically interpreted as the destruction of buildings (walls, roofs) and their contents (e.g. storage jars filled with linseeds), was dated to the Early IA IIA. These elements are usually interpreted as coming from household activities (kitchen waste, ashes, organic waste in general; Entwistle et al., 1998, 2000; Wilson et al., 2008, 2009; Horák et al. 2018; Janovský et al. 2020). Thus, the fill-in Squares B6 and B7 consisted not only of building materials but also of household organic waste.

Patterns supporting our interpretations were found in the analysis of modality in elements and PCA component histograms. Multimodality was recorded for Cu (also for Cu-connected comp. 1) in the stratum IA IIA/B fill. This multimodality was divided into two squares as C6 (bimodal) and D6 (unimodal). This geochemical diversification of the stratum IA IIA/B fill, an archaeologically uniform stratum, was present across Squares C6 and D6 and within Square C6. The same phenomenon was noted in the element P, P-connected to the comp. 5, LE, which reached bimodal distribution in Square B7 and stratum Early IA IIA, characterized by destruction debris and household organic matter. Phosphorus was bimodal in Square D6 (stratum IA IIB).

5.3 Chemical and sedimentation processes observations

In Area B2 there are two chronological development patterns in the sediments, manifested by two different chemical patterns: i) the natural processes related to the observed Ca content trend in the sediments; and ii) the contents of P, K, and Cu which could be related only to the anthropogenic activities during the existence and following the abandonment of the settlement. These processes seem to have been consistent and mutually influenced throughout the existence of the site.

The first is the Ca content, demonstrating its lower content in the older strata (mainly in Squares B6 and B7), which were archaeologically characterized as collapsed buildings. The higher Ca content was found in the younger strata (mainly in Squares D6 and D7), located in the highest portion of the slope. This same trend was also observed in Squares K9 and K10 on the summit of the tell (Šmejda et al., 2018, Figure 7:d).

The subject of the origin of Ca and its relatively high content in the sediments of archaeological sites in Levant region has been discussed several times (e.g. Lucke et al., 2019a,b; Itkin et al., 2018). Itkin found, that $CaCO_3$ content in a tell's sediments was similar to the content in reference soils (Itkin et al., 2018). However, the $CaCO_3$ content was spatially diversified in the area of the tell and its form was mainly connected to the coarser fraction coming from the anthropogenic materials originating from bricks and walls (similar to the tell's soil characterisation of Urbic Technosols, also noted by Sedov et al., 2017).

Whereas Lucke et al. (2019a,b) studied the Ca content in the archaeological sediments in the context of aeolian processes, interpreting archaeological sites as acting as sedimentary traps. The higher content of Ca therefore came from the deposition of dust material originally derived from dolomitic rocks. The measurement of the Ca content in Area B2 at Tel Burna is notably similar to the processes described by Lucke et al. (2019a,b). Abandoned archaeological structures increase surface roughness and could function as sedimentary traps.

The Ca (or $CaCO_3$) stability is related to climate and the consequent dissolution and re-precipitation potential. While Itkin et al. (2018) characterised $CaCO_3$ in a tell's sediments as stable in profile, Amadio (2019) found evidence of $CaCO_3$ mobility and re-precipitation in an archaeological site in Cyprus. Our observation in Tel Burna did not show any evidence of re-precipitation. This was following our presumption that Tel Burna had experienced similar natural environmental conditions (humidity) as the sites studied by Itkin et al. (2018).

