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Hierarchical organization and skilled workforces for constructing the Tartessic earthen building at Casas del Turuñuelo (Guareña, Spain)

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This article presents the results of the geoarchaeological study of earthen building materials used in a Tartessic public building at Casas del Turuñuelo. The construction dates back to the fifth century BCE and is one of the monumental buildings of Tartessic culture, characterized by its complex architecture, prestige goods, and intentional destruction after a feast and animal sacrifice. We applied an integrated methodology combining macro and micro approaches to investigate earthen construction processes, such as techniques, labour organization, workers' specialization, and environmental exploitation. The sample mainly consists of mudbricks, but we also include other forms of earthen materials such as mud plasters, mud mortars, and geological soils for comparison. In total, 64 samples from different building parts were studied through X-ray fluorescence, X-ray diffraction, thin-section petrography, and CHN analyses. The results reveal that the workforce involved in the construction process used different resources and presented different skill levels, but was centrally planned and organized. This study reflects on the communities' knowledge of the environment, the logistic effort and technical skill employed in the building process, and the existence of strong political structures capable of managing the erection of the complex Tartessic buildings.

Earthen architecture reached one of its most extraordinary manifestations in Western Mediterranean Protohistory with the Tartessic buildings of the Middle Guadiana Valley. These monuments are part of the culture known as *Tartessos* ('*Tarteso*' in Spanish), which is the name Greek sources gave to a complex phenomenon of cross-cultural interaction and diachronic evolution in the southern Iberian Peninsula[1]. Between the eighth and sixth centuries BCE, Phoenician colonization led to extended interactions linking autochthonous communities and newcomers, generating a new hybrid culture with its main centre in the lower Guadalquivir valley. However, Tartessian coastal communities experienced a deep crisis in the mid-sixth century, and as a consequence, some inland communities underwent intense development during this period. This new situation, which lasted until the early 4th BC, has been interpreted as a second wave of adaptation of Levantine influences and led to a well-defined culture in the middle course of the Guadiana River[2,3].

The political-territorial structure of the Tartessian communities was based on monumental and isolated public buildings located on a plain characterized by a marked orientalizing influence, especially in their architecture. The best-known example, Cancho Roano (Zalamea de la Serena, Extremadura), probably had multiple functions: political, economic, and religious[4]. This site underwent a three-phase development associated with different cult spaces[5], and each destruction phase was clearly intentional. The final collapse sealed the rooms creating a tumulus that still stands out on the plains. Precisely this planned destruction after the celebration of certain feasts or sacrifices is a common characteristic of the Tartessic buildings of the Guadiana Valley, which explains their unique appearance and the reason why they are known as "buildings buried under tumuli"[2].

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The tumuli were created by covering with additional earth the destroyed structure and relative building materials, mainly consisting of sun-dried mudbricks[2]. Tartessian public architecture features large and thick earthen walls that were adorned by complex architectural elements such as vaults, halls, corridors, window-like openings or courtyards[6,7]. Mud plaster was used as an architectural finish, including some cases in the courtyard where handprints have been preserved, while mud mortar was identified in the joints as binder. Despite the importance that earthen architecture acquired in the Tartessian and other cultures of the Iberian Peninsula, little research has been conducted to investigate these archaeological materials. On the other hand, multiple studies have explored several socio-cultural, political, and environmental data through geoarchaeological methods analysing earthen architectural remains in the Eastern Mediterranean and in Western Asia[8–13].

To show the applicability of this approach to the Western Mediterranean context, we undertook a comprehensive geoarchaeological investigation to study Tartessic earthen architecture, taking advantage of the excavations carried out since 2014 at Casas del Turuñuelo (Guareña, Extremadura). Ongoing works uncover a Tartessian building dated to the fifth century BC (Fig. 1), characterized by its monumental architecture and the exceptional banquets and sacrifices carried out before its collapse[5]. This is also an outstanding example of a complex building structure comprising two stories, multi-functional rooms, long corridors, and a monumental staircase, making it one of the Iberian peninsula's most iconographic sites.

In this article, we provide the geoarchaeological results of analysing earthen building materials (hereafter EBM) used to build Casas del Turuñuelo, and we reflect on their cultural implications. Our main aim is the characterization of these EBM by applying physical–chemical and mineralogical analytical techniques to explore the socio-economic and construction process. Behind the traditional study of earthen architecture, the application of a multidisciplinary approach allows us to gain a more in-depth understanding of specific steps of the *chaîne opératoire*, providing helpful information regarding the procurement of raw sources, the particular features of each *know-how*, the specialization degree of the workers, or the relationship between construction materials and architectural function[12,14–17]. Our results reveal multiple human–environment interactions and the identification of different workforces involved in constructing Casas del Turuñuelo building. Reflecting on all these elements is essential to understanding the complexity of the work strategies and routines behind the building process and its political connotations in the historical framework of the Tartessian culture.

The site and its geological framework

The Casas del Turuñuelo site is located in the meadow of Vegas Altas region of Extremadura, Spain. Its position on the plain does not prevent it from controlling one of the main communication arteries of the territory, the Guadiana River and the fertile lands it irrigates. The site's specific functionality is still difficult to establish in detail because of the limited excavated area and the complexity of the structure as well as the rituals carried out before its destruction, which makes its interpretation difficult. The monumentality of its architecture and the richness of the buried materials point to an important structure that may have played a political, economic and perhaps religious role in the fifth century BC, such as an Iron Age rural administrative centre.

Since the beginning of archaeological excavation in 2014, we are only now recognizing the complex anthropic nature of the tumulus, which hides the building and was generated after its abandonment[7]. The structure comprises a two-storey building, unique in the Western Mediterranean, in an excellent state of preservation (Fig. 2a). The upper floor contains—to date—three rooms and a small vestibule with painted wall plaster that has direct access with the lower floor. Among the rooms in the upper floor rooms, the so-called 'Room 100' stands out as the largest room of the building[18]. The 60 m^2 room presents some extraordinary elements, such as a central bull-skin-shaped altar, and a semi-circular lime-lined basin interpreted as a possible decorated lime tub or sarcophagus[18]. In addition to an extraordinary furniture repertoire consisting of delicate ceramics, bronze elements or ivories, its building analysis evidences the presence of a mudbrick vault on the top. On the sides of this space are located different adjoining rooms: on the North side 'S1', also known as the 'Banquet Room' due to the material remains recovered during the excavation[18], and to the South room 'N1', still in excavation, where we have recovered the only human remains discovered so far.

The access to the lower floor occurred through an eleven-step monumental staircase of 2.94 m in height, 2.34 m in width, and a 35° slope[19]. The five upper steps are made of a solid module of mudbricks, topped by thick slabs that cover the treads of the steps. In comparison, the six lower steps were created using lime blocks. The staircase leads to a large courtyard of 125 m^2 where we documented a massive slaughter of animals, similar to a hecatomb (Fig. 2b), with the remains of the articulated bodies of 52 horses, 4 cows, 4 pigs, and 1 dog[18]. Some outstanding materials recovered include the feet and pedestal of a painted pentelic marble sculpture and a set of glass bowls from the eastern Mediterranean[20,21] (Fig. 2d).

