INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE

ISSN: 2067-533X Volume 13, Issue 3, July-September 2022: 771-792 www.ijcs.ro

ARCHAEOMETRIC ANALYSES AND RESTORATION OF SILVER JEWELLERY FROM THE PUNIC NECROPOLIS OF THARROS – CAPO SAN MARCO (SARDINIA, ITALY)

Anna Chiara FARISELLI[1], Sara FIORENTINO[1*], Maria Pia MORIGI[2], Matteo BETTUZZI[2], Isabella RIMONDI[3], Katiuscia DOPPIU[3], Mariangela VANDINI[1]

[1] Department of Cultural Heritage, University of Bologna – Ravenna Campus, via degli Ariani 1, 48121, Ravenna - Italy

[2] Department of Physics and Astronomy "Augusto Righi", University of Bologna, viale Carlo Berti Pichat 6/2, 40127 Bologna - Italy

[2] *Kriterion Restauro e Conservazione*, via XXI Ottobre 1944, 28, 40055 Castenaso - BO - Italy

Abstract

The paper reports and discusses data from archaeometric analyses and restoration intervention carried out on an assemblage of silver jewellery pieces from the Punic Southern necropolis of Tharros – Capo San Marco (Sardinia, Italy), a site whose relevance is primarily linked to its stratification, extending from the Nuragic age to the Middle Ages. Belonging to a funerary equipment from a primary incineration tomb, confidently ascribable to 7th-6th century BCE, the jewels were found in a precarious state of conservation, extremely fragmented and, in some cases, held together by a surface alteration layer. High-resolution X-rays CT allowed gaining insights into working techniques and decorative features of the finds under study, whose legibility was severely compromised by the alteration layer. OM and SEM-EDS analyses were also performed, to achieve a more exact characterisation of the alteration products. Obtained data allowed, on the one hand, to establish possible contact with North Africa and, on the other hand, to carry out a meticulous restoration intervention, fully respecting the original integrity of the artefacts despite the precarious state of conservation.

***Keywords**: Punic archaeology; Sardinia; Silver jewellery; Computed tomography; SEM-EDS; Metals restoration*

Introduction (*ACF*)

Recent studies dealing with the material culture of Punic Tharros, located at the end of the Sinis Peninsula on the Gulf of Oristano, Sardinia, Italy (Fig.1), allow us to frame the settlement within the colonial foundations that Carthage promoted in the central Mediterranean, both in Sicily and Sardinia, between the 8th and 7th centuries BCE, according to a precise geopolitical and economic programme [1].

Specifically, on the available data, we can exclude that Tharros has an eastern Phoenician origin, although some trade relations with the Levant are attested in this area since the beginning of the 8th century BC. These trades could in fact also refer to the emporium activities of the nuragic village of Murru Mannu, situated in the north of the present settlement before the Tharros' foundation. However, the village was abandoned before the time of the first urban planning of Tharros, which is probably attributed to North African settlers and placed in

* Corresponding author: sara.fiorentino2@unibo.it

the 7th century BCE. It is therefore not surprising that a late Punic inscription from Tharros defines the city as "qarthadasht", i.e. "Carthage": the term has an adjectival value as "new foundation" or "twin city", i.e. the administrative centre of Carthage of Africa in Sardinia [2].

Fig. 1. a) Map of Sardinia with location of Tharros (redrafting from Google Earth); b) the funerary area on the promontory of Capo San Marco (photo A.C. Fariselli); c) tomb 18 in the southern Punic necropolis of Tharros - Capo San Marco (photo A.C. Fariselli)

Placed on the promontory of Capo San Marco, the Southern necropolis is characterised by pit and chamber tombs with access shafts dug into the limestone and was in use from the archaic age until late antiquity, according to currently available archaeological data [3].

During the 19^{th} century, the necropolis suffered savage violations by the local population with the destruction of grave goods and the dispersion of the most valuable materials in the antiques market. Most of the jewellery from Punic Tharros is currently housed in various European museum collections, notably the British Museum, the G. Sanna National Museum in Sassari and the Archaeological National Museum of Cagliari. These materials are completely devoid of an archaeological context and, therefore, difficult to place in chronological and functional terms, as well as being almost unusable for the study of funerary *pietas* and ritual in use in the Punic world.

This paper reports and discusses archaeometric analyses and the restoration intervention carried out on an assemblage of nos. 17 silver jewellery pieces belonging to an élite funerary equipment from a primary incineration tomb (TB 18) of the Tharros' Southern necropolis [4]. The tomb was unearthed in the Punic cemetery of Capo San Marco during the excavation campaign directed by prof. Anna Chiara Fariselli (University of Bologna – Department of Cultural Heritage) in 2018, within the framework of Ministerial Concession for Archaeological Research and Excavations (DG-ABAP Prot. 9426, Class. 34.31.07/15. 3, 27/03/2017). Tomb TB 18 is an irregular elliptical pit excavated in the rock, just over 1.50m long, with an average width of 80cm and a depth of less than one metre. The pit had been stripped of most of the transverse covering slabs, except for two, which were still in place. The violation of the grave, however, stopped at the superficial layers of the pit and fortunately spared the grave goods placed at the bottom, together with the few burned bones. The abundant layer of charcoal and the traces of combustion on the walls of the pit itself provided evidence that it was a primary cremation, i.e. used as a place for burning and later as a place to deposit the cremated remains of the deceased and their accompanying objects. The typology of the tomb context and the features of the grave goods lead to confidently hypothesise that the finds can be placed in the first phase of the Capo San Marco necropolis, 7th-6th century BCE.