The research of Šmejda et al. (2017, 2018) on the topsoil P and Ca contents at the site and its surroundings (approximately up to 200 to 500 meters from the hilltop), demonstrate that whereas both elements are strong at the top of the tell, the farther the sampling was collected from the tell, the P contents declined significantly (Šmejda et al., 2017: Figure 3:a). Variously, the Ca content was higher on the slopes than on the summit (Šmejda et al., 2017: Figure 4:a), yet Ca ranges were similar to those presented above (section 4.3) (surroundings: approx. from 3% to 28%; hilltop: approximately from 6% to 30%). The Ca content measured in Area B2, as part of the present study, demonstrates higher values in the topmost layers (Figure 5 and 6). These findings suggest that for aeolian sedimentation with Ca bearing material in the archaeological contexts had two possible origins: i) both the hilltop and surroundings values are an aeolian deposition from an unknown source, or ii) the environs of the tell could have been a source for the material found on the hilltop. The second option seems more likely, as such sedimentary traps, as walls, buildings, and the like, are absent on the lower parts of the tell. Further research of aeolian deposition should focus on micromorphological analysis, especially the topic of grain types and shape as used by Lucke et al. (2019a,b).

The second pattern is associated with K, with values diversity between the two older phases and distinct two younger phases (Figures 5 and 6), and also that the overlap for these values was minimal (compare also Šmejda et al., 2018, Figure 7:c). There is a potential for the K content to be used as a proxy-dating method at Tel Burna in future studies. The K content, measured by PXRF device, increased with depth, i.e. with the earlier strata or phases. Its content in the sediment was the result of the past human settlement activities, which were archaeologically recorded in the deeper levels of Tel Burna. Therefore, demonstrating that K can be deemed a pseudo-dating element in such contexts. This approach has only site restricted potential. A similar situation occurred with the P content (Figure 5); however, the overlapping of the P values was more pronounced and therefore P cannot be used as a "proxy-dating" approach in this case. At this stage, such a "proxy-dating" approach is strictly site-restricted, and it cannot be generalized to a local or even a regional scale. Nevertheless, this phenomenon may be observed at other archaeological sites where such a "proxy-dating" approach could occur.

The element Cu could have been used in the same way; however, Cu relocation and deposition was strictly connected to the human activities and intentional behaviour. Therefore, more factors played a role in the Cu deposition than in the other elements. Conversely, the K content recorded human activities independently of the direct human intention and can therefore be used for relative dating in tell's sediments. However, the final decision concerning the usage of the Cu content should be made based on the future research of more LB sediments and materials.

5.4 Historical interpretation

The granulometry, POSL and Cu content have made it possible to formulate a statement on the formation history at Tel Burna during the IA II. It can be argued that somewhere in the IA IIB the inhabitants transferred the soil from the slopes of the tell, likely in the vicinity of Area B1 where extensive evidence of LB remains were exposed, (e.g. Shai et al., 2015; McKinny et al., 2019; Shai and McKinny 2020) to add a glacis in front the Iron Age casemate wall on the western slope (a glacis is an artificial slope that makes it difficult for attackers to access the wall). The transferred soil was contaminated by Cu and included artefacts clearly related to Late Bronze Age metallurgical activities (examples of findings connected with metallurgical activities are shown in Figure 2). Nevertheless, high Cu content was measured in the fill in squares without crucibles and slags accumulation. It means that the Cu contamination of the soil on the tell was probably very high in the ancient times, at least locally (see the reference median values in Table 2). Finally, it can be assumed that this transfer of soil was part of the preparations carried out in apprehension as by Sennacherib 's military campaign in 701 BCE (2 Kgs 19:8-9).

6. Conclusion

The main focus for this study has been how natural and anthropogenic processes of sediment accumulation can be identified at Tel Burna and how they contribute to a broader understanding of the tell’s formation. The research adds new insights to previous geoarchaeological studies conducted both at Tel Burna and at other sites in the southern Levant. It has been demonstrated that it is possible to integrate several geoarchaeological methods and thus explain certain past human activities at a tell, based on sedimentary traces analysis.

The PXRF and POSL devices implementation and conventional granulometric analysis, indicate that Tel Burna fill is associated with the IA fortification casemate wall, on the western side, which was the result of an intentional sediment transfer from the tell’s slope. This anthropogenic activity was followed by soil formation process, supported by dust deposition (Lucke et al., 2019a,b) and Ca fixation in the soil. Furthermore, the results of this study contribute greatly to the ongoing discussion of tell formations in the southern Levant in the way of how to differentiate between anthropogenic and natural processes (Itkin et al. 2018; Lucke et al., 2019a,b).

