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The Palaepaphos-*Laona* rampart. A pilot study on earthen architecture and construction technology in Cyprus

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A R T I C L E I N F O

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A B S T R A C T

Excavations conducted in the context of the Palaepaphos Urban Landscape Project (PULP) have revealed a defensive monument of the Cypro-Classical period (fifth and fourth centuries BCE), which had been preserved under an anthropogenic mound (tumulus) of the 3rd century BCE. Besides stone-work, the construction of the monumental rampart made extensive use of mudbricks. In 2016–2017, PULP introduced a pilot study based on analytical techniques (pXRF, SEM-EDS, granulometric and petrographic analysis) to address issues relating to the manufacture and construction of the earthen architecture of the rampart. The paper presents a description of the geoarchaeological analyses and their results, which have highlighted specific manufacturing practices in relation to the construction of the monument. Given that the rampart constituted a major investment of the royal authorities of ancient Paphos, the results provide new information on the production of earthen building materials and also on environmental choices with respect to raw material selection in the context of a public project carried out by a central authority circa the mid first millennium BCE.

1. Introduction

Since the 1980s numerous geoarchaeological studies in the Near East have showcased the importance of earthen architectural analysis not only in relation to the built environment but as an expression of social agency (French, 1984; Friesem et al., 2011; Goldberg, 1979; Love, 2013; Morgenstein and Redmount, 1998; Rosen, 1986). In the eastern Mediterranean island of Cyprus mudbricks were, and are, an integral part of its architectural identity. While the earliest have been recovered in the context of Neolithic sites (e.g. Aurenche, 1981; Love, 2012; Philokyprou, 1998), mudbricks are still in use today as a key component of vernacular architecture (Costi De Castrillo et al., 2017; Illampas et al., 2011).

Earlier studies of earthen architecture in Cyprus have focused mainly on 5th and 4th millennium BCE sites (Clarke, 2007; Peltenburg, 1978; Thomas, 1995; Todd, 1979), and provided a comprehensive analysis of the architecture (Philokyprou, 1998, 2012; Wright, 1992: 42, 378–381). Recent geochemical studies of Cypriote earthen building materials focus on their performance and preservation (Costi De Castrillo et al., 2017; Demetriou et al., 2003). The potential, however, of geoarchaeological research to investigate production, manufacturing and environmental issues regarding raw material selection and motivational choices has been tapped for the first time in the archaeology of Cyprus with the scientific analyses of earthen building materials from the first millennium BCE site of Palaepaphos-*Laona*, currently under excavation. The need to study earthen techniques, and the absence of previous investigations of Iron Age mudbrick architecture on the island, motivated the authors to undertake the research presented here. The impressive mudbrick architecture of a recently discovered Cypro-Classical public monument (Iacovou, 2017a) has been sampled and analysed. The results initiate a new research venue in the study of the manufacture and construction technology of earthen architecture in the context of the establishment of a defensive monument by the ruling authorities of the polity of Paphos in the Cypro-Classical period.

2. The archaeological context of the case-study: Palaepaphos-*Laona*

The Palaepaphos Urban Landscape Project (PULP 2006–2018) is a long-term landscape analysis project initiated in 2006 for the purpose of studying the largely invisible urban structure of Ancient Paphos (Iacovou, 2008; Iacovou et al., 2009), one of the most celebrated ancient city-states of the island, better known since the 3rd c. BCE as Palaepaphos (Old Paphos) [Fig. 1]. In the context of the project, which is also studying the economic territory and potential resources of the ancient polity within the hydrological basin of Paphos (Iacovou, 2012,

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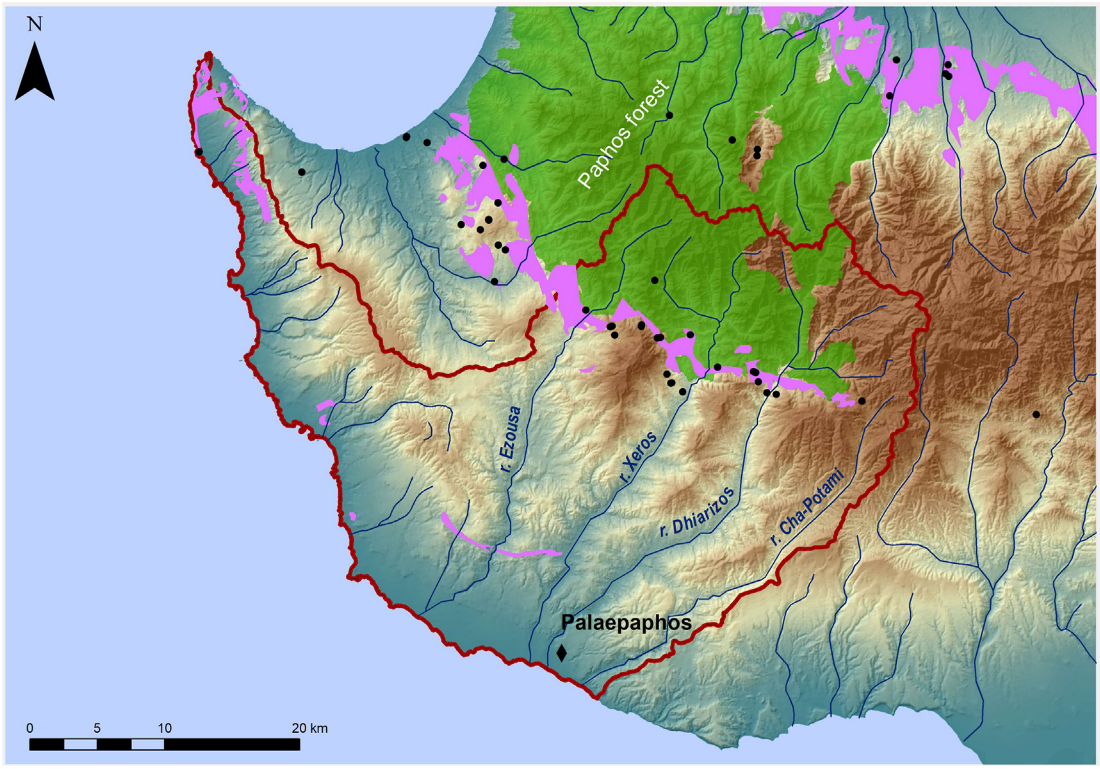

Fig. 1. The hydrological basin of Paphos indicating the main rivers and the Paphos forest.
(Data source: Geological Survey Department).

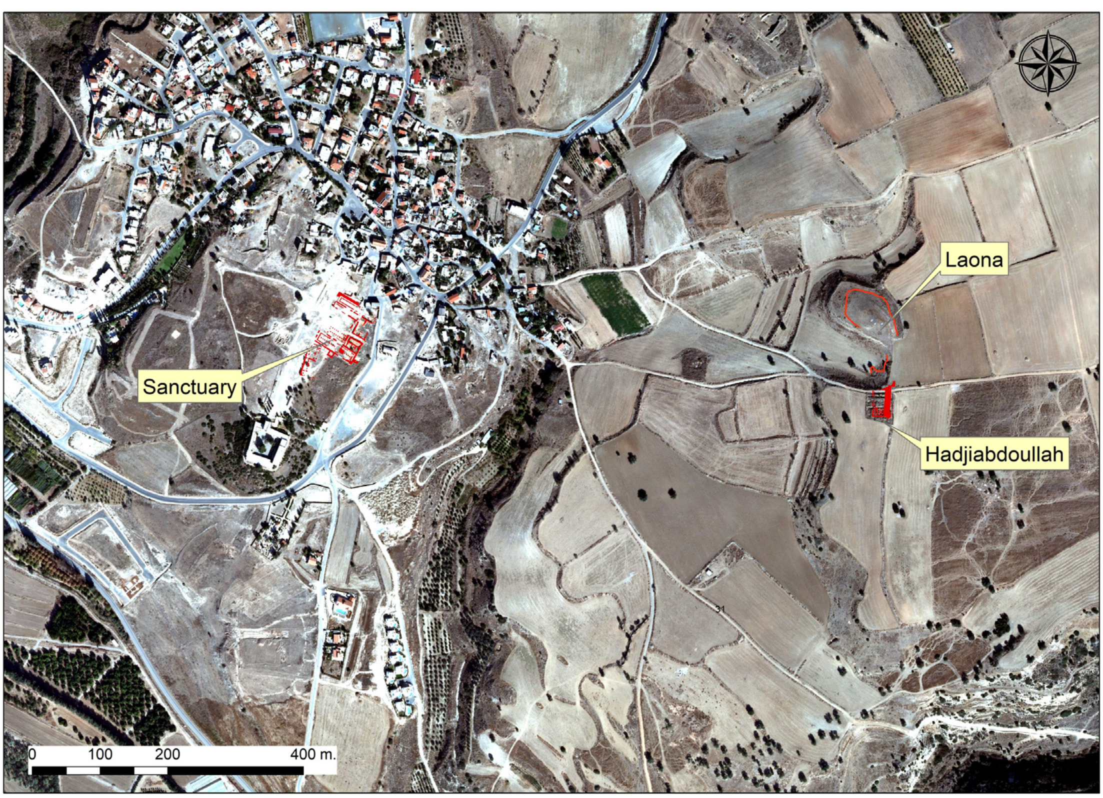

Fig. 2. Orthophoto map of the modern community of Kouklia, indicating archaeological sites mentioned in the text.
(Data source: Department of Lands and Surveys).