The extraordinary finds should not shadow the effort put into place by the site inhabitants in sealing the structure with earth after the collapse. The intentional cave-in has helped to preserve the earthen architecture (Fig. 2c), making it possible to detect different complex building techniques used in walls, roofs, or auxiliary structures[2]. We have identified sun-dried mudbricks as the main building material in three different modules: $40 \times 20 \times 10$ cm, $41 \times 41 \times 9$ cm and $55 \times 40 \times 10$ cm, which were used in different parts of the building. The walls were covered with diverse mud plaster, sometimes decorated with painted motifs or even geometric wave decorations in high relief. The knowledge of mudbrick was so radicated that it enabled the builders to create exceptional architectural elements during Iron Age I, such as the aforementioned vault or the staircase, but also the construction of complementary architectural elements, such as hearths, benches, altars or pedestals like the one under the sarcophagus.

At a geological level, the site is located on Quaternary deposits formed in the Lower Pleistocene (Fig. 3). These are mainly quartzite formations, which are identified with sand deposits linked to the river activity characterized by a groundmass matrix of ochre and reddish tones[22]. The site is flanked to the north and west by aeolian deposits

Figure 1. Casas del Turuñuelo archaeological site. (**A**) Location of the site in the context of the Iberian peninsula (Digital Terrain Model from OpenStreetMaps, QGIS version 3.4.6); (**B**) Map of the settlement of the Middle Guadiana Valley during the sixth/fifth centuries BC (DTM from Instituto Geográfico Nacional de España, QGIS version 3.4.6); (**C**) Aerial view of the Casas del Turuñuelo tumulus, 2017 (Proyecto Construyendo Tarteso).

made up of sands and gravels from the Guadiana River's historic watercourse and terraces[22]. The current terrain surrounding the settlement is made of lands used for water-intensive crops, such as rice (Figs. 1c and 3b), easily explained by the area's abundant water sources and fertile soil. To the east of the site, the small Sierra de Yelbes presents a metamorphic deposit where black quartzites and heavily fragmented black shales are intercalated (Fig. 3). Finally, about 4 km south of the site and on the opposite bank of the Guadiana River we find a radically different lithology with outcrops of igneous rocks such as granodiorites and porphyritic leucogranite of variable grain size[22].

Results

Chemical composition and clustering

Casas del Turuñuelo EBM and soil samples were analysed chemically by WD-XRF and evaluated through the statistical models of Aitchison[23,24] and Buxeda[25,26]. Of all the recognized elements, twenty-six were retained for

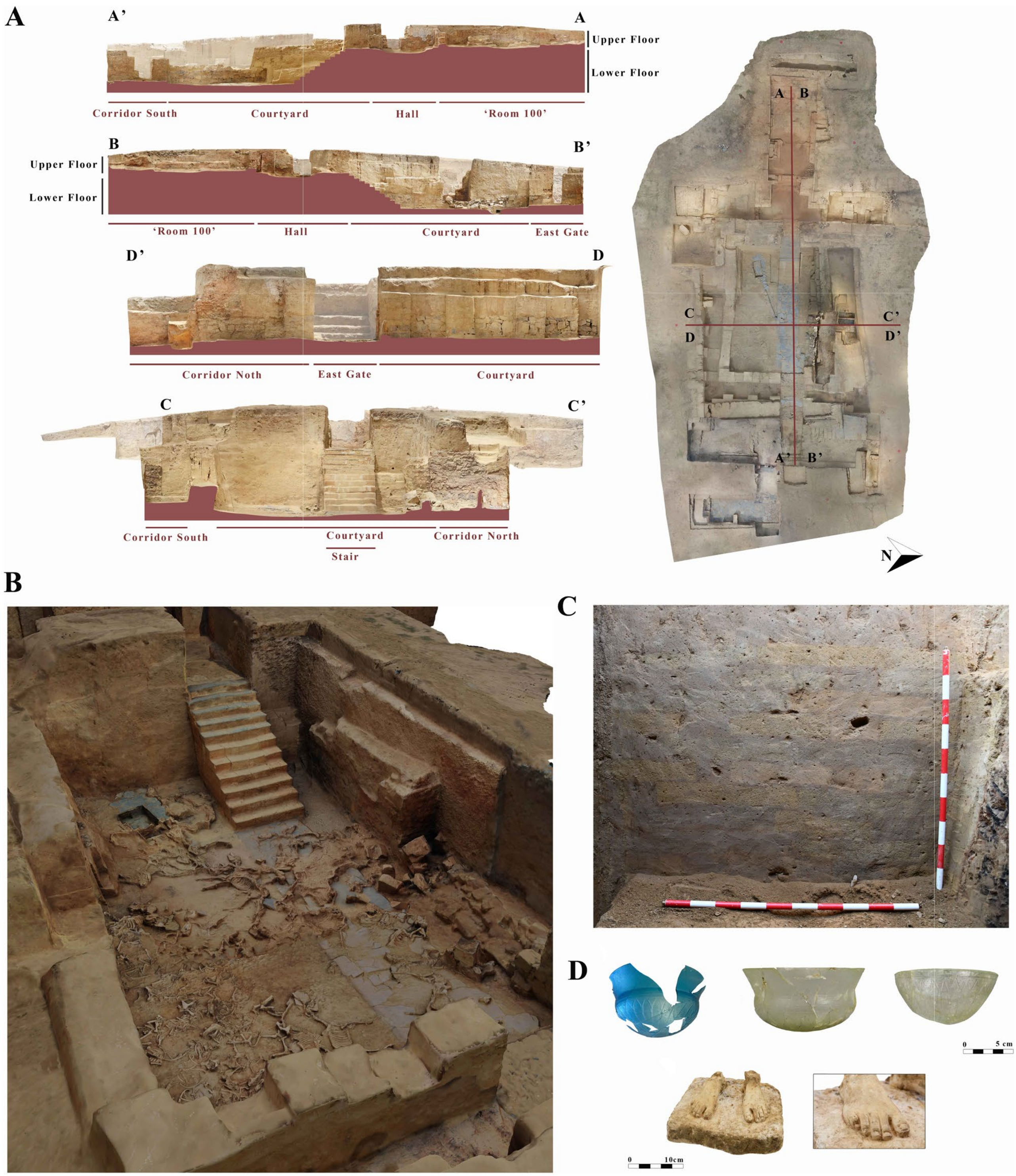

Figure 2. Longitudinal and cross-section of Casas del Turuñuelo building. (**A**) Photogrammetric model June 2023. (**B**) 3D model of the animal sacrifice documented in the courtyard. (**C**) Mudbrick wall documented in the south corridor. (**D**) Selection of imported materials, including glass bowls from the Eastern Mediterranean and a fragment of Pentelic marble sculpture (Project Construyendo Tarteso).

the analysis: Na_2O, MgO, Al_2O_3, SiO_2, P_2O_5, K_2O, CaO, TiO_2, V_2O_5, Cr_2O_3, MnO, Fe_2O_3, CoO, NiO, CuO, ZnO, Ga_2O_3, As_2O_3, Rb_2O, SrO, Y_2O_3, ZrO_2, Nb_2O_5, BaO, PbO and LaO (Supp. Table 1). These elements are reliable according to the scientific literature[9,12,27,28]; the remaining elements were discarded due to low analytical precision, or their possible alteration by post-depositional processes.