The funerary equipment consisted of an archaic plate of the «suspended flat *umbo*» type, of Carthaginian origin [5] and a conspicuous number of silver objects (Appendix 1): twelve «basket-shaped» pendants; one rectangular with rounded arched top pendant and one circular pendant; six hollow cylindrical elements – of which two are perfectly intact and, therefore, were not restored; a small semi-cylindrical pendant and another one in the shape of a crescent moon with its ends pointing down; about thirty beads made of silver and coloured glass; a twisted wire chain element; an hypothetical scarab seal mount with a smooth ring, in silver, a thin gold amulet mount and a gold *crux ansata*-shaped pendant, decorated with granulation (Fig. 2).

Fig. 2. Plate with a general view of the finds under study

The original scarab and the amulet were lost as they were probably made of a material that is not very resistant to heat - like siliceous paste, typically used in the archaic period. The last three above-mentioned intact artefact (the hypothetical scarab seal mount, the gold mount and the *crux ansata*-shaped pendant) were not involved in the conservation project, as they did not require reconstruction or consolidation work. The gold *crux ansata*-shaped pendant and two hollow silver cylindrical elements were found inside the plate, covered in a thick layer of charcoal and ash. The other artefacts were found in the carbonaceous fill layer above the plate and below it, in direct contact with the rocky floor of the pit.

The state of conservation of the silver jewels suggests that they were placed in the tomb after the fire was extinguished and were, therefore, not directly affected by its action. Under visual examination, artefacts show a greyish-brownish layer of surface alteration products, coherent and well adhered to the metallic core. The discovery of some basket-shaped pendants attached to each other (nos. 58-59) deserves a particular note, as it was unclear whether this occurrence was a result of the corrosion process or a consequence of the partial heating of their surface as well, since they could have been affected by the still intense heat in the pit. Moreover, the alteration layer also incorporated incoherent soil residues, root fragments and limestone deposits, strongly compromising the legibility of the surface and decorative details of the artefacts and thus, not allowing an in-depth study of both the working techniques and the decorative patterns.

Considering the precarious state of conservation, before proceeding to the restoration intervention high-resolution X-ray tomographic analyses and characterisation of surface alteration products were performed on selected silver finds. The study allowed supporting the restoration process in the selection of the most suitable intervention methods, and to gain information on the silver working techniques and decorative features, setting the basis for a typological comparison with Central-Mediterranean manufacture.

Experimental part (*SF-MPM-MB)*

The following methodological approach has been implemented on an assemblage of nos. 17 silver jewellery pieces from the necropolis of Tharros. Due to the strongly compromised state of conservation of the finds, micro-sampling was not allowed; therefore, only non-invasive techniques were selected for this study.

Preliminary visual inspection and documentation was performed by an Olympus SZ61 stereomicroscope (OM) with fixed ocular magnification of 10× and objective magnification up to 4.5×, associated with an Olympus Soft Imaging Solutions GmbH model SC100 camera.

An X-ray Computed Tomography (CT) system developed at the Department of Physics and Astronomy - University of Bologna was used for analysing finds nos. 47, 48, 50, 51, 55, 56, 58, 62 and 63, whose legibility was strongly compromised by surface alteration products. It is a very different equipment from a medical CT scanner, which allows to obtain images with a higher spatial resolution; a feature that is particularly relevant when analysing small finds. The system is equipped with a microfocus X-ray tube (Thermo Kevex, model PXS10-65W) as a source and, as a detector, a Varian flat panel with a usable area of $20\times25cm^2$ (model PS2520D, equipped with 1536×1920 pixels of 127µm). For the tomographic analysis of the findings, a voltage of 130kV and a current of 200µA were set as working parameters in the X-ray tube; the findings, positioned on a high-precision rotary table, were rotated over 360 ° with angular steps of 0.4°, to acquire 900 radiographic projections. The tomographic system has a flexible setup, adjusted to obtain a voxel size of about 40µm. The tomographic reconstruction was performed using an in-house developed programme based on the Feldkamp algorithm [6], while VGStudio Max 2.1 software was used for the 3D rendering of CT data.

A LEO EVO 40XVP-M Zeiss scanning electron microscope (SEM), connected to an energy dispersion microanalysis system (EDS) INCA Energy 250 - Oxford Analytical Instruments Ltd (UK), available at the Department of Industrial Chemistry - University of Bologna, was used for analysing basket-shaped pendants nos. 56 and SN, to investigate micro-textural and micro-textural features of the metallic nucleus and the surrounding alteration layer. These finds were selected from the entire assemblages as, given the impossibility of micro-samplings, they were the only ones to show clear and sharp fracture, with exposure of the metal core and visibility of the surrounding alteration layer. BSE and SE images at different magnifications were acquired; EDS elemental analyses were performed operating in high vacuum at 20.00 kV, with a tungsten filament current of 100µA, 100s of acquisition and 8.0-9.5mm working distance.