Fig. 3. Photorealistic representation of the northwest side of the *Laona* tumulus based on a UAV (unmanned aerial vehicle) campaign (PULP + Eratosthenes Research Centre, CUT).

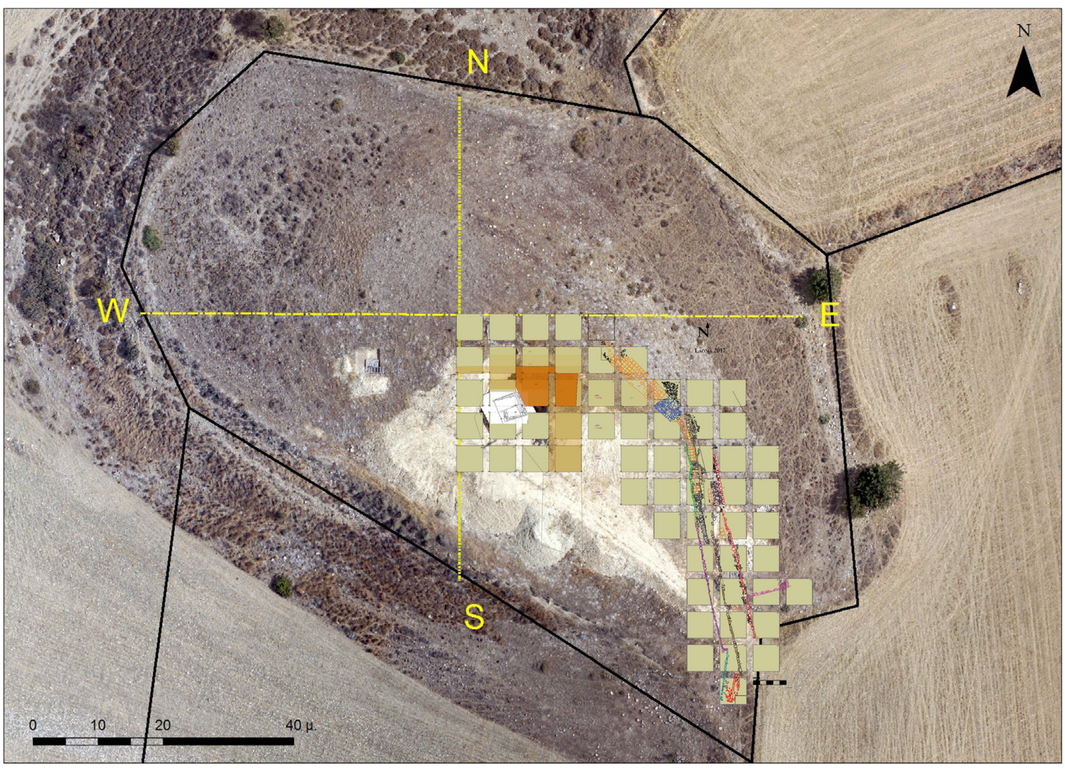

Fig. 4. Ground plan of *Laona* indicating the rampart and the excavation squares in the SE quarter of the mound (background: UAV orthomosaic, Eratosthenes Research Centre, CUT).

2014), a number of special function areas were identified to the north and east of the famous sanctuary of the Cypriote Aphrodite, which is situated on the SE fringe of the modern village of Kouklia (Iacovou, 2013a). Fieldwork on the plateau of *Hadjiabdoulla* and the hillock of *Laona* [Fig. 2] revealed the existence of hitherto unknown, and surprisingly well-preserved, Iron Age monuments (Iacovou, 2017b; https://ucy.ac.cy/pulp/).

The most impressive of the new monuments is a man-made mound raised on the natural hillock of *Laona*. Large mounds (tumuli) are foreign to the material culture of ancient Cyprus. In part, this must be the reason why it was not previously identified, despite its dimensions (100 × 60 × 10 m) and high visibility in the landscape [Fig. 3].

Following the confirmation of its antiquity (Iacovou, 2017a: 322), a new field project was designed for its investigation, which began in 2012. In order to preserve the better part of this mysterious landscape marker, excavations were concentrated exclusively in the SE quarter of the tumulus [Fig. 4].

During the initial 2012 season trial trenches revealed that the mound was constructed by the consecutive dumping of marl and soil. The fill consists "of horizontal lenses of beige angular marl fragments … alternating with red relatively massive clay-rich soils" (Karkanas and Goldberg, 2018: 219). The source of this material is the local Miocene-Pliocene pelagic sediment bedrock characteristic of the southwestern coastal plains of Cyprus. The thinner layers of soil consist of red clay mixed with gravels and cobbles of exotic lithologies. The source of this material is in the immediate vicinity of the site of the tumulus. More specifically, the marl bedrock is topped by Quaternary fluviomarine gravel terraces consisting of transported materials, later covered by a

Fig. 5. The two facing staircases of the rampart during excavation of the foundation trench in 2016 (PULP 2016).

Fig. 6. The mudbricks at the highest preserved section of the rampart (113.086 m asl.) at the northernmost excavated section (PULP 2018).

layer of in-situ formed red soil, a typical Mediterranean landscape component widely known as terra rossa (Zomeni, 2012). It has been estimated that the mound is made of circa 13.700 m^3 of soil materials (the calculation was based upon the contour lines from 107 to 114 m above sea level, using the method of the average area multiplied by the equidistance between the contour lines). The transported soils contain very few diagnostic artefacts: small sherds, tiny parts of terracotta figurines and some pithos fragments. Ceramic analysis provides a terminus for the construction of the mound, which is currently placed in the 3rd century BCE.

2.1. The rampart preserved under the Laona mound

In 2014, an older public monument was found under the thick layers of compact marl and red soil along the east side of the SE quarter of the mound. This is a monumental rampart, whose preservation in height increases from south to north along with the increase in height of the mound itself. On the inner side of the rampart, two staircases facing each other appear to have ascended to towers [Fig. 5].

The pottery from the foundation trenches below the two staircases provides a construction date around the transition from the 6th to the 5th c. BCE. The foundation line of the rampart is at 107.20 m asl. Hence, at 113.086 m asl. The maximum preserved height of the rampart at the north-eastern section (excavated in 2017) must reach over 6 m [Fig. 6]. A fifth-century BC built monument standing up to 6 m in height is certainly unprecedented in Cyprus and extremely rare in the rest of the Mediterranean.

The date of its construction and its sensitive location 70 m to the north of what is now identified as the plateau of the contemporary Cypro-Classical citadel on the terrace of *Hadjiabdoulla* (see Fig. 2 above; Iacovou, 2017b: 207–209, Figs. 16–17), would confirm that the project was decided and executed by the ruling dynasty of Paphos (cf. Satraki, 2012: 227, 391). As the excavation progresses, the *Laona* rampart is bound to become the focus of many specialised studies, primarily as regards the style of its architecture and the materials employed for its construction. Besides its historical significance as a major building project of the same royal agency that was also in charge of the megalithic temenos of the Cypriot goddess – the urban focus of the polity since 1200 BCE (cf. Hermary, 2014; Iacovou, 2013b: 152; Maier, 1989) – study of the materials, in this case the mudbricks, opens up a rare opportunity to understand the manufacturing and building practices of the Paphian builders.

2.2. Mudbricks and stone work

Although the excavation of the rampart will not be completed for some time (the north and west sides have not been excavated and the south appears to be completely eroded), a preliminary study of the ground plan of the east side, currently exposed to a length of 63 m, reveals the basic principle behind the implementation of the architectural design: mould-made and perfectly preserved mudbricks are packed between long stretches of stonework. The north-eastern section of the rampart, for example, has on the preserved top surface six parallel rows of mudbricks of identical size (40 × 50 × 12 cm), visible on the ground plan [Fig. 7]. Evidence for the use of supporting wooden elements has not been observed.