Following the normalization of values, we ran the principal component analysis (PCA) of the geochemical dataset based on the singular value decomposition of the transformed double *clr* data[29] to explore the existence

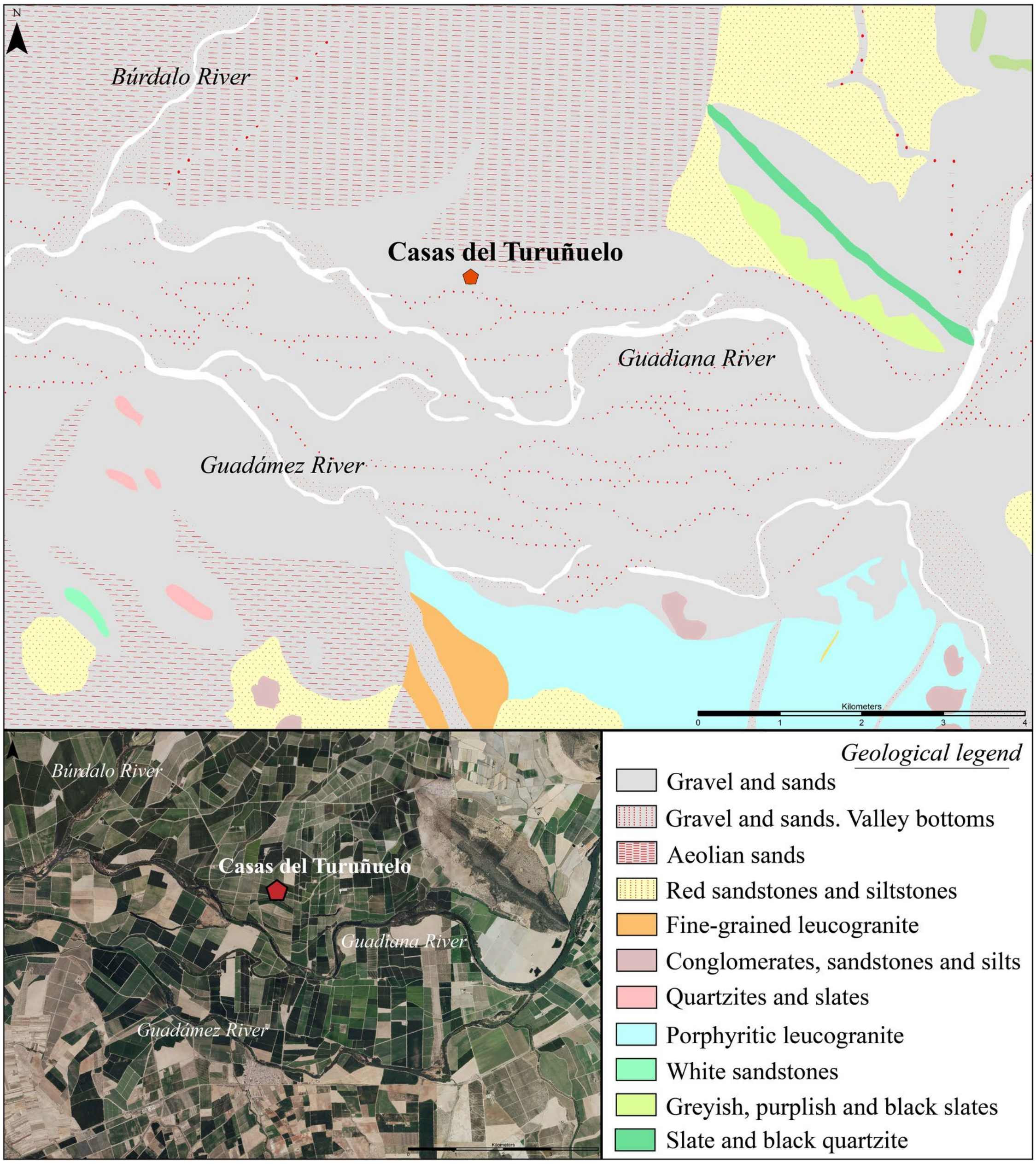

Figure 3. Geological map (Source: Geological and Mining Institute of Spain, sheet number 778) and aerial view (PNOA from Instituto Geográfico Nacional de España, QGIS version 3.4.6) of Casas del Turuñuelo surroundings.

of possible clusters. The calculation of the compositional variation matrix to determine the total variation (*tv*) of the analyzed assemblage[23,25] showed a value of 1.64, which might point to the existence of a polygenic assemblage (Fig. 4a). However, the first results reveal an agglomerative trend in which a homogeneous compositional cluster is easily recognizable, even if the two principal components only account for 44% of the total variability (Fig. 4c). Only TUR 37 can be considered an outlier. The $CaO–Al_2O_3–SiO_2$ ternary diagram confirms these results, with a very homogeneous group located in the quartz-anorthite-mullite thermodynamic equilibrium triangle reflecting the low calcareous composition ($< 2.8\%$ in CaO values), from which only TUR 37 and TUR 14 dissociate (Fig. 4b).

Casas del Turuñuelo EBM grouping is further confirmed by a hierarchical clustering analysis (HCA) based on the squared Euclidean distance and the average algorithm. This dendrogram assesses the total of the selected geochemical elements and exhibits a main branch (Fig. 4d) whose total variation is near 1 ($n = 59$; $tv = 1.14$). This large cluster is a mix of non-calcareous mudbricks and EBM, which defines a common chemical footprint of the materials used to construct the building. This compositional feature confirms the previous analysis and should be highlighted because then we have established a series of internal differences in this cluster based on its mineralogical and petrographic characteristics. Outside the main cluster, we find four samples probably related to the assemblage separated due to contamination or over-representation of elements such as CaO (TUR 14,