Results and Discussion

Archaeometric analyses (SF-MPM-MB)

In-depth magnified observation and documentation of finds under OM allowed a better evaluation of the morphological features of the alteration layer, of greyish colour and having a waxy consistency (Fig. 3a and b); as anticipated, the layer also incorporated incoherent soil residues, root fragments and limestone deposits, strongly compromising the reading of the surface and decorative details of the artefacts (Fig. 3c).

Fig. 3. Some pieces of silver jewellery from the necropolis of Tharros before restoration:
a) curved pendant no. 47; b) basket-shaped pendants no. 58;
c) details of surface alteration under OM (mag. 10x),
highlighting the waxy appearance and showing embedded soil deposits and roots

Moreover, spontaneous fractures and numerous cracks were also observed on the majority of finds from the assemblage; in particular, the basket-shaped pendants were fragmented and incomplete, and, in the most critical conservative status, the fragments were joined together by alteration products.

The occurrence, on basket-shaped pendants nos. 56 and SN, of clear and sharp spontaneous fractures, made it possible to examine the morphology of the alteration layer in more detail under OM (Fig. 4a and b); it was observed how the layer had developed around the entire core of the ornaments, reaching a thickness of about 1.5-2.0mm (Fig. 4c). This preliminary inspection highlighted morphological and textural features of the alteration layer had the typical appearance of silver chloride, while a thinner darker layer was detected in direct contact with the metal core. On archaeological objects from burial environment made of silver, the formation of corrosion layers of silver chlorides typically occurs on the outside, often incorporating components from the soil, while a thin, dark layer of sulphides is generally found in direct contact with the metal [7–9].

To gain further insights into the metallic core and to examine the surrounding alteration layers, SEM-EDS analyses were carried out. Due to the impossibility of micro-sampling the finds, basket-shaped pendants nos. 56 and SN were selected for this purpose, as they showed fractures with exposure of the stratigraphy to be analysed (Fig. 5a).

EDS spot measurements (Fig. 5b) showed that the core is mainly made of silver (64.85wt%), with copper around 2.7wt% (qualitative data are provided in Table 1).

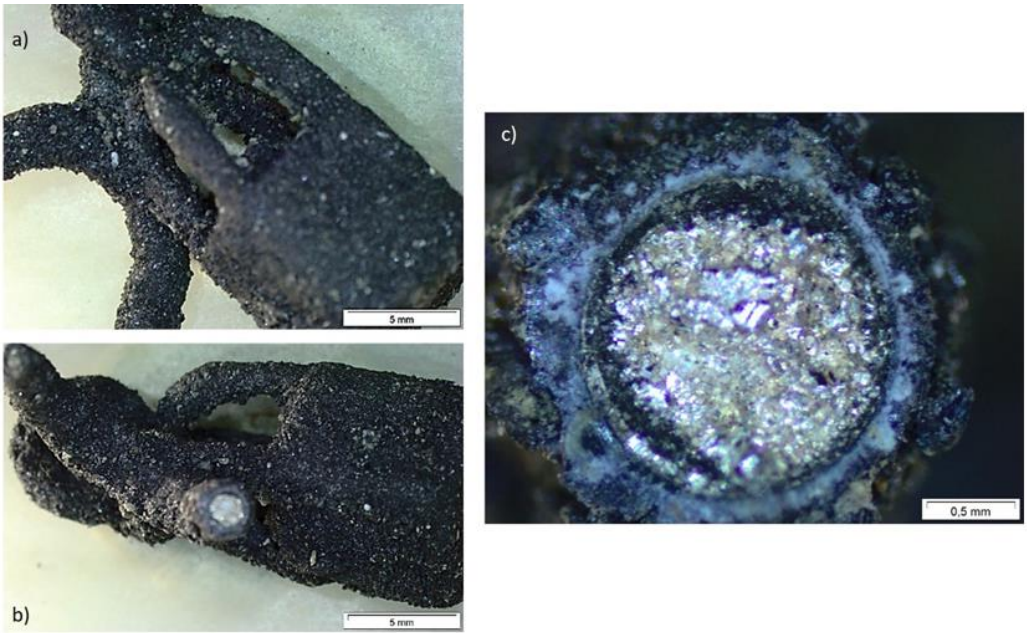


Fig. 4. Detail of piece of silver jewellery from the necropolis of Tharros: a) basket-shaped pendant no. 56; b-c) spontaneous fracture on the pendant, exposing the metal core and the alteration layer [mag. b) 10x and c) 40x]

Table 1. Data from SEM-EDS measurements performed on the metallic core of find no. 56

Element	Intensity Corrn.	Weight (%)	Weight (%) Sigma	Atomic (%)
C K	1.1945	8.53	0.35	25.31
O K	0.3491	22.59	0.71	50.34
Al K	0.6938	0.23	0.07	0.31
Si K	0.8177	0.19	0.06	0.25
Cl K	0.9241	0.39	0.08	0.39
Ca K	0.8452	0.52	0.08	0.46
Cu K	0.9236	2.69	0.20	1.51
Ag L	0.9212	64.85	0.67	21.43
Totals		100.00		