In the context of the MEANING research project,[1] which has received funding from the University of Cyprus A.G. Leventis Research Programmes, PULP secured a two-year grant (2017–2019) with which to initiate a series of archaeo-environmental data analyses. This included the macroscopic and geochemical analyses of the *Laona* mudbricks, which was undertaken by Marta Lorenzon. The goal of the pilot study was to identify the mineralogical and chemical composition of the

[1] MEANING stands for the abbreviated reference to the project, *From the metalliferous sources to the citadel complex of Ancient Paphos: archaeo-environmental analysis of the mining and the built environment*; the project description is available in Iacovou (2017a, 2017b) in Academia.edu.

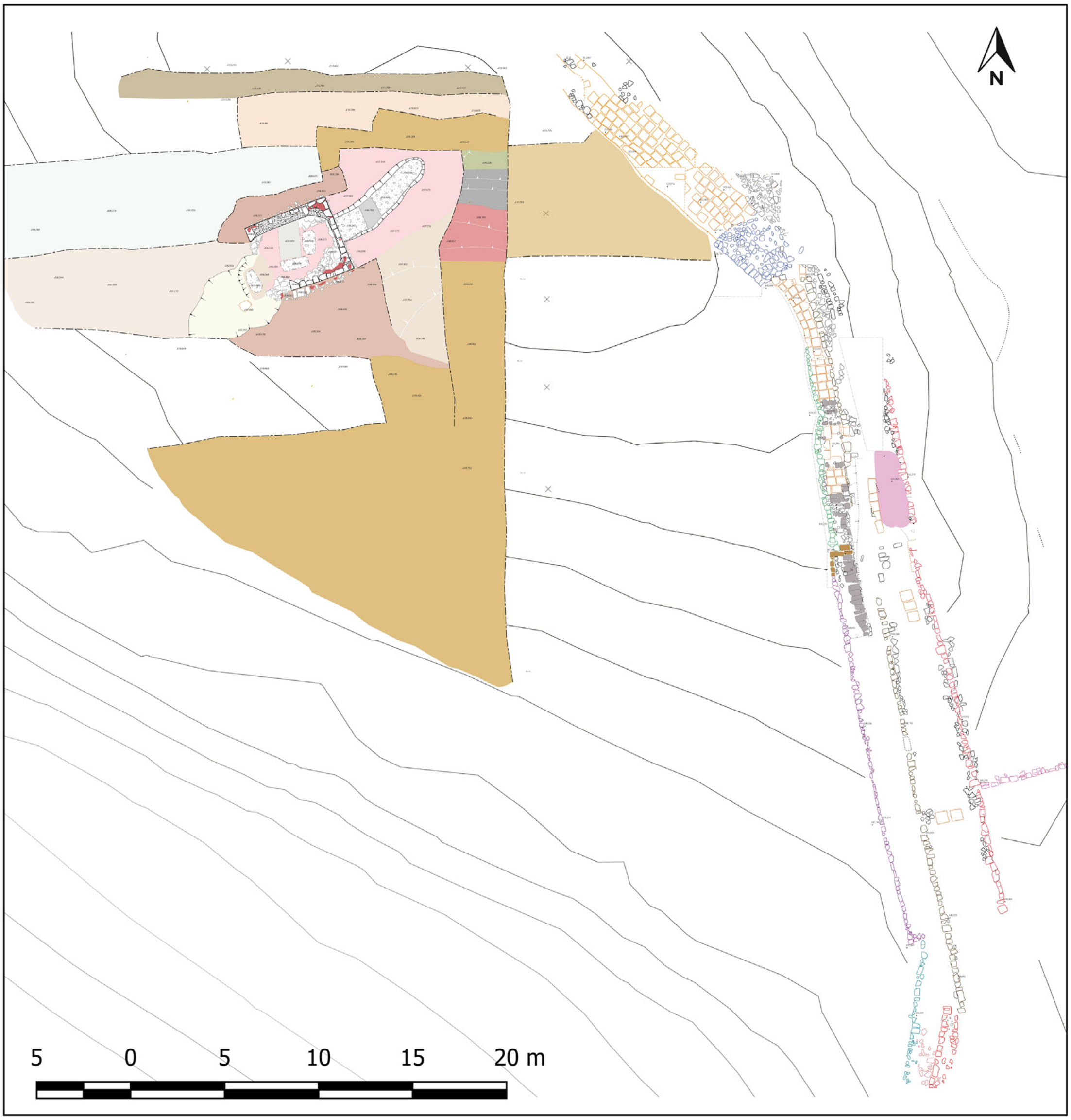

Fig. 7. Ground plan of the excavated SE quarter of the mound showing the East and North-East section of the rampart (Raphael Soler for PULP 2018).

mudbricks. Procurement of raw materials and the characterisation of manufacturing and construction phases were also addressed. The ultimate goal is to establish an interdisciplinary methodology for researching mudbrick manufacturing and construction practices from excavation contexts.

3. Sampling, materials and methods

Sampling took place in 2016 and the first macroscopic analysis was done in situ. All 34 samples come from the excavated east side of the rampart [Fig. 7]: PA 1–12, 32–34 were selected from the central area of the East wall against which the two staircases are built; PA 15–31 come from the exposed NE curved section of the East wall, which is a rare feature in mudbrick architecture (Aurenche, 1981: 124; Ginns, 2015: 138); finally, two samples (PA 13 and PA14) were collected from the preserved top surface of the mudbricks.

3.1. Macroscopic analysis

Macroscopic observations were carried out in the field in 2016 and included the recording of size, colour and fabric for each of the mudbrick samples as well as analysis of the wall structure. The macroscopic fabric was characterised as coarse or fine based on quantity and consistency of inclusions bigger than 2 cm, which consists mainly of pottery and stone fragments (Lorenzon, 2017). The colour was determined through the Munsell colour chart (Munsell Color, 2010). The investigation of each mudbrick focused on size, colour and macroscopic inclusions and was completed alongside the analysis of the bricklaying and construction techniques [Table 1].

3.2. Microscopic analysis

Microscopic observations were carried out using portable X-Ray Fluorescence (pXRF), Scanning Electron Microscope (SEM) followed by Energy Dispersive X-Ray Microanalysis (SEM-EDS), and petrographic analysis. pXRF was performed in situ during the cutting of the 34 samples by Dr. Andreas Charalambous of the Archaeological Research Unit of the University of Cyprus with a handheld pXRF Innov-X DELTA Premium model [Fig. 8]. This method was selected because of its on-site application and its non-destructive nature. Limitations of the pXRF were carefully considered and included in the consideration of the results (Liritzis and Zacharias, 2011; Lorenzon, 2017; Shackley, 2011).

The specific instrument was equipped with a 4 W, 50 kV tantalum anode X-Ray tube and a high-performance Silicon Drift Detector (SDD)

Table 1
Macroscopic analysis of the samples.