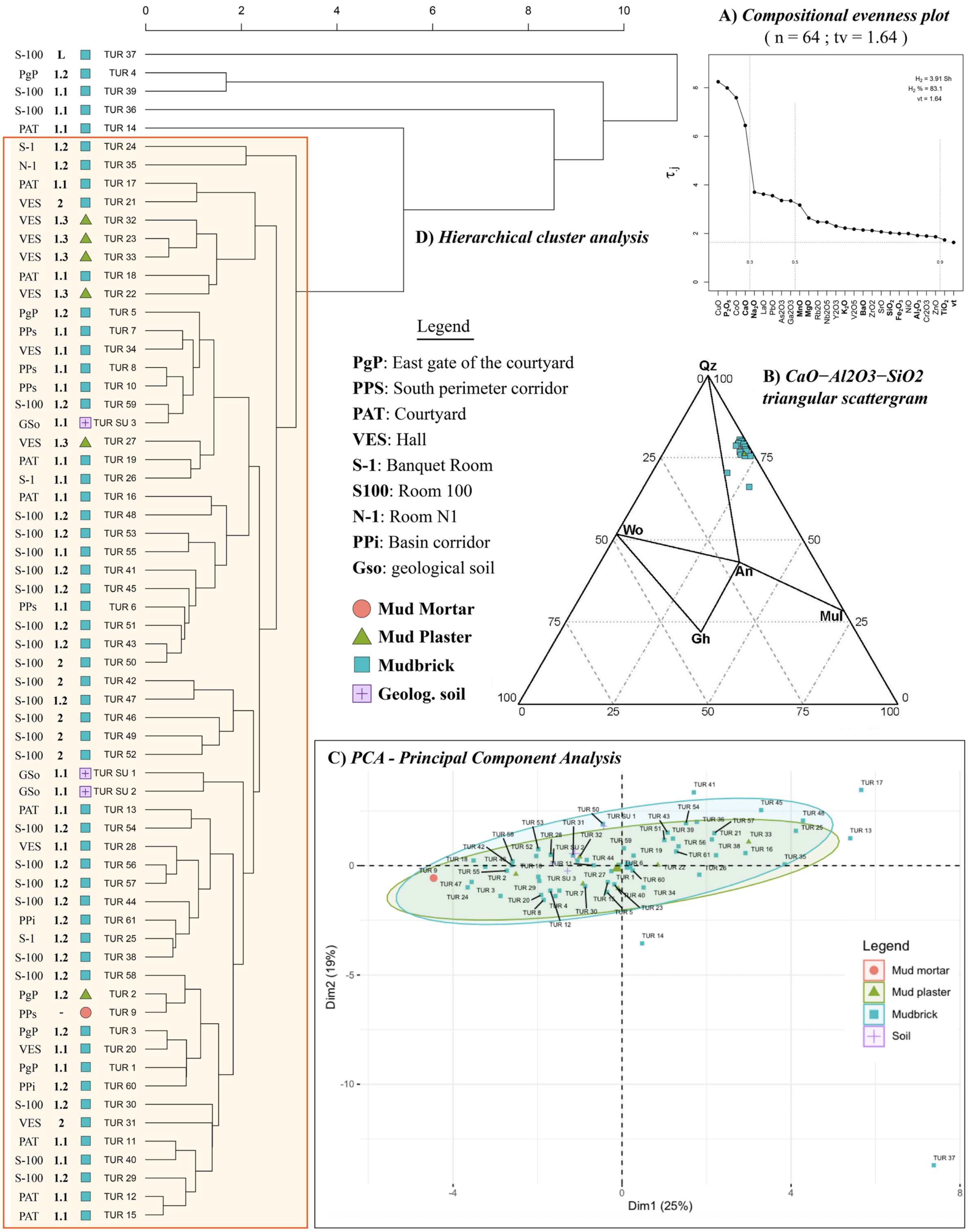

Figure 4. Statistics results of XRF chemical data: (**A**) Compositional evenness plot for the 64 samples analyzed. H2, information entropy (in Shanons, Sh); H2%, percentage on the possible maximum; (**B**) Ternary phase diagrams of the CaO-Al_2O_3-SiO_2 system with the situation of the individuals analyzed; (**C**) PCA mapping of Casas del Turuñuelo samples considering the twenty-six chemical elements retained for the statistical approach; (**D**) Dendrogram of 64 individuals after a HCA performed on the twenty-six chemical elements cited in the text, including archaeological location, type of sample and petrographic fabric.

explaining its deviation in the ternary diagram), P_2O_5 (TUR 36), CuO (TUR 4 and 39), and the individual TUR 37 that exhibits a different chemical composition characterized by higher values of CaO, MgO, Al_2O_3 or Fe_2O_3, and lower values of BaO and Rb (Supp. Tables 1 and 2).

Petrographic characterization

Thin-section analysis allowed the recognition of different petrographic fabrics (PF) and sub-fabrics, plus one sample that could not be assigned to the previous groups and it is classified as a loner (Fig. 5).

The best-represented PF is TUR-1, which is composed by *coarse quartz sand and vegetal temper* (n = 53 + 3 soil samples). This fabric is homogeneous in terms of geological composition. It has, nevertheless, been possible to recognize internal differences in the size parameters, colour groundmass and temper inclusions that led to identifying three different sub-fabrics:

-Sub-fabric TUR 1.1 (n = 22 + 3 soil samples, c.f.v. 30:60:10, samples TUR 1, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 26, 28, 34, 36, 39, 40, 55, S-1, S-2 and S-3). The groundmass presents a homogeneous yellowish tone and fibrous pattern. The aplastic inclusions are moderately sorted and the grain size ranges between coarse silt (> ca. 0.04 mm) to small pebbles (< ca. 4.6 mm). They are mainly represented by sub-rounded to angular monocrystalline quartz, followed by others such as few quartzite, feldspars (mainly plagioclase), very few carbonates (micrite), and rare muscovite and biotite. The voids are present in a medium–low frequency, and they follow the shape of meso and macro channels and vughs. The structure of the voids points to the addition of vegetal temper, and the remains of vegetal structure have been attested in TUR 7, 15, 18, 20, 26, 28, 39 and 40.

-Sub-fabric TUR 1.2 (n = 25, c.f.v. 40:50:20, samples TUR 2, 3, 4, 5, 24, 25, 29, 30, 35, 38, 41, 43, 44, 45, 47, 48, 51, 53, 54, 56, 57, 58, 59, 60, 61). It shows the same type of aplastic inclusions, but a high percentage of inclusions of a bigger size characterizes the matrix. Moreover, the main difference is the groundmass, which exhibits a homogeneous brownish colour and a well-packed structure. The aplastic inclusions reach sizes between fine silt