Processing options: all elements analysed (Normalised)
Number of iterations = 4

It is known from the literature [8, 10] that silver was often alloyed with copper to enhance its mechanical properties. As copper has a low solubility in silver, copper-silver alloys are composed of a silver-rich phase and a copper-rich phase, the alteration of the latter often resulting in the formation of greenish corrosion products [11], not detected on the finds under study. BSE and SE images of the metallic core show a homogeneous nucleus, with neither different back-scatters of electrons nor micro-textural differences that could indicate phase separation between copper and silver (Fig. 5a). SE images highlight clean grain-boundary fracture facets, with narrow and sharp cracks, with few slip lines detectable at higher magnification (Fig. 5c and d).

These features could suggest the occurrence of the so-called synergistic embrittlement, resulting from a combined corrosion-induced and microstructurally induced embrittlement [12, 13]; however, the hypothesis could not be further verified as no sampling was allowed and, therefore, no etching on cross-section could be performed.

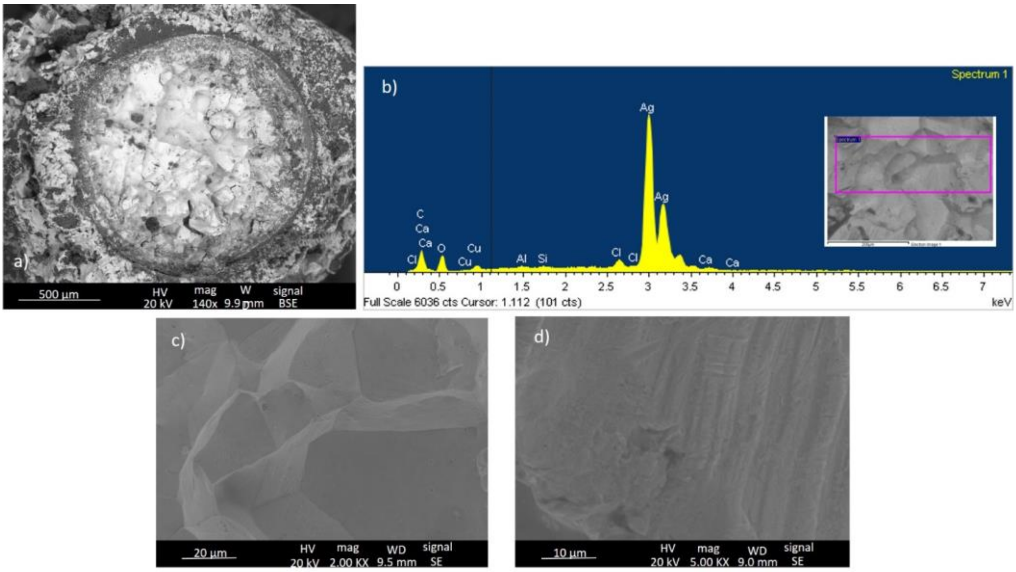


Fig. 5. SEM-EDS analyses performed on basket-shaped pendant no. 56:
a) BSE image of the exposed fracture; b) EDS spectrum acquired on the metal core;
c) SE image of the silver metal core, showing clean grain-boundary fracture facets;
d) SE image of the silver metal core, showing traces of slip lines

EDS measurements performed on the alteration layer surrounding the metallic core confirmed that this layer was mainly composed of silver and chlorine. Elemental mapping (Fig.6) also highlighted that a higher concentration of chlorine is found in the outer rim of the layer compared to the inner, adhering to the metallic nucleus, where higher Ag is detected. Ca, Si and Al were also found in the alteration layer, plus oxygen; the nature of these oxygen-containing phases was not clearly identified, and it can be linked to soil deposits. Relatively higher calcium contents were detected in the middle part of the layer; as no reference has been found in the literature dealing with the occurrence of Ca-based phases in silver alteration, the most plausible hypothesis is that it can be ascribed to surface deposits from the soil as well. Last, sulfur (S) was found in relatively low percentage contents, equal to about 0.2wt%; SEM-EDS elemental mapping shows that it is mainly localised in the vicinity of the metal core, where it is plausible to hypothesise silver sulphides have formed, non-detected under preliminary visual investigation and under OM.

The detection of Ag and Cl in the outer alteration layer is consistent with the formation of silver chlorides, the main corrosion products affecting archaeological silver objects from burial sites [14, 15]. Still scarcely investigated, their formation is linked to the oxidising properties of near-surface, aerated seawater and shallow land burials [16], an environment which is in line with the Tharros necropolis. Jaro [17] suggested that in burial conditions ammonia dissolves silver oxides, and silver ions react to form AgCl. As silver chloride does not create a protective layer, the metal can mineralize: it can be completely transformed into silver chloride under unfavourable conditions [12]. However, such a mineralization process does not seem to have occurred in the basket-shaped pendants under investigation, where the silver-based metallic core is still clearly displayed.