Sample number	Area	Size (cm)	Macro-fabric	Colour
PA1	E wall-central area	50 × 12	Fine	10 R 5/8
PA2	E wall-central area	50 × 12	Fine	2.5 YR 6/8
PA3	E wall-central area	50 × 12	Fine	2.5 YR 6/8
PA4	E wall-central area	50 × 12	Fine	2.5 YR 6/8
PA5	E wall-central area	50 × 12	Fine	2.5 YR 6/8
PA6	E wall-central area	50 × 40 × 11,5	Fine	2.5 YR 5/6
PA7	E wall-central area	50 × 12	Fine	2.5 YR 5/6
PA8	E wall-central area	50 × 40 × 12	Fine	2.5 YR 5/6
PA9	E wall-central area	50 × 11,5	Fine	2.5 YR 5/6
PA10	E wall-central area	40 × 12	Coarse	2.5 YR 6/8
PA11	E wall-central area	50 × 40 × 12	Coarse	2.5 YR 6/8
PA12	E wall-central area	50 × 40 × 12	Fine	2.5 YR 6/8
PA13	Top E wall-central internal area	50 × 40 × 12	Fine	2.5 YR 6/8
PA14	Top E wall-central internal area	50 × 40 × 12	Fine	2.5 YR 6/8
PA15	E wall-NE curved section	50 × 11,5	Coarse	2.5 YR 6/8
PA16	E wall-NE curved section	50 × 12	Fine	2.5 YR 6/8
PA17	E wall-NE curved section	50 × 12	Fine	2.5 YR 6/8
PA18	E wall-NE curved section	49,5 × 12	Fine	2.5 YR 6/8
PA19	E wall-NE curved section	50 × 12	Fine	2.5 YR 6/8
PA20	E wall-NE curved section	50 × 12	Fine	2.5 YR 5/6
PA21	E wall-NE curved section	50 × 12	Fine	2.5 YR 5/6
PA22	E wall-NE curved section	50 × 12	Fine	2.5 YR 5/6
PA23	E wall-NE curved section	50 × 12	Coarse	2.5 YR 5/6
PA24	E wall-NE curved section	49 × 12	Fine	2.5 YR 5/6
PA25	E wall-NE curved section	50 × 12	Fine	2.5 YR 5/6
PA26	E wall-NE curved section	50 × 12	Fine	2.5 YR 5/6
PA27	E wall-NE curved section	50 × 12	Fine	10 R 5/8
PA28	E wall-NE curved section	50 × 12	Fine	10 R 5/8
PA29	E wall-NE curved section	50 × 12	Coarse	2.5 YR 5/6
PA30	E wall-NE curved section	50 × 40 × 12	Fine	2.5 YR 6/8
PA31	E wall-NE curved section	50 × 40 × 11,5	Fine	2.5 YR 6/8
PA32	E wall-internal part	50 × 40 × 12	Fine	2.5 YR 6/8
PA33	E wall-internal part	50 × 40 × 11,5	Fine	10 R 5/8
PA34	E wall-internal part	50 × 40 × 12	Fine	10 R 5/8

with a resolution of 155 eV (Mo-Kα), covered by a 20-mm detector window. Multiple measurements were taken for each spot, and the analysis was carried out in soil mode and each spot analysed for 80 s. All the readings were taken on the clean surface cut for the sampling. Standard reference material was used for calibration, while consistency within the samples was assessed by comparison with the geological study of the area (Zomeni, 2012). Values of 24 elements (P, S, Cl, K, Ca, Ti, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Zr, Mo, Pd, Ag, Cd, Sn, Sb, Pt, Au and Pb) were collected and recorded in ppm (part per million) and then exported in an excel file. Elements below detection or affected by post-depositional factors (e.g. P and Cl) were not considered in the statistical analysis (Frankel and Webb, 2012; Goodale et al., 2012; Hunt and Speakman, 2015;). The eight elements selected (Co, Ni, Cr, Fe, Zn, Zr, Ti and Mn) are included in the statistical analysis for their reliability in pXRF, as evidenced in previous studies on their relevance in soil composition (Emery and Morgenstein, 2007; Goodale et al., 2012; Morgenstein and Redmount, 1998). Principal component analysis (PCA) and bivariate scatterplot were performed on the pXRF results with the R software (3.3.2) in order to provide data on continuity in the procurement of raw sources and manufacturing and construction phases.

The samples were extensively tested in the laboratory, performing granulometric analysis, SEM-EDS, and thin section petrography. Initially, the lithography of the sample was performed to record colour, inclusions and grain size analysis. Approximately 10 g of sample were sub-samples to establish the ratio of clay, silt and sand through hydrometer analysis and wet sieving as referred by ASTM D422-63 (ASTM, 2007; Costi De Castrillo et al., 2017; Love, 2013). Error should be considered at 1–2% of the measure estimated, taking into account both inaccurate readings and loss of sediment during the procedure. A selected number of samples were then subjected to SEM-EDS at the Wiener Laboratory (using a SEM JEOL JMS-IT300LV) for a more detailed analysis of binders and aggregates (Love, 2017; Zhang et al., 2016), and to investigate the elemental composition of the mudbricks. Further investigation included petrographic analysis of the samples through thin section petrography using a polarized microscope Leica DM2700P (Nodarou et al., 2008).

4. Results

4.1. Macroscopic observations

The results of the macroscopic analysis of the *Laona* mudbricks indicate that they have a standardised size, 50 × 40 × 12 cm (slight differences in measurement, which vary between 49 and 50 × 40 × 11,5–12 cm, are due to the shrinking of the bricks after manufacturing) and were produced with the use of a wooden mould as attested by the regular impressions on their lateral surface. Two bricklaying techniques are evident in the rampart, which attest to two distinct approaches to construction. The first consists of an irregular, so-called English bond (Wright, 2005: 104), i.e. alternating headers and stretchers in different rows, and is mainly present in the East wall. The second technique consists of a running bond, which has been recorded in the NE curved section of the wall. The difference in bonding between these two parts of the wall could be related to their different architectural structure: the East wall was meant to be straight, while the NE wall develops curve. Macroscopic analysis of the fabric indicates an overall similarity of the bricks employed in both areas, not only in regard to their colour (Munsell 2.5 YR 6/8, 2.5 YR 5/6 and 10 R 5/8), but also their composition, which in all cases consists of yellowish-brown marly-clay with a small number of inclusions such as gravel (grain size > 2 mm), pottery sherds and vegetal temper (i.e. chaff).

Fig. 8. pXRF performed on the NE curved section of the mudbricks (PULP 2016).

Fig. 9. Chaff impression on sample PA 16.

4.2. Granulometric analysis

Granulometric analysis was performed through use of a hydrometer and wet-sieving to determine possible recipes of production. Samples were dried for several days in the laboratory, before microscopic observations were conducted with a stereoscopic microscope on the sieved fractions.

Granulometric results show that *Laona* mudbricks are characterised by a high percentage of sand and gravel (i.e. coarse fraction, usually > 40%) mixed with silt and clay (i.e. fine fraction). Stereoscopic analysis has determined the use of chaff as the main vegetal temper in mudbrick production, likely a by-product from agricultural practices (i.e. barley) [Fig. 9]. Initially, two different groups of mudbricks were separated based on their coarse and fine fraction percentages [Table 2, Figs. 10–11].

The distribution of fine and coarse fractions shows at least two recipes for mudbrick production, indicating that mudbricks superficially similar in colour, macro-inclusions and size may have different grain size percentages. The groups identified through granulometric analysis are the following:

- Group 1 is characterised by a higher percentage of sand (coarse fraction > 60%); PA3, PA5, PA7, PA8, PA9, PA11, PA12, PA13, PA14, PA15, PA16, PA19, PA23, PA25, PA27 and PA34.
- Group 2 is characterised by a higher fine fraction: PA1, PA2, PA4, PA6, PA10, PA17, PA18, PA20, PA21, PA22, PA24, PA26, PA28, PA29, PA30, PA31, PA 32, and PA33.
- This result could indicate either the presence of different manufacturing teams working at the same time or different production times for the mudbricks. Thus, to investigate this issue further geochemical analyses of the two groups were undertaken to determine and better understand specific patterns of manufacture and consumption.

4.3. Geochemical results

The results of the pXRF analysis (see Table 3) and the trends in the chemical data were analysed through Principal Component Analysis (PCA) and bivariate statistical analysis to shed light on geochemical groups and a possible classification based on chemical fingerprints.

The PCA was performed on eight variables using as discriminant the rampart sampling areas. The raw data has been normalised in R and the confidence ellipse has been calibrated at 95% with the two main Principal Components (PC1 and PC2) explaining 78.9% of the total variability. The PCA shows all the samples collected from different parts of the wall structure, presenting a tight cluster of points, which supports the hypothesis of a common source of raw material procurement [Fig. 12].

Bivariate analysis based on the variability of Fe and Mn within the mudbrick recipe indicates different mudbrick clusters within the same structure. Four chemical clusters were identified in the bivariate scatterplot that point to distinctive production batches [Fig. 13].

The four clusters are comprised of mudbricks which have similar percentages of Manganese and Iron, thus supporting their production during the same manufacturing event with the same type of soil. Consistency in the PCA and bivariate analysis was determined by comparison with the local geological analysis of the area (Zomeni, 2012). Additionally, the SEM-EDS analyses on selected mudbrick samples from both the East and North-East wall confirm the presence of illite, kaolinite and calcite in the matrix to create the best workable recipe; morphologically, it shows the consistent presence of a compressed and compacted matrix, which results from the manufacturing technique of pressing the mud mixture into the mould. The chemical spectra reflect a high quartz concentration as well as the presence of Wollastonite, a key component of calcite and pyroxenes, which are present in the marly-clay sediments around Palaepaphos and may work as natural stabiliser alongside sand (Liberotti and Quaresima, 2010) [Fig. 14]. The small number of pores and cracks in the matrix of the mudbricks results from the limited presence of vegetal temper, the activity of biological agents and progressive evapotranspiration linked to water erosion.