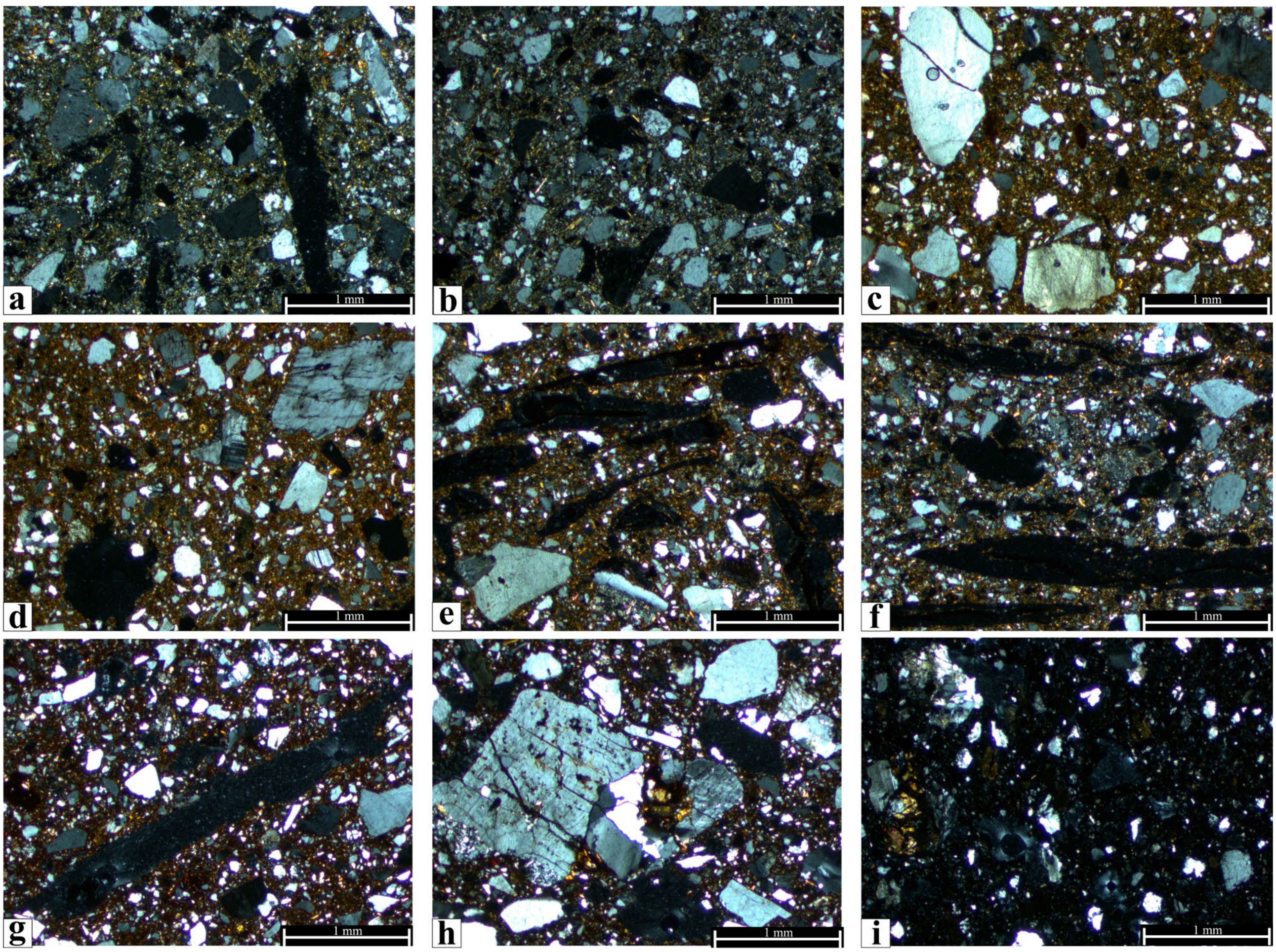

Figure 5. Representative microphotographs of the identified petrofabrics from Casas del Turuñuelo building, crossed polars (XP): (**a**) PF 1.1, Mudbrick TUR 13 with a vugh as result of the addition of vegetal temper; (**b**) PF 1.1, Mudbrick TUR 40; (**c**) PF 1.2, Mudbrick TUR 3; (**d**) PF 1.2, Mudbrick TUR 51; (**e**) PF 1.3, Mud Plaster TUR 23 with frequent voids linked to the vegetal temper; (**f**) PF 1.3, Mud Plaster TUR 33 with frequent voids linked to the vegetal temper; g) PF 2, Mudbrick TUR 21, with a vugh as result of the addition of vegetal temper; (**h**) PF 2, Mudbrick TUR 49, with detail of a leucogranite inclusion; (**i**) Loner TUR 37.

(< ca. 0.08 mm) and very coarse sand (> ca. 1.90 mm), and it is worth noting the higher frequency of clay pellets, the lesser importance of carbonates, and the presence of rare phyllites. The frequency of vegetal temper is also higher, with more common meso and macro voids following a shape-structure of channels and vughs. TUR 2, 4, 5, 24, 29, 30, 38 and 61 present the remains of vegetal material in some voids.

-Sub-fabric TUR 1.3 (n = 5, c.f.v. 30:50:20, samples TUR 22, 23, 27, 32 and 33) follows the same characteristics mentioned in the sub-fabric, 1.2, but differs from it in the increased presence of voids linked to vegetal temper. The voids are channel-shaped and mega-size (> 2 mm) following an orderly distribution linked to sediment mixing and in many cases they preserve the organic structure of the plant remains.

The second fabric is TUR-2, characterised by *coarse quartz sand, leucogranite and vegetal temper* (n = 7, c.f.v. 50:45:5, samples TUR 21, 31, 42, 46, 49, 50 and 52). The groundmass presents a homogeneous dark brown and densely packed structure where the aplastic inclusions reach a size between medium silt (< ca. 0.02 mm) and very coarse sand (> ca. 1.92 mm). The distribution of the coarse fraction is very poorly sorted, and the spatial distribution of the inclusions is measured within the single to double-spaced frame. The main inclusions are sub-rounded to sub-angular quartzite (micaceous sandstone) and monocrystalline/polycrystalline quartz, angular plagioclase and some porphyritic leucogranite. Other inclusions in very few frequencies are rounded reddish clay pellets, phyllites, orthoclase, rare carbonates, and isolated pyroxenes and iron oxides. The voids follow a structure of channels and vughs reaching large sizes but without an orderly distribution pattern. These are occasionally linked to vegetal remains used as temper and detecting part of the micro-internal structure of the vegetal inclusions in TUR 52.

Loner TUR 37, burnt groundmass with altered rocks (c.f.v. 20:45:5). This sample exhibits a black groundmass with aplastic inclusions ranging from medium silt (< ca. 0.02 mm) to very coarse sand (> ca. 1.76 mm). The coarse fraction presents a few sub-angular to angular granite inclusions and feldspars (plagioclase and microcline) often altered by high-temperature effects. Other minerals are quartzite, monocrystalline quartz, rare iron oxides, clinopyroxene and clay pellets. The presence of voids is irregular, classified as micro and meso vughs and vesicles, with no apparent link with vegetal temper.

In accordance with previous analysis of phytoliths in soil thin sections, the presence of phytoliths within EBM voids can be attributed to the intentional use of plant material as temper[30–32]. Our analysis of the Turuñuelo materials reveals the inclusion of dung as human-induced tempering as indicated by the presence of dung spherulites in various samples belonging to Fabrics 1.1 and 1.2—e.g. TUR 30, 40 and 60. Additionally, these samples also presented a high percentage of reed phytoliths, as indicated in previous research[33], they may indicate that both were used as temper or that herbivore dung containing reeds was used. The phosphate levels that can be associated with dung seems to suggest the second option as the more likely occurrence in Turuñuelo. While the analysis of phytoliths present in the voids directly connected plant material used in mudbrick manufacturing with agricultural products, we could identify *poaceae* represented in both globular and elongate phytoliths (Fig. 6a–d).

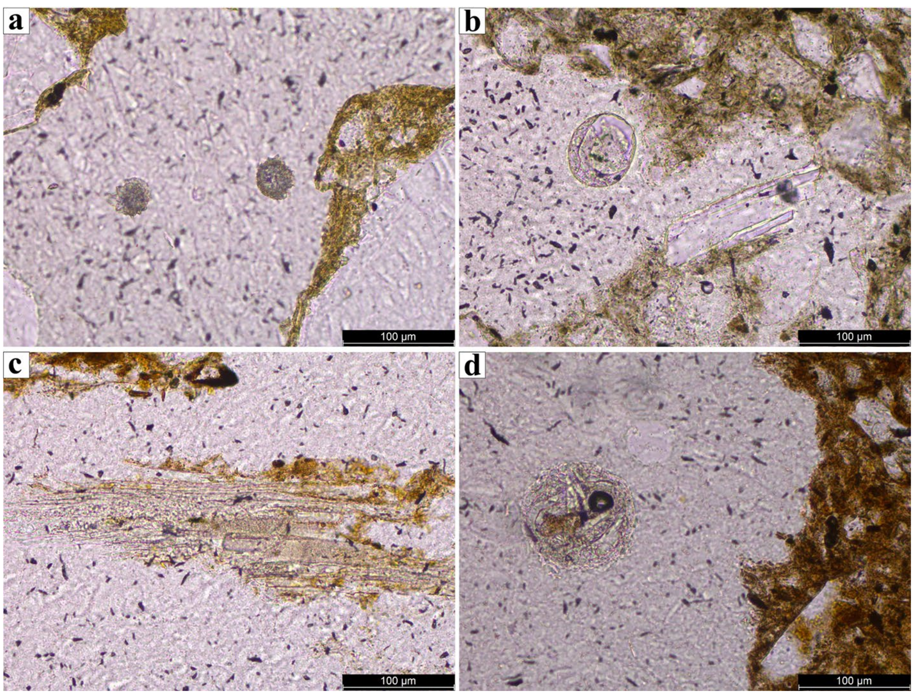

Figure 6. Phytoliths in samples (× 50 PPL); (**a**) a SPHEROID phytolith (TUR 6); (**b**) an ELONGATE ENTIRE multicell (TUR 40); (**c**) ELONGATE multicells from grass leaves/bracts in anatomical connection (TUR 59); (**d**) an unidentified opal body (TUR 60).