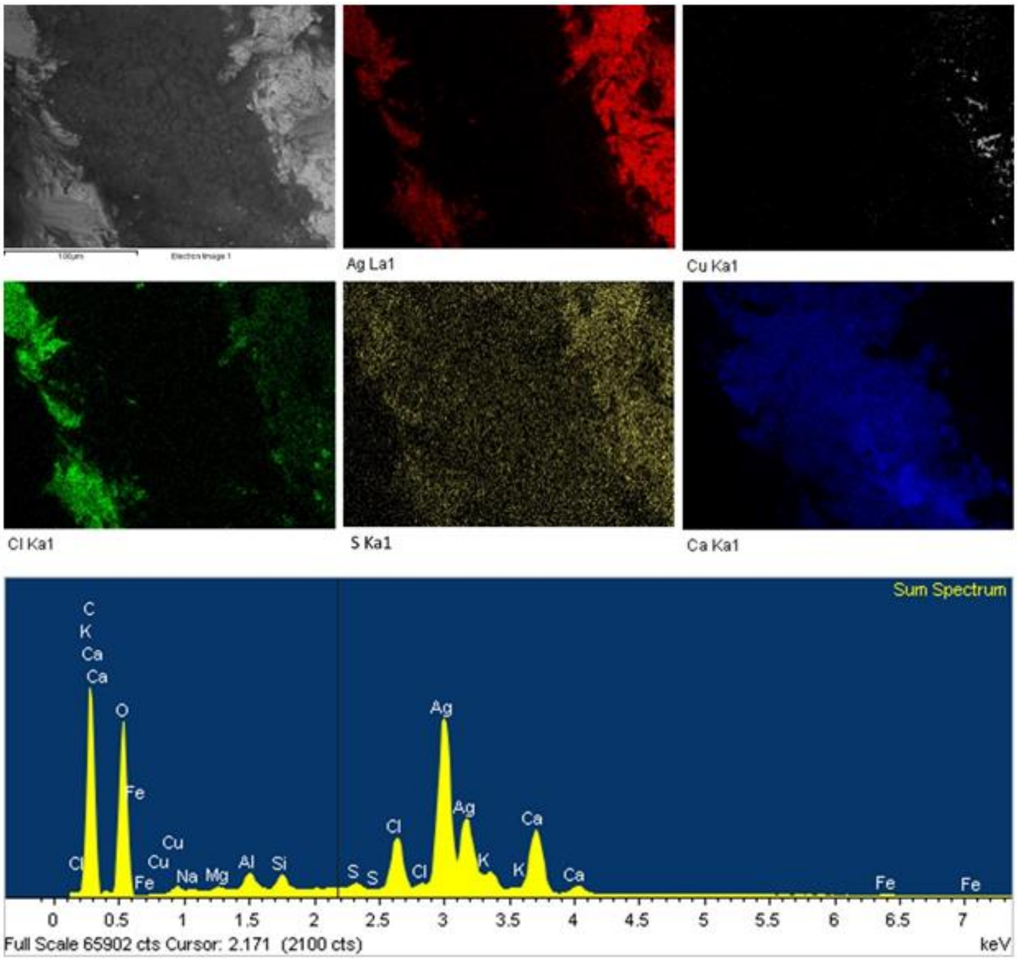


Fig. 6. SEM-EDS qualitative and semi-quantitative mapping, performed on basket-shaped pendant no. 56

Considering the precarious state of conservation of the finds, X-ray computed tomography was carried out on a selected number of objects before proceeding with the restoration intervention. This non-invasive and non-destructive technique could provide physical and morphological information about the internal structure of materials under study, whose legibility was severely compromised by the alteration products. The tomographic analyses and the subsequent 3D rendering allowed to virtually eliminate the outer layers, corroded and with lower density, and to bring to light the internal part of the objects, which, in many cases, was still perfectly legible. Analyses made it possible to identify the types of decoration and, in some cases, the working techniques, laying the foundations to the subsequent typological study of the finds and related comparisons.

Frontal tomographic sections of the curved pendant no. 47 (Fig. 7a) highlighted relevant details of its decorative features, completely hidden by the surface alteration layer. The decorations are made with metal elements in relief, small point-like spheres and larger spheres as well as bands, all made of the same metal. The dimensions of the point-like spheres vary from 0.4 to 0.6mm, while the larger spheres have a diameter of about 2mm; the bands are about 1.0mm wide (Fig. 7b and c). The density of the various elements is the same and, presumably, the metal is silver anywhere. An element containing a "spring" structure made up of 7 rings or coils is also visible at the top of the pendant; the diameter of the wire used is about 0.3mm.

The disc-shaped pendant no. 48 was entirely corroded as well. The tomographic front sections of the artefact (Fig. 8a) show a decoration on both sides (Fig. 8b and c).