The geochemical analysis of the sample performed through SEM-EDS highlights a strong consistency of raw material sources among the different batches of bricks identified through grain size and pXRF analysis [Fig. 15].

Table 2
Granulometric analysis.

Sample	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Fine Fraction	Coarse Fraction	Vegetal Temper
PA1	21.75	22.75	55.5	0	44.5	55.5	None
PA2	14.29	28.57	57.14	0	42.86	57.14	10%
PA3	8.75	22.5	40.3	28.45	31.25	68.75	10%
PA4	11.43	28.57	60	0	40	60	10%
PA5	7.5	30	62.5	0	37.5	62.5	10%
PA6	12.5	30	57.5	0	42.5	57.5	10%
PA7	8.75	16.25	53	22	25	75	10%
PA8	14.29	14.29	71.42	0	28.58	71.42	10%
PA9	3.33	13.33	63.3	20.04	16.66	83.34	10%
PA10	16.67	33.33	50	0	50	50	10%
PA11	18.75	18.75	62.5	0	37.5	62.5	30%
PA12	18.18	9.09	72.73	0	27.27	72.73	30%
PA13	6.25	12.5	59.2	22.05	18.75	81.25	30%
PA14	11.11	22.22	66.67	0	33.33	66.67	30%
PA15	17.33	2.67	67	13	20	80	40%
PA16	22.22	11.11	66.67	0	33.33	66.67	10%
PA17	11.76	29.41	58.83	0	41.17	58.83	10%
PA18	18.75	25	56.25	0	43.75	56.25	10%
PA19	12.99	22.08	50.3	14.63	35.07	64.93	10%
PA20	12	32	56	0	44	56	40%
PA21	31.5	32	36.5	0	63.5	36.5	40%
PA22	24.51	31.37	44.12	0	55.88	44.12	30%
PA23	14.55	12.73	50.5	22.22	27.28	72.72	20%
PA24	16.67	25	48	10.33	41.67	58.33	20%
PA25	13.5	20	66.5	0	33.5	66.5	20%
PA26	11.29	36.29	52.42	0	47.58	52.42	20%
PA27	11.15	22.76	52.9	13.19	33.91	66.09	20%
PA28	39.99	22.27	37.74	0	62.26	37.74	20%
PA29	14.52	30.65	54.83	0	45.17	54.83	20%
PA30	10	35	55	0	45	55	20%
PA31	15.38	26.92	57.68	0.02	42.3	57.7	20%
PA32	8.33	33.33	50.2	8.14	41.66	58.34	20%
PA33	12.62	33.98	53.4	0	46.6	53.4	20%
PA34	8.89	13.33	60.4	17.38	22.22	77.78	20%

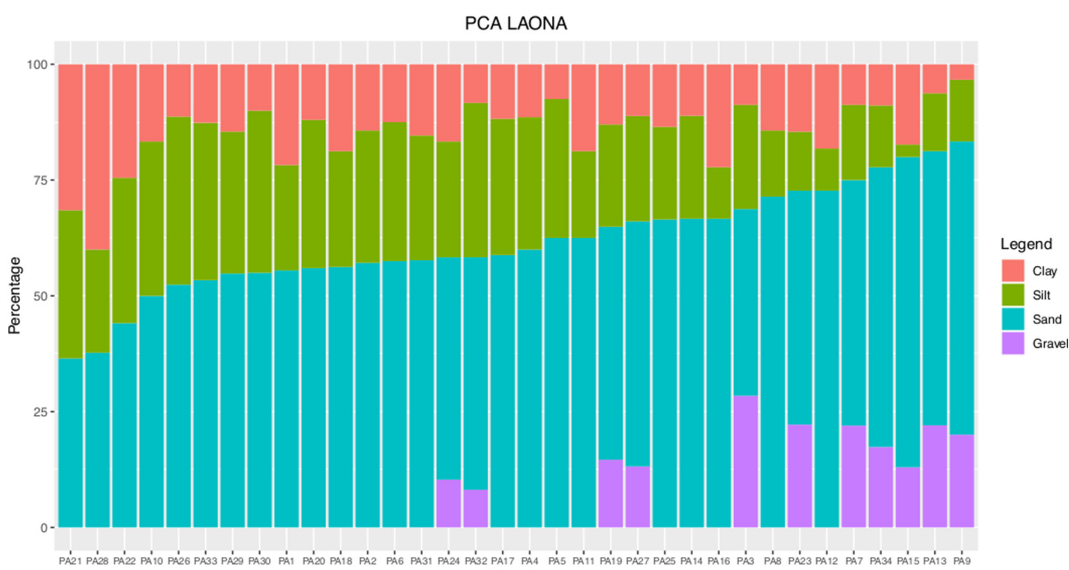

Fig. 10. Granulometric analysis.

4.4. Petrographic results

Petrographic analysis shows the presence of a single mudbrick fabric with two distinct sub-fabric groups within the 34 samples collected. The Palaepaphos mudbrick fabric is quite standardised and characterised by a light-brown colour and numerous poorly-sorted inclusions. Both sub-fabrics are characterised by a bimodal distribution of medium to fine sand elements with small, even equant particles of other grain sizes (clay-silt). The distinction between the two sub-fabrics is based on the average number of inclusions present: sub-fabric 1A contains at least 40% inclusions, while sub-fabric 1B has only 10% of inclusions [Fig. 16].

Most of the inclusions in both sub-fabrics are comparable, being equant, rounded to sub-rounded, with a frequency from common to dominant. The inclusions detected are quartz, olivine, pyroxene, chlorite, iron oxides nodules and clay pellets, and, in lesser numbers,

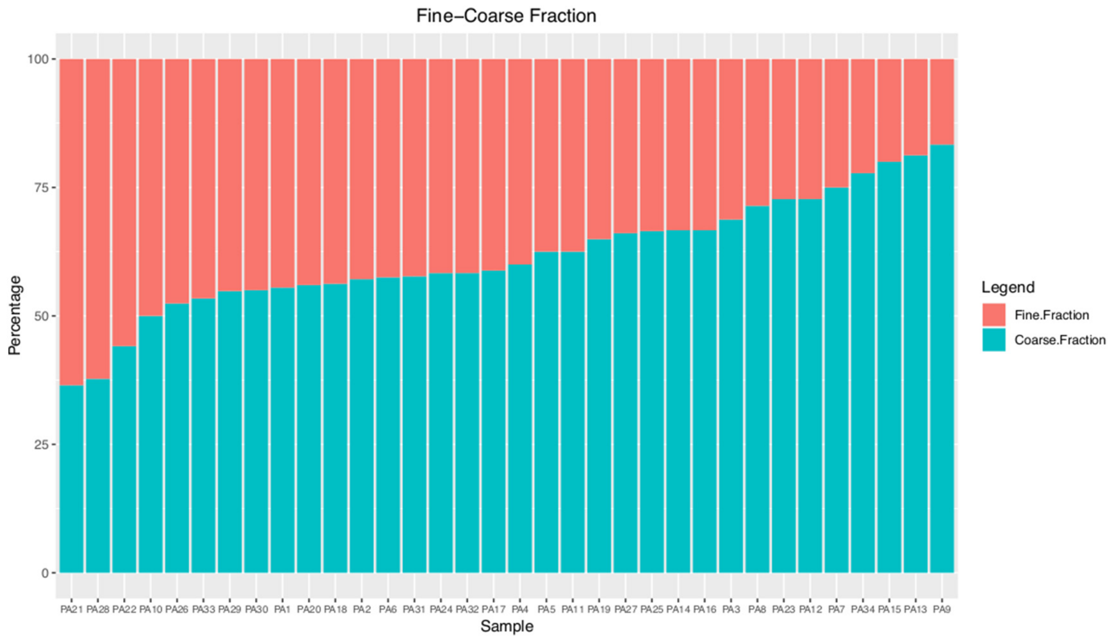

Fig. 11. Fine-Coarse fraction. Fine fraction comprises clay and silt, while coarse fraction includes sand and gravel.

Table 3
pXRF results.