Mineralogical composition (XRD)

From the defined clusters, we selected 22 EBM samples and two soils representative of the established petrofabrics to further investigate their mineralogical composition by XRD. The study of the diffractograms points to a majority of samples composed by illite-rich clays with minor differences in their crystalline phases (Fig. 7). In this regard, samples that belong to PFs 1.1 and 1.2 share peaks identified as quartz, albite, illite-muscovite, clinochlore, microcline, montmorillonite/smectite, but also kaolinite is identified in both sub fabrics. Microcline associated with potassium-rich feldspar and clinochore, a Mg-rich chlorite linked to metamorphic deposits, are present in all the fabrics with the exception of TUR 37.

These peaks match with the geological soils TUR S1 and S3, providing strong evidence for a local catchment area of the sediments selected for this EBM assemblage. The composition of PF 1.3 differs slightly due to the absence of kaolinite, which suggests the selection of another type of soil for the mud plaster. This absence also implies a difference between the composition of the mud plaster and the white coatings used in other areas of the building and in which kaolinite seems to be the element used to provide this colour[34]. No kaolinite was detected either in the PF 2 samples. However, goethite is present in the diffractograms of PF 2 samples, which explains the reddish colouration of the groundmass observed in thin sections within this group linking it to a different provenance area.

Finally, individual TUR 37 presents peaks for quartz, albite, kerimasite, and hercynite. The presence of the latter element is identified in non-calcareous ceramics fired at high temperatures in reducing atmospheres. Because of the very high temperatures, the iron oxides are dissolved in the vitreous matrix, and the remains are incorporated in the spinel mineral hercynite[35]. The presence of hercynite and the vitrification recognized in

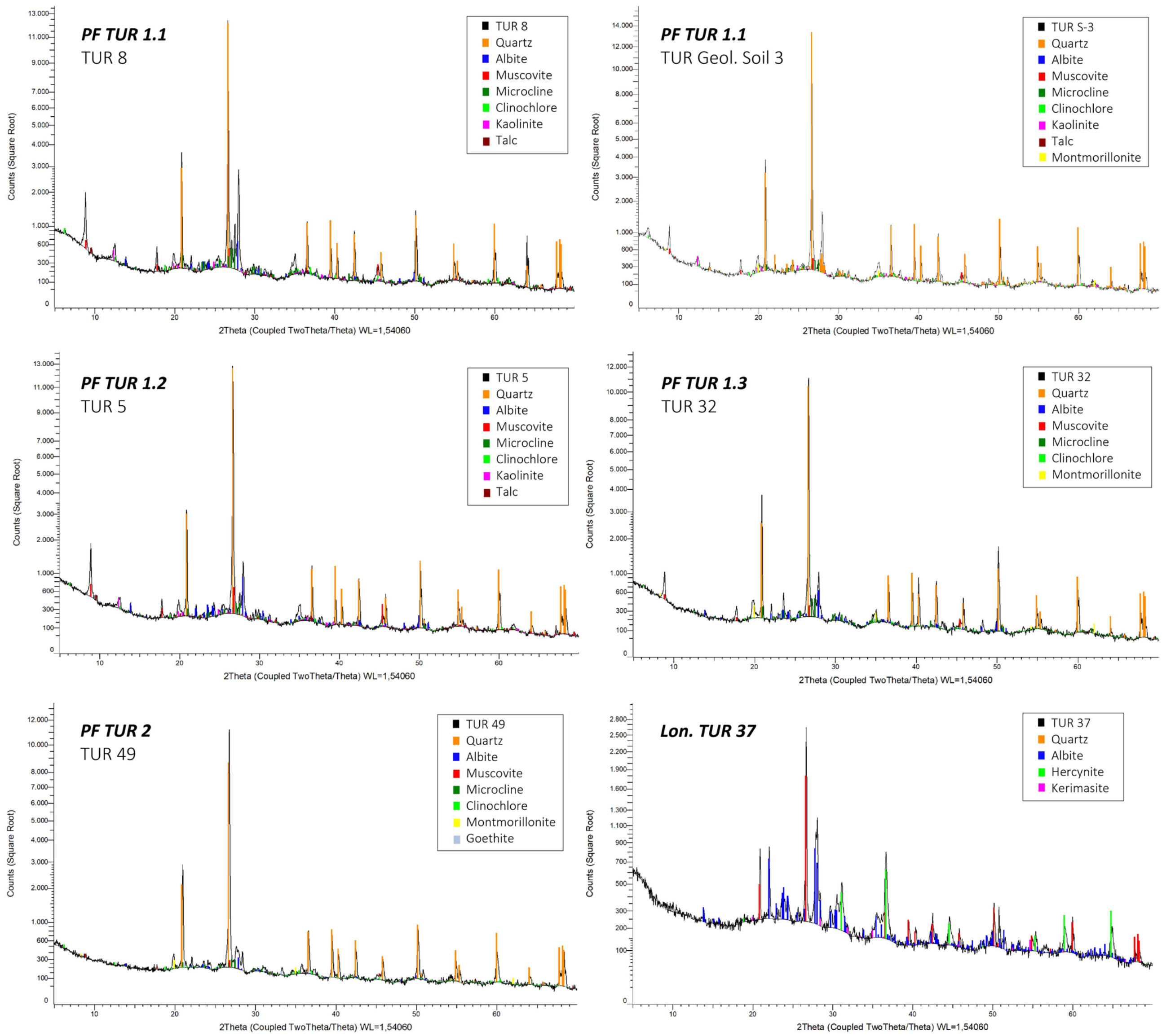

Figure 7. XRD diffractograms with identified crystalline phases representative of the petrographic groups.

this mudbrick is caused by the high temperatures reached by the building during the fire event associated with its collapse.

Discussion

The geoarchaeological approach points to three different raw material catchment areas exploited synchronously during the construction of Casas del Turuñuelo. Although all the samples share a similar geochemical fingerprint—except TUR 37, we have recognized subtle differences mainly based on petrographic and XRD results that are essential for historical and archaeological interpretations:

- The characteristics of the PF TUR-1.1 (n = 22) match the three soil samples—TUR S1, S2, S3—collected near the site that exhibit a yellowish mass matrix rich in quartzite sands. This reveals the existence of an initial exploitation area adjacent to Casas del Turuñuelo, which exploited sediments rich in gravel and sand linked to the Guadiana River deposits (Fig. 3).
- The results also reveal the presence of a second catchment area in the vicinity which includes the EBM classified as PF TUR-1.2 (n = 25) and TUR-1.3 (n = 5). It is true that the samples of these groups present similar chemical compositions to those of the previous sub-fabric, but their matrix with a higher percentage of inclusions and clay pellets, and the absence of kaolinite point to a different provenance or, at least, a nearby extraction area.
- The third soil catchment area is situated further away from the site, probably about 3–4 km to the south, where we found geological formations rich in granites (Fig. 3). The correlation between these formations and the petrographical composition of PF TUR-2 (n = 7) is well evidenced and also supported by the high presence of ferric materials, such as goethite recognized in XRD.