The chemical elements contents imply chronological development through increasing (Ca) and decreasing (P, K, Mn, Zn) trend in the stratigraphic record. Management strategies and intentional human behaviour in specific time periods are noted through the geochemical analysis of Cu (relocation of dumped material for defensive purposes), P and K contents (household activities identified in collapsed buildings). Potentially, geochemistry could be used as a proxy-dating method.

The similar OSL signal along the entire profile suggested short-time fill related to the anthropogenic activities, while gradual increasing the OSL signal from the top to the bottom indicated the natural fill. PXRF allowed to determine anthropogenic activities as well by accumulation of several elements. The natural processes were determined by high Ca content in the sediments.

Future studies at Tel Burna, may include other areas than fortification walls, collapsed structures, one-time sediment fills, and the continually evolving stratigraphy. It would be interesting to compare micromorphological observations from the different contexts with others such as the fill of grain silos, buildings, floor sequences and tell summit stratigraphy (e.g. Area A2 at Tel Burna). In addition to studies which have proven the usefulness of applying micromorphology to archaeological interpretation (Matthews et al., 1997), the combination of PXRF and POSL methods with the micromorphology has the potential to enrich methodologies of the future archaeological research at Tel Burna, as well as at other archaeological tells in the region. Furthermore, leading to the collection of more samples for multi-elemental analyses (Abrahams et al., 2010; Entwistle et al., 1998) and to conducting a holistic analysis of the compositional geochemical data.

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Figure and table captions

Figure 1. (a) Map of Iron Age settlements in the Shephelah in the vicinity of Tel Burna, (b) Area B2 situated on the western slope of Tel Burna, (c) Excavated squares of Area B2 discussed in article – casemate fortifications and fill inside them are marked in yellow.

Figure 2. Examples of the archaeological findings connected to the metallurgical activities from Area B2. The green colour on the tuyere and crucible is oxidized Cu. Photography Benjamin Yang.

Figure 3. Sections showing where samples were collected and schematic showing the POSL results of soil profiles in Squares C7 and D6, in stratigraphic contexts (X Axis is photon counts. Y Axis is depth in centimetres. Horizontal dashed lines show strata boundaries and vertical dashed lines highlight trends in photon counts).

Figure 4. The component 1 of ilr-transformed data in Area B2. X Axis are categories according to the squares given in Figure 1:c and strata given in Table 1; Y Axis are scores of PCA components. "Max" represents number of cases in the maximum value in histogram. "Count" represents number of cases in histogram.

Figure 5. The content of P, K, Ca, and Zn in Area B2. X Axis are categories according to the squares given in Figure 1:c. Y Axis is content of elements in percentage. "Max" represents number of cases in the maximum value in histogram. "Count" represents number of cases in histogram.

Figure 6. The content of P, K, Ca, and Zn in Area B2. X Axis are categories according to the strata given in Table 1. Y Axis is content of elements in percentage. "Max" represents number of cases in the maximum value in histogram. "Count" represents number of cases in histogram.

Table 1. Description of stratum and granulometry results given by depth in centimetres from the surface.

Table 2. Basic statistical description of obtained data for main elements in Area B2 (reference represents control field – natural median values in the vicinity of Tel Burna according to Šmejda et al., 2017; * represents the absence of relevant data; LE, light elements, i.e. overall content of elements from H to Na, which are not recognizable separately due to the limitations of the measuring device.

Table 3. Eigenvalues and explained variability of PCA after ilr-transformation (only PCs and loadings, with loadings greater or lesser than 0.25 [-0.25 respectively] are present).

Supplementary 1. Data from POSL measurements.

Supplementary 2. Data from PXRF measurements.