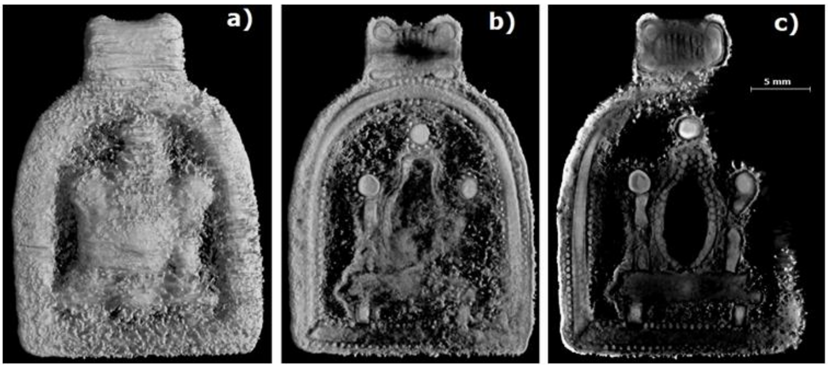


Fig. 7. X-ray CT images of curved pendant no. 47:
a) 3D rendering; b) internal section of the reconstructed volume;
c) coronal slice, showing details of granulation and filigree decorations

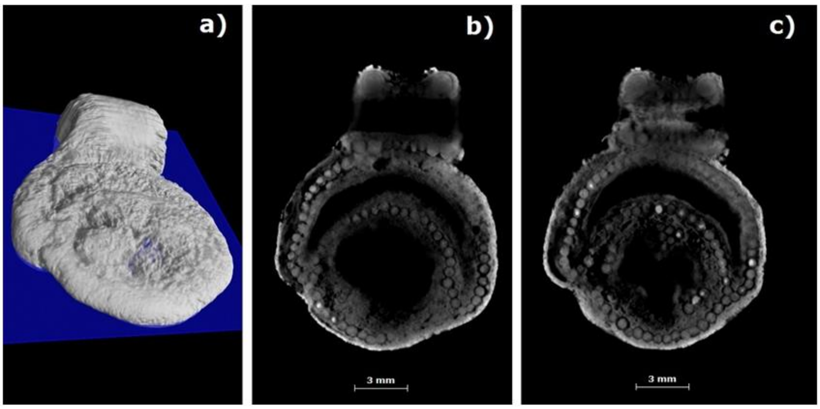


Fig. 8. X-ray CT images of circular pendant no. 48:
a) coronal plane sectioning the 3D rendering; b) crescent moon decoration and c) star decoration.

The elements of the granulation decoration have a diameter of about 0.5mm. As it can be clearly seen in the axial and sagittal sections shown in figure 9, empty spaces can be observed inside the pendant. This feature confirms that the pendant is made up of two sheets welded together or of a single folded and riveted sheet. Above, a "spring" or "spool" element consisting of 7 rings or coils has been detected. Some elements of the granulation show a higher density, more similar to that of the external lamina: this could suggest the use of a different, heavier metal with respect of most of the decoration. However, the unfeasibility of a spot, elemental analysis (due to the thick corrosion layer of the metal and the consequent inability to sample the find safely) did not allow to confirm this hypothesis.

Regarding the cylindrical element no. 49, CT images did not allow univocally distinguishing the original metal sheet; it can be identified with the external one - although strongly weathered - due to the higher density compared to that of the internal layer (Fig. 10a).

Artefact no. 50 is made of two objects accidentally fused together: a hollow cylindrical element and a pendant with a spool suspension element. Tomographic sections of the cylindrical element (Fig. 11a) show various layers of material inside the object. A thin sheet of metal constituting the walls can be observed in the cylinder, with a thick layer of corrosion inside the cavity (Fig. 11b). The thickness of the sheet is between 150 and 200μm, while the thickness of the corrosion layer inside ranges between 500 and 600 μm. The pendant is made of an external sheet composed of several layers, presumably of the same material as that of the cylindrical element. Instead of the corrosion layer, the presence of a less dense material can be observed inside, with a thickness ranging between 0.5 and 1.0mm. An in-depth analysis of the tomographic sections shows that the spool suspension element houses a wire wound in five coils. The thickness of the wire is about 0.5mm (Fig. 11b, red square).

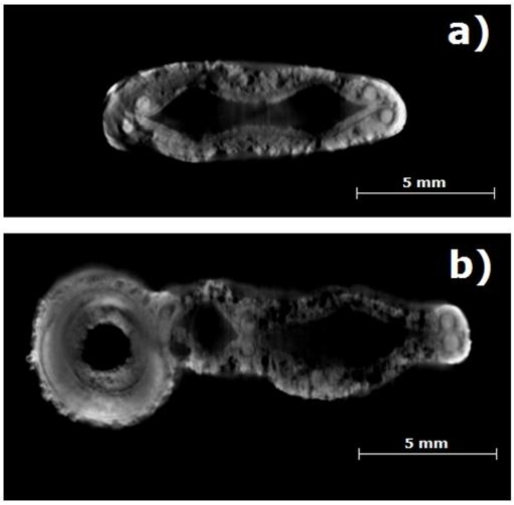


Fig. 9. a) axial and b) sagittal slices showing the presence of cavities inside pendant no. 48