Sample	Area	Zr	Zr ±	Ti	Ti ±	Cr	Cr ±	Mn	Mn ±	Fe	Fe ±	Co	Co ±	Ni	Ni ±	Zn	Zn ±
P1	E wall-central area	89	3	2107	83	97	9	552	15	27,214	237	325	43	15	8	−7	3
P2	E wall-central area	71	2	2101	79	110	9	452	13	28,074	237	229	42	38	8	3	3
P3	E wall-central area	73	2	2053	71	84	7	463	12	27,584	215	338	39	10	7	21	3
P4	E wall-central area	69	3	1732	89	84	10	403	15	21,462	233	211	45	25	10	−55	4
P5	E wall-central area	77	2	1814	69	59	7	468	12	23,283	187	200	35	53	8	9	3
P6	E wall-central area	76	2	1871	75	93	8	465	13	25,639	210	216	38	22	8	1	3
P7	E wall-central area	95	2	2960	93	92	9	467	13	43,887	350	496	52	11	9	8	3
P8	E wall-central area	43	2	1535	68	55	7	331	10	18,684	164	166	34	31	7	−13	3
P9	E wall-central area	66	2	2306	82	120	9	609	15	36,910	295	297	47	29	9	8	3
P10	E wall-central area	47	2	1544	68	41	6	344	10	20,562	174	217	35	20	7	−6	3
P11	E wall-central area	106	3	2418	77	86	8	495	12	33,530	250	375	42	15	8	16	3
P12	E wall-central area	88	3	2336	86	132	9	535	14	27,139	236	163	42	40	8	−4	3
P13	Top E wall-central area	80	2	2289	75	58	7	470	12	31,603	245	308	41	38	8	21	3
P14	Top E wall-central area	91	2	2283	73	60	7	493	12	38,911	285	491	45	23	8	26	3
P15	E wall-NE curve	83	2	2907	91	96	9	580	15	43,101	335	371	50	30	9	8	3
P16	E wall-NE curve	85	3	1895	76	188	10	391	12	25,090	226	224	41	26	8	−9	3
P17	E wall-NE curve	88	2	2678	86	68	8	516	13	41,995	331	320	49	38	9	10	3
P18	E wall-NE curve	120	3	3050	86	153	9	680	15	42,244	309	562	47	17	8	25	3
P19	E wall-NE curve	77	2	2118	75	62	7	479	12	27,909	221	247	39	43	8	8	3
P20	E wall-NE curve	94	2	2650	85	213	10	599	15	37,261	291	497	47	23	9	14	3
P21	E wall-NE curve	111	3	2594	75	92	7	599	13	29,661	221	316	39	40	8	31	3
P22	E wall-NE curve	100	2	2549	75	100	8	552	12	36,013	259	345	42	35	8	32	3
P23	E wall-NE curve	62	2	2480	79	62	7	433	11	32,841	251	56	41	59	8	12	3
P24	E wall-NE curve	95	3	2750	89	79	9	535	14	37,351	294	369	47	10	8	6	3
P25	E wall-NE curve	81	2	2712	85	73	8	591	14	43,179	320	490	48	14	8	13	3
P26	E wall-NE curve	110	3	3571	92	115	9	666	15	47,754	352	601	51	15	9	29	3
P27	E wall-NE curve	97	2	2982	87	99	9	544	14	46,767	346	530	50	9	9	19	3
P28	E wall-NE curve	80	2	1873	72	64	7	365	11	26,261	213	352	39	4	8	0	3
P29	E wall-NE curve	89	2	2266	72	152	8	480	12	34,003	252	424	42	24	8	21	3
P30	E wall-NE curve	88	3	2745	86	98	8	439	12	31,737	256	257	43	30	8	2	3
P31	E wall-NE curve	78	2	2400	82	95	8	501	13	27,649	228	226	40	52	8	−7	3
P32	E wall-internal	114	3	2936	86	87	8	637	15	30,266	239	385	42	30	8	22	3
P33	E wall-internal	119	3	2786	85	110	8	625	14	28,745	230	346	41	31	8	15	3
P34	E wall-internal	122	3	2772	91	71	8	627	15	30,637	252	305	43	31	8	9	3

sandstone fragments, charcoal and calcite [Fig. 18a and b]. Numerous microfossils have been identified, such as foraminifera (i.e. globular planktic foraminifer), radiolarian and bioclast fragments, which occur naturally in the Palaepaphos deposits of marine limestone (Zomeni, 2012) [Fig. 18c]. Several clasts are surrounded by a continuous clay coating, creating a rolling pedofeature around the clast (i.e. PA 23) [Fig. 18d]. The mapping of the two sub-fabrics against the chemical analysis highlights their chemical consistency. The similarity of their fabric is differentiated only by the size and percentage of the inclusions [Fig. 17].

The limited number of voids suggests a conservative use of vegetal temper. In fact, the elongated voids usually associated with vegetal

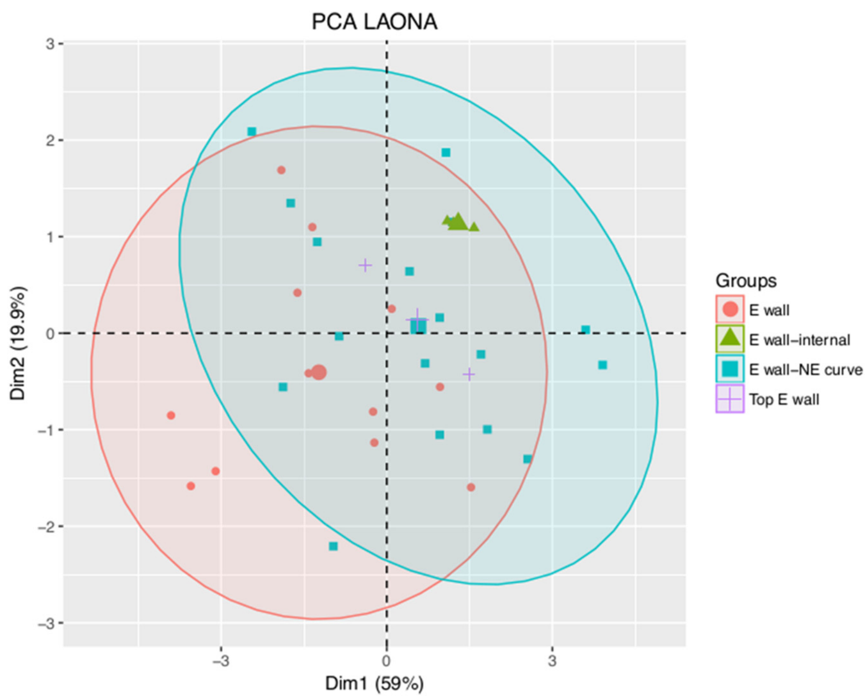

Fig. 12. PCA discriminated based on wall areas.

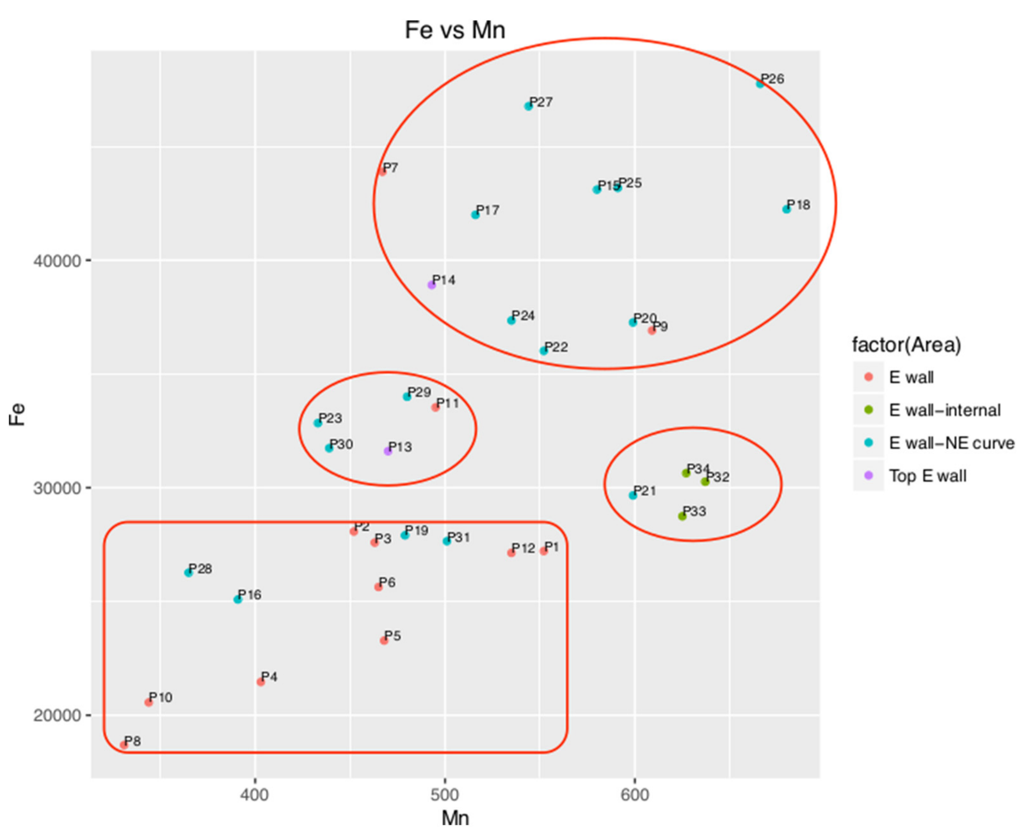

Fig. 13. Scatterplot Fe vs Mn.

temper are rare in all the samples analysed. Vesicular voids and microfissures were also recorded and associated with multiple activities, including progressive evapotranspiration and thawing during production and cracking during the drying process (Cammas, 2018; Friesem et al., 2014) [Fig. 18d].