Our results show the combination of manufactured materials with soils located at different distances from the site. They demonstrate that at Casas del Turuñuelo there was such a high demand for resources that it exceeded the availability of soil adjacent to the site. This management of resources required the planning and organization of workers to exploit several areas at once, including more distant raw material sources, even though these required a greater investment in time and energy to transport the materials to the construction area[36]. The exploitation of different soils has been attested in the construction of other public buildings, such as the enclosing wall of the necropolis of El Hibeh, Egypt[37], and the Early Iron Age rampart from Villares de la Encarnación, Spain[38]; or even in domestic houses as revealed by analyses from the Neolithic Çatalhöyük[9] or the Egyptian case of Tell el-Muqdam[39].

Recognizing these fabrics and sub-fabrics has also been essential for investigating other logistical processes during the construction of Casas del Turuñuelo. Archaeological evidence shows at least three different size modules in use during the building process and therefore during the mudbrick manufacturing. Our initial hypothesis considering this differentiation was that this distinction would also be reproduced in terms of the selection and manipulation of different raw sources, following a logic of segmented work in which each group of workers would be in charge of constructing a certain part of the building(s). This strategy has been proposed for the Inca pyramids of Moche[40], the Minoan palace of Malia[11] or the Cyprio-Classical wall of Palaepaphos[12]. However, the results of our study have allowed us to identify mudbricks of the PFs TUR-1.1, TUR-1.2, and TUR-2 manufactured in the different modules and used in various parts of the building walls and vault (Fig. 8). In other words, different groups of workers made different sized mudbricks from the same soils and recipes.

In fact, the key condition that would enable this solution is the circulation of standardized moulds distributed among the different groups of mudbrick manufacturers. This is confirmed by the fact that in the construction of most parts of the building—the hall, the vault, the banquet room, the east door of the courtyard (Fig. 8)—we find mudbricks made from different soils, which implies that the EBM production processes must have taken place synchronously. The situation in which different mudbrick makers have used different moulds according to the needs of each building element is well documented in certain examples of present-day vernacular architecture (e.g.,[41–43]). However, the fact that different groups produced the mudbricks does not mean that these were the same people who carried out the construction. Mixing materials of different provenances in the same walls allows us to hypothesize two different phases or spheres of influence in the chain of production and construction of the building. One in which the mudbricks were manufactured and left to dry, and a second in which a different team worked on the actual construction of the building. Hence, the materials are located without a clear pattern beyond their dimensions throughout the building, sometimes with mudbricks of different colours (Fig. 2c) whose heterogeneity was not a problem as they were late covered with plaster and coatings to homogenize the surfaces and protect the integrity of the construction.

The Casas del Turuñuelo building would have required an extremely large number of builders and building materials. Specific energetics calculations are difficult to estimate until the building has been uncovered in its entirety, but such an effort would probably involve the participation of unskilled people alongside a skilled labour force. The less skilled people could likely collaborate in the collection of raw materials and the initial mixing of recipes. The fact that some of these steps were carried out by low-skilled workers does not imply that other, more skilled processes did not occur, or more experienced individuals were not involved in the construction activities. For instance, the identification of PF TUR-1.3, which clusters together the mud plaster samples from the upper floor vestibule, shows a high percentage of vegetal temper and when combined with the macro observation of multiple layering episodes toward a specialized activity. In this regard, we consider that there are diverse working strategies visible in the construction methods at Casas del Turuñuelo that convey the idea that the manufacture must have been centralized. For instance, the production of mudbricks of identical typologies near the site and in areas that are more distant is a perfect instance. Another would be the difference between the mud-brick

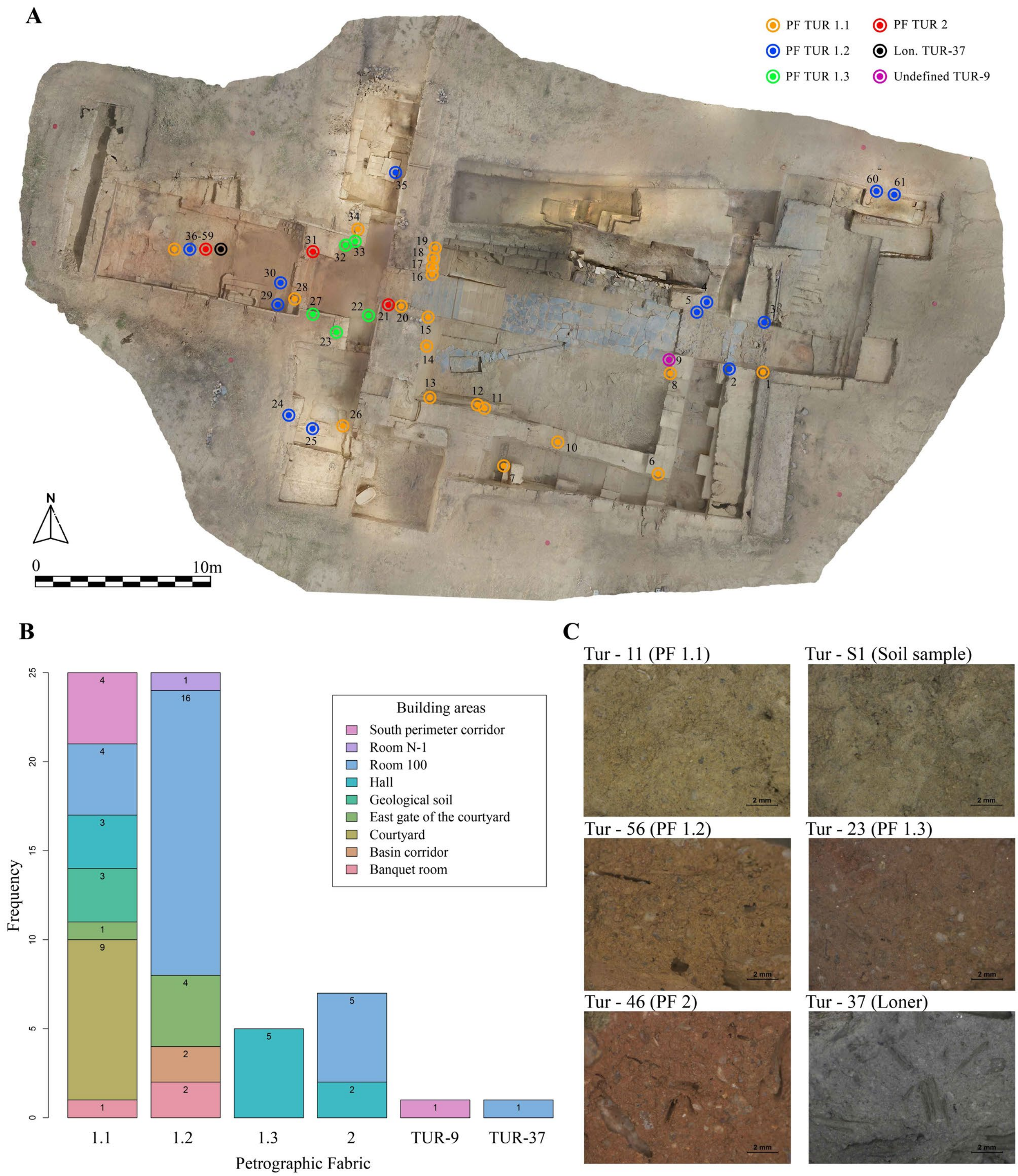

Figure 8. Location and provenance of Casas del Turuñuelo earthen building materials: (**A**) Situation of analyzed EBM and their petrographic assignment; (**B**) Graphical representation of the distribution of the samples according to their petrographic assignment and their location in the different parts of the building; (**C**) Representative stereomicroscope photographs of each group identified.

makers and the builders, who used the mudbricks according to their needs and their availability on site. Finally, the operational chain could also include other groups dedicated to covering and decorating surfaces with plaster and coatings that followed specific recipes to achieve a more resistant building surface.