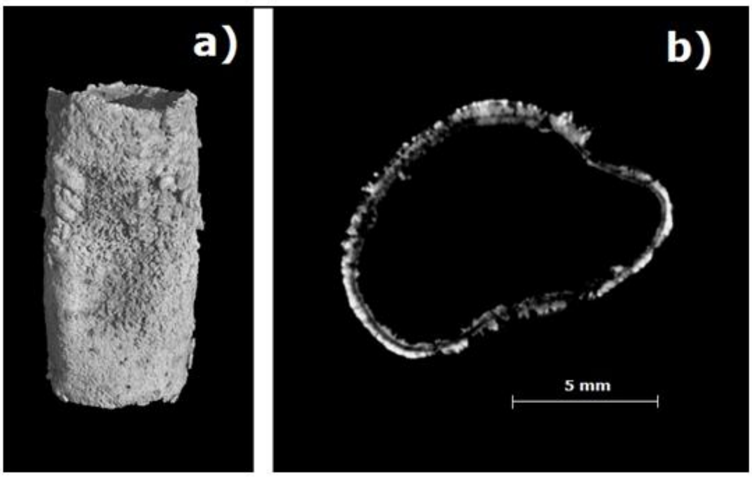


Fig. 10. X-ray CT images of cylindrical element no. 49:
a) 3D rendering; b) axial section of the element showing the two corrosion layers with a thin gap between

Find no. 51 is a small hollow tube element with a “spring” mechanism at one end (Fig. 12a), with a series of 6 coils or rings made with a filament having a diameter of around 0.5mm (Fig. 12b). A heavily corroded, deformed and denser layer can be observed on the external surface of the find, having a thickness between 0.2 and 0.4mm; a much less deformed ring (a kind of bushing), about 0.3mm thick and with a lower density than the outer layer, is found inside the cylinder (Fig. 12c).

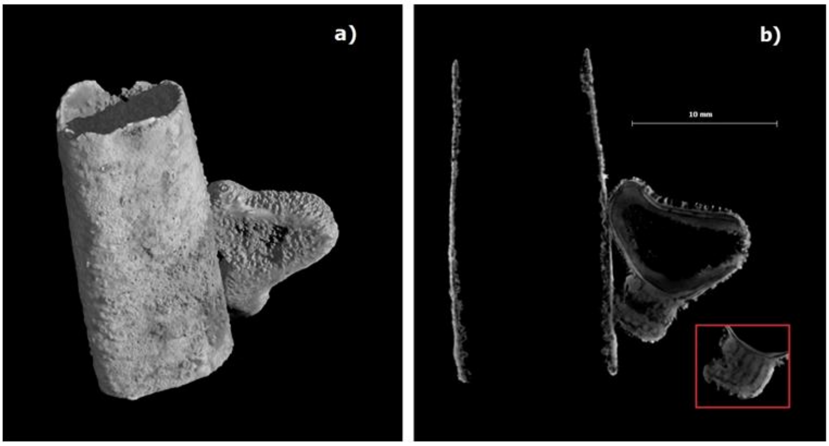


Fig. 11. X-ray CT images of artefact no. 50: a) 3D rendering; b) frontal slice showing the hollow cylindrical element and the semi-circular pendant with the spool suspension element

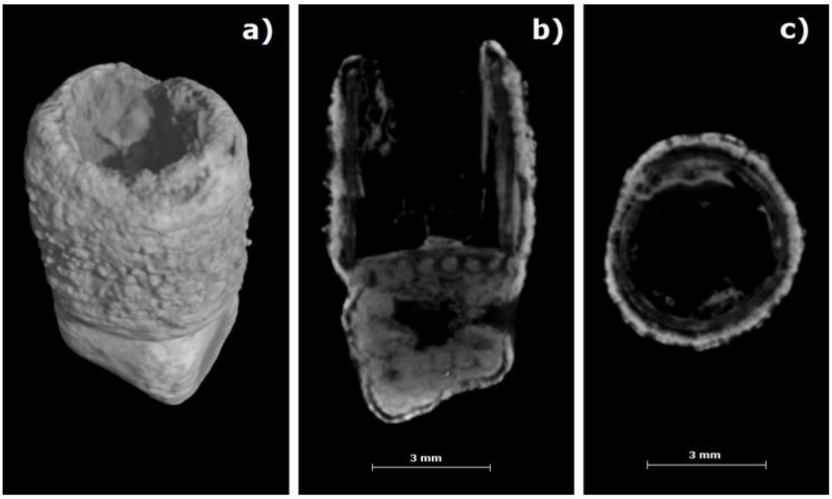


Fig. 12. X-ray CT images of cylindrical element no. 51: a) 3D rendering; b) vertical section; c) axial section of the element, showing a denser outer layer and an inner ring of regular thickness

As regards the basket-shaped pendant no. 55, its external surface is highly compromised by the corrosion phenomenon observed in all the finds from the assemblage under study (Fig. 13a). CT sections show that the inside of the basket is hollow (Fig. 13b) and that the two arched arms intertwine at the top, connecting to a small ring. On the upper face of the basket, four small decorative spheres can be noticed (diameter about 1.0mm). The axial section at the basket shows the thicknesses of the inner foil (0.3-0.4mm) and of the outermost corrosion layer (0.16-0.4mm). CT section in correspondence of the large ring (Fig. 13c) allowed to obtain the diameter of the wire, which is about 1.7mm. In this case, a difference between the density of the external corrosion layer and the density of the internal metal sheet at the level of the basket has not been highlighted. The double ring element is made of two metal filaments, with a section of about 0.5mm completely covered by a corrosion layer with a thickness of 0.1 to 0.4mm. In the upper part, two larger rings can be observed: in the middle, a cylindrical body and a single ring below (Fig. 13c). Upon closer inspection, the tomographic sections highlighted that in the central part four filaments are twisted in a spiral and then, form a double ring at the bottom which appears as a single body because the threads are completely hidden by corrosion (Fig. 13d).