5. Discussion

The granulometric and petrographic analyses of the 34 samples have identified the presence of two groups that relate to different practices followed in the manufacturing of the *Laona* mudbricks (e.g. the use of sand as temper). As in earthen architecture elsewhere,

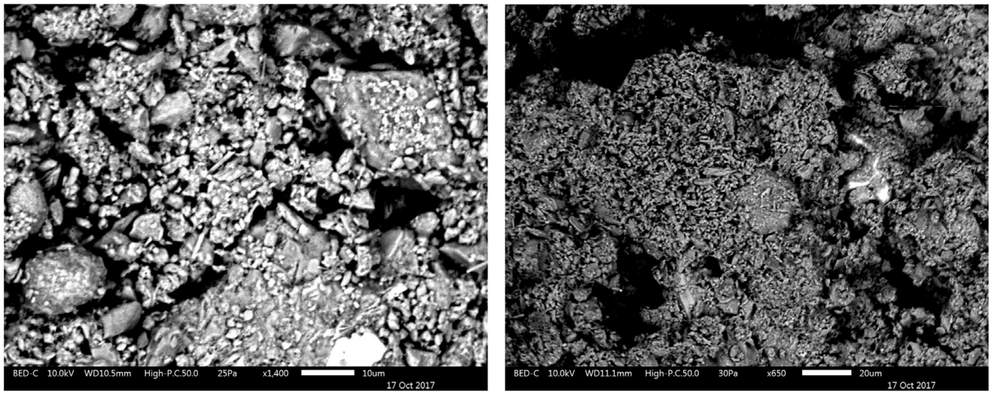

Fig. 14. SEM of mudbrick fabric (PA22 and PA25).

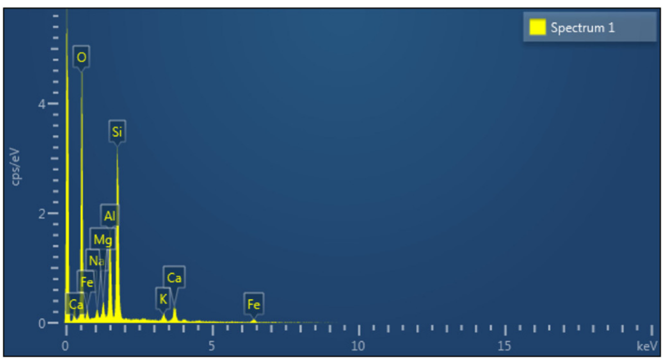

Fig. 15. SEM-EDS graph photo, Sample PA25.

sediments with a high clay content were degreased by using sand in the mixture (Minke, 2006: 39–40) to prevent cracking. This is reflected in the two groups identified in both the granulometric analysis, and the petrography: sub-fabric 1A corresponds with granulometric group 1 and sub-fabric 1B with granulometric group 2. These small deviations of the local mudbrick recipe highlight a direct connection between the built and natural environment as they indicate that the builders were able to adapt traditional manufacturing practices to the resources that were to hand. Mineralogical analyses, for example, document the specific use of locally-available sand as temper when chaff was unavailable or not available in sufficient quantities.

The results also indicate that the *Laona* mudbricks, despite being produced with a similar recipe, were manufactured in multiple batches, which are easily distinguished based on grain size ratio and the amount and/or type of temper in the mixture. The marly-clay nature of the bricks makes the high sand percentage in one of the two macro-groups, identified during grain size analysis [Figs. 10 and 11], particularly noticeable as not typical of ancient production. The quantity of sand is within the margins suggested in earthen architecture manuals (Minke, 2006: 65–66; Oliver, 2008: 102), as sand likely constituted an easily-available degreaser alongside chaff, and one which was available all year around. Local availability may have influenced the selection of sand as the preferred temper to prevent shrinking and fissuring in the marly-clay mudbricks (Aurenche, 1981: 51–52; Lorenzon, 2017: 194; Minke, 2006: 39). These data point to different manufacturing practices that can be affected by seasonal changes (i.e. drought) and/or multiple groups of builders involved in the production of the mudbricks. However, the mudbricks of different granulometry are widely spread between the two sections of the wall from where the samples were taken, and they are located both near the preserved top and also close to the currently excavated bottom. This distribution pattern weakens the case of multiple phases in the construction of the rampart and strengthens the presence of multiple groups working for the production of the mudbricks.

The SEM-EDS results combined with the pXRF analysis indicate a comprehensive consistency in the raw material sources used for all the mudbricks and, also, in the types of degreasers, which include only sand and a limited presence of chaff. The use of sand as the predominant temper in the production of the *Laona* mudbricks is also supported by the SEM, which shows a high quantity of sand quartz in a number of samples [Fig. 16].

Although PCA analysis shows consistency in local raw source procurement, the bivariate plot of Iron and Manganese values indicates at least four mudbrick production events, represented in the four geochemical groups of the *Laona* samples. These results further support the hypothesis of multiple manufacturing groups using the same raw sources but 'personalising' the recipes by sampling a different part of the quarry and then also adding a different temper. Evidently, the same sources were quarried multiple times in order to collect enough material to produce the required number of mudbricks for the construction of the *Laona* rampart. The granulometry, the arrangement of the mudbricks in the wall, shows that mudbricks from different geochemical groups, probably produced by different teams, were laid down together. This points to a single construction event, which is well exemplified, for instance, by the chemical similarities between PA 34, PA 32, PA 21 and PA 33. These mudbricks were manufactured at the same time within the same bunch, yet PA 34, PA32 and PA33 were used in the internal central part of the wall and PA21 in the external NE curved section of the wall. The same dissemination pattern is observed with mudbricks which belong to the other three geochemical groups: geochemically similar mudbricks are found next to each other, but also in different sections of the wall both in the internal and external face. It is, therefore, evident that the mudbricks were not produced for immediate consumption; they were manufactured, stored and then used for a single construction event. This suggests a well-organised, centrally-managed building process, which involved a large supply of workers (probably working in small groups), and a well-coordinated storage and use of structural materials.

Although the rampart is considered a single construction event, differences in bricklaying techniques used in the E wall (the irregular so-called English bond) and the NE curved section of the wall (regular running bond), in conjunction with the results of the geoarchaeological analysis, suggest the presence of multiple construction teams within the same cohesive architectural project. In this context, repairs of eroded or broken mudbricks that would have taken place at a later stage would be visible macroscopically on the external surface of the wall by fissures created by evapotranspiration, and microscopically by the presence of different petrographic fabric. However, repairs, which would have made a clear dissonance within the wall fabric, have not been attested. The short life-span of the rampart, which had already been abandoned when the mound was constructed in the 3rd century BCE, may have required a limited degree of repair work. Although the mud plastering

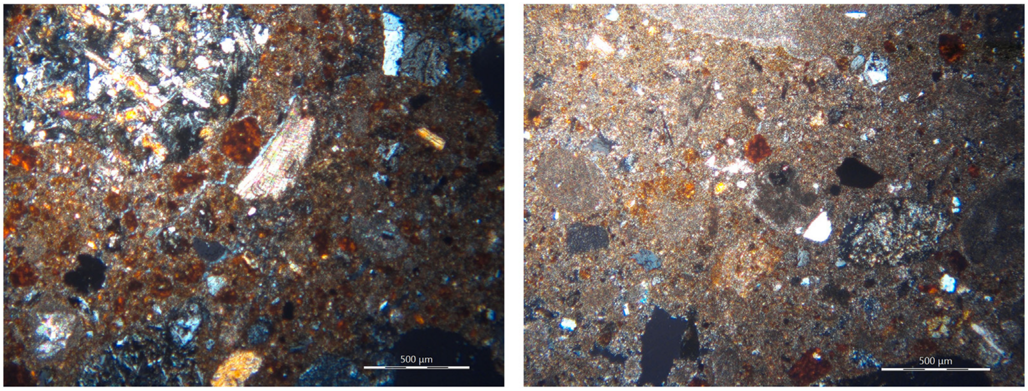

Fig. 16. Sub-fabric 1a (PA 25) and sub-fabric 1b (PA 6) in crossed nicols.