This degree of complexity in the operational chain, working synchronously and on the same architectural project, cannot, in our opinion, be understood without a fully logistic organization in charge of designing the building and planning the volume of materials necessary. The political power that ordered the construction was able to mobilize the necessary workforces and resources would have coordinated a group of specialists or 'architects' who could distribute and order the production of mudbricks among the different groups that manufacture mudbricks autonomously, based on the resources assigned and the size required.

Conclusion

The analysis of the EBM employed at Casas del Turuñuelo provides new understanding of public earthen architecture and building practices in Mediterranean Protohistory. Our interdisciplinary approach provided data to identify 5 different compositions from which to extract relevant environmental and socio-economic data. The scope of the interpretations of these Tartessian building materials have been very significant, as different catchment areas have been detected associated with different architectural elements such as mud plaster. Firstly, they provide new evidence on the degree of knowledge that protohistoric communities attained about the natural environment and landscape based on the availability and adaptability of local soil sources for the manufacturing of earthen architecture. From the immediate vicinity of the building to much more distant areas, this study demonstrates how the raw source procurement of EBM could be extended territorially according to needs, even if this meant facing new logistical challenges such as work organisation or materials transport.

Secondly, the discovery of the building's monumentality also reveals the complex labour organisational chains and the different working groups involved in highly important public buildings. The analysis carried out at Casas del Turuñuelo has allowed us to recognise particular strategies involved in Western Mediterranean Protohistory, specifically the manipulations and different know-how that took place in a coordinated manner for the construction of this building. In this regard, one process that stands out is the distribution of tasks among mudbrick makers resulting in the production of adobes of similar modules manufactured in different production areas, which likely points to the existence of a group in charge of controlling the development and/or planning of the construction, alongside the preparation of raw material sources. Therefore, this case study has not only demonstrated the agency of this community from the fifth century BC to select and manage the resources from their environment but also that these buildings cannot be fully understood without acknowledging the existence of a robust political organization capable of mobilizing raw materials and workforces to build monumental architecture such as the Tartessian *buildings under tumulus*.

Methods

Archaeological sampling

Sampling of the Casas del Turuñuelo EBM was conducted in March 2022 and was planned to include individuals from different parts of the building excavated since 2014 (Fig. 8). The 61 EBM samples included a range of different building materials (Supplementary Table 1), mainly mudbricks (n = 54), but also mud plaster (n = 6) and mud mortar (n = 1). These samples were chosen, whenever possible, from different rows of the wall and from buildings outside walls. We took around 60 gr from each individual to implement the analyses described above, except for the TUR 9 mud mortar, the disintegration of which prevented the thin section from being carried out. The sample location (Fig. 8) was as follows: TUR 1–5 (east door of the courtyard), TUR 6–10 (south perimeter corridor), TUR 11–19 (courtyard), TUR 20–23, TUR 27–28 and TUR 31–34 (hall), TUR 24–26 (Room S-1), TUR-35 (Room N-1), TUR 29–30 and TUR 36–59 (Room 100), and TUR 60–61 (Basin corridor). The extraction method was mechanical and the condition of the samples were heterogeneous, ranging from disintegrated to altered depending on the exposure to the final fire in the building. Three soil samples—TUR S1, S2 and S3—from the surrounding of the site have also been analyzed as a comparison for the material collected.

XRF and CHN analyses

The chemical composition of the 61 EBM samples and 3 geological soils was performed by X-ray fluorescence (XRF) and CHN elemental analyses to characterize their chemical composition and examine potential cluster formations[28,44]. Sample preparation consisted of homogenizing the mudbricks with a Mixer Mill (MM 400, Retsch) to prepare the pressed beads using 8 g of sample and 2 g of wax that were analysed by a commercial spectrometer WDXRF (Bruker S4 Pioneer). This spectrometer was equipped with an anti-cathode Rh X-ray tube (20–60 kV, 5–150 mA and 4 kW maximum), five analyser crystals (LiF200, LiF220, Ge, PET and XS-55), a sealed proportional counter for the detection of light elements, and a scintillation counter for heavy elements. Vacuum mode analysis was used to enable the detection of low-presence elements. The recorded spectrum was evaluated using SPECTRAplus software linked to the equipment (EVA 1.7, Bruker-AXS and Socabim, 2006). The elemental compounds determined were Na_2O, MgO, Al_2O_3, SiO_2, P_2O_5, SO_3, Cl, K_2O, CaO, TiO_2, V_2O_5, Cr_2O_3, MnO, Fe_2O_3, CoO, NiO, CuO, ZnO, As_2O_3, Ga_2O_3, Rb_2O, SrO, Y_2O_3, ZrO_2, Nb_2O_5, PbO_2, BaO and La_2O_3. Elemental analysis of carbon (C), hydrogen (H) and nitrogen (N) was performed using a 628 Series Elemental Determinator (LECO) to record the volatile elements contained in the samples, a necessary step to know the exact composition of each sample. Thus, the sum of major, minor, trace element concentrations and CHN is located within a range of 99.7–100.1% (Supplementary Table 1).

XRD analyses

X-ray diffraction was implemented to characterize the mineralogical composition of a selection of EBM samples. The analyses were performed using a Bruker D8 ADVANCE (q–goniometer) X-ray powder diffractometer, with Cu K-alpha radiation, equipped with a LynxEye detector with an active length of 2°. The acquisition time was fixed on 2 s per step and sizes were taken from 5 to 70° 2Θ with a measured step of 0.05°. The evaluations of the crystalline phases present in each sample were conducted using DIFFRAC plus EVA V8.0 software that includes the ICDD–JCPDS and ICSD databases.

Petrography

Petrographic analysis of thin sections was carried out using a Leica DM2000 polarizing microscope with an attached Flexacam C3 camera, working with a magnification between ×5 and ×40. To prepare the thin sections, each sample was impregnated with epoxy resin, mounted using an ultraviolet light activation glue and sectioned with a thin Buehler Petro system (Buehler), being hand-finished with silicon carbide until reaching a thickness of 30 µm. The study of the samples followed the structure and component descriptions of ceramics[45,46] and soils[47–49].

Statistical analysis

The statistical analysis of the different types of geochemical data—XRF and CHN results—have been performed with the open software R Core Team (2023).

Data availability

All data supporting the findings of this study are available within the paper and its supplementary material files.

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