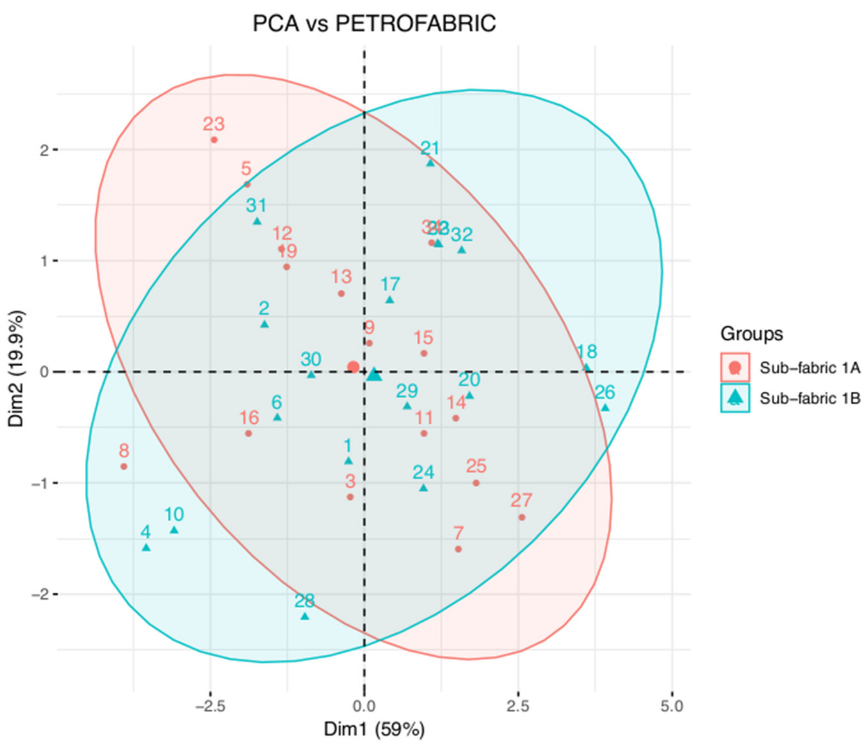

Fig. 17. PCA discriminated based on petrofabric groupings.

of the exposed mudbrick surfaces would have been regularly renewed during the period of use, no evidence of plaster was found on the mudbricks during their excavation. This observation highlights an unknown episode that must have forced the local authorities to give up on the regular upkeep of the rampart. Consequently, its abandonment and gradual deterioration had occurred before the decision to use *Laona* for the construction of a very different, and even more labour demanding, monument: the tumulus.

6. Conclusions

This pilot study has shed light on earthen architecture practices in relation to a recently discovered public monument that was built in the Cypro-Classical period, almost certainly around 500 BCE. Mineralogical, geochemical and archaeological data have been combined to investigate manufacturing and construction events, and they have provided manufacturing recipes and motivational choices regarding raw material selection - such as the use of sand as degreaser. Macroscopic and microscopic data, on the other hand, led to the identification of the different steps in the *chaîne opératoire* from raw source collection to construction techniques.

The manufacture of the required quantity of the mould-made mudbricks was evidently linked to a centrally organised form of production and was carried out by multiple teams of local workmen. A similar earthen architectural narrative is known from other islands in the Mediterranean (Lorenzon, 2017). Distinct local traditions have also been confirmed in the case of the *Laona* earthen architecture. The use of a stone socle and a mudbrick superstructure (Demetriou et al., 2003; Wright, 2000, 22) may be superficially similar to Near Eastern building techniques, but it also differentiates the Cypriote tradition from Anatolian and Aegean building practices, where wooden elements were employed as a supporting framework on stone socles.

The pilot study has also highlighted a well-coordinated and successfully implemented building project of circa 500 BCE. Fortifications tend to have very long lives, but in this particular case, despite the investment in materials and human labour, the combined data reveal that the monument had a relatively short life span; apparently, it was abandoned sometime in the fourth c. BCE. The reasons that led to its abandonment may be revealed as the excavations continue. Once archaeological data had confirmed the date of the initiation of the

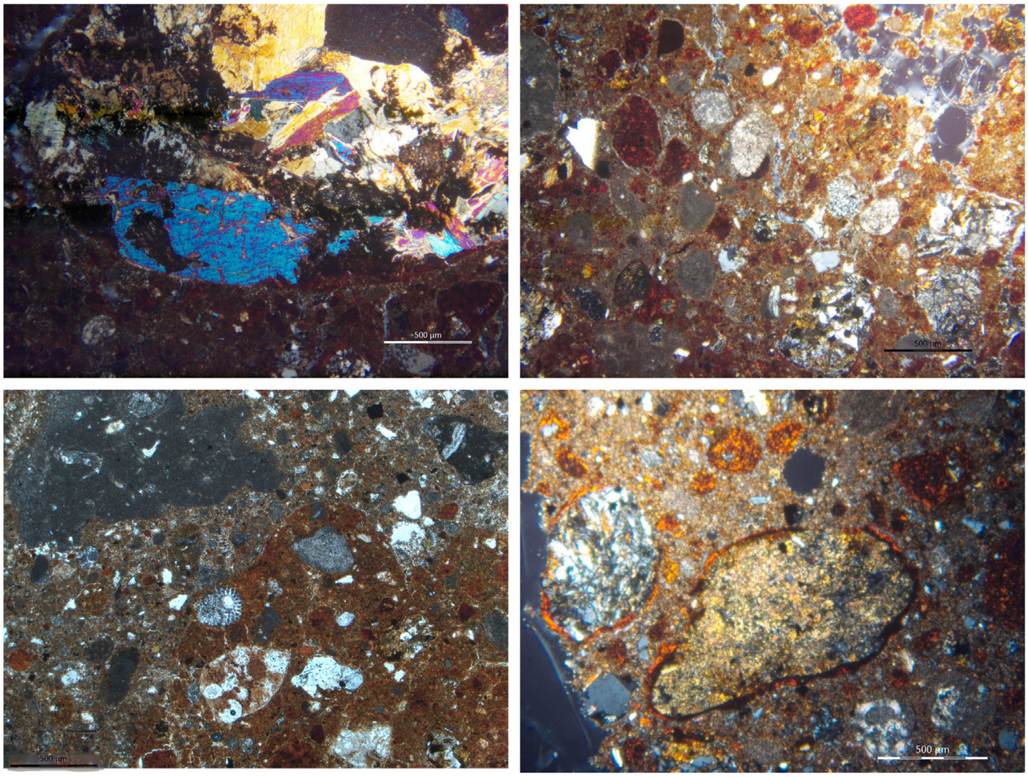

Fig. 18. Thin section in crossed nicols. Top a and b. Mudbrick fabric with visible voids caused by thawing activities and inclusions such as quartz, plagioclase and pyroxene. Bottom c. Foraminifera in the mudbrick fabric. d. Details of rolling pedofeature.

building project, there was no difficulty in identifying who must have been responsible for building the *Laona* rampart: it had to have been one of the *basileis* (kings) of the Paphian city-state; their rule is amply attested by textual data from the beginning of the seventh to the end of the fourth centuries BCE (cf. Iacovou, 2006).

To this day, however, we have rarely had the chance to link the material remains of state-endorsed building project to a local workforce. This pilot study has shown that the techniques employed during the production and construction of the mudbricks highlight intimate traditional knowledge and expertise of local builders. Consequently, the most compelling aspect of this research is the establishment of mudbrick as a powerful source of information on the social and cognitive aspects of monumental architecture in the archaeology of Cyprus, in particular in the context of a complex socio-economic system.

We hope that this pilot study has demonstrated the importance of introducing a geoarchaeological methodology alongside building archaeology in the investigation of mudbrick manufacturing and construction practices from excavation contexts. In seeking to understand the development of earthen architecture and the relationship between the natural and the built environment, this methodology offers a strong potential that has been proven successful in this particular case study.

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