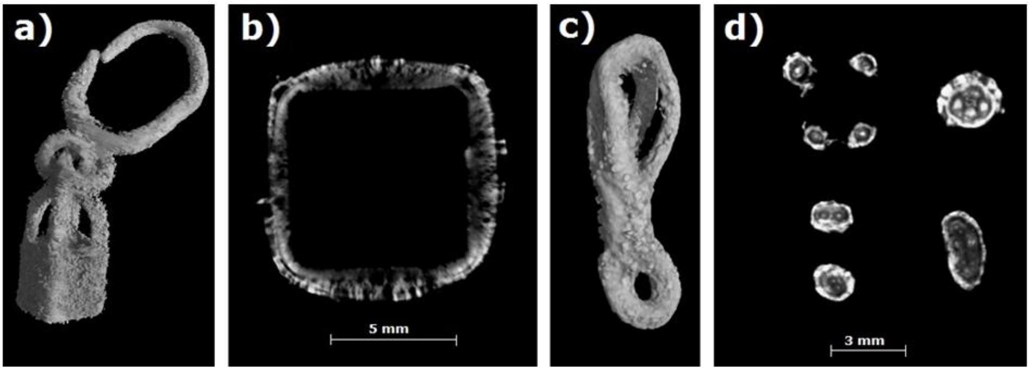


Fig. 13. X-ray CT images of basket-shaped pendant no. 55: a) 3D rendering; b) axial section of the basket, showing a regular-shaped internal lamina surrounded by an external corrosion layer; c) 3D rendering of the double ring element; d) axial sections of the double ring element at different heights

CT images of find no. 58 are provided in Fig. 14. In the three-dimensional rendering, two basket-shaped silver earrings hooked together can be observed (Fig. 14a). A strong corrosion of the metal can be seen on the outside, despite the find has been unearthed intact.

The two earrings are welded together. The metal sheet that makes up the walls of the basket has a thickness of about 0.3mm. The corrosion layer that covers it externally reaches a thickness of up to 0.5mm. The arched arm of the basket (Fig. 14b) consists of a metal wire with a diameter of about 1.0mm and is externally covered by a layer of corrosion up to 0.5mm thick. In the middle, a group of three small spheres can be observed, whose diameter can be estimated in about 1.5mm.

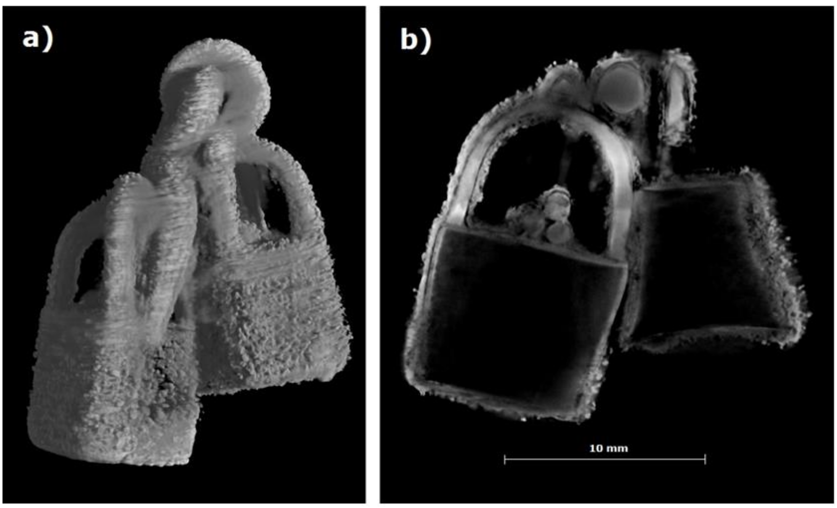


Fig. 14. CT images of basket-shaped pendant no. 58: a) 3D rendering; b) vertical section of the object showing inner details of the artefact

Artefact no. 56 is another example of basket-shaped pendant with an arched arm (Fig. 15a), similar to those of finds no. 55 and no. 58. The metal sheet that makes up the basket is thinner than in the previous case, with an average thickness of 0.16mm (Fig. 15b), while the corrosion layer outside the foil is about 0.5mm thick. One of the two arched arms of the basket, again with a circular section as in the previous cases, has a diameter of about 1.0mm (intact metal part) and it is covered with a degraded layer 0.5mm thick. The basket is hollow and empty. Small spheres are also found, resting on the upper face of the basket and having a diameter of 1.3-1.4mm. It is interesting to note how the metal filaments that make up the arched arms of the basket, as well as those of the rings, have an inner core of denser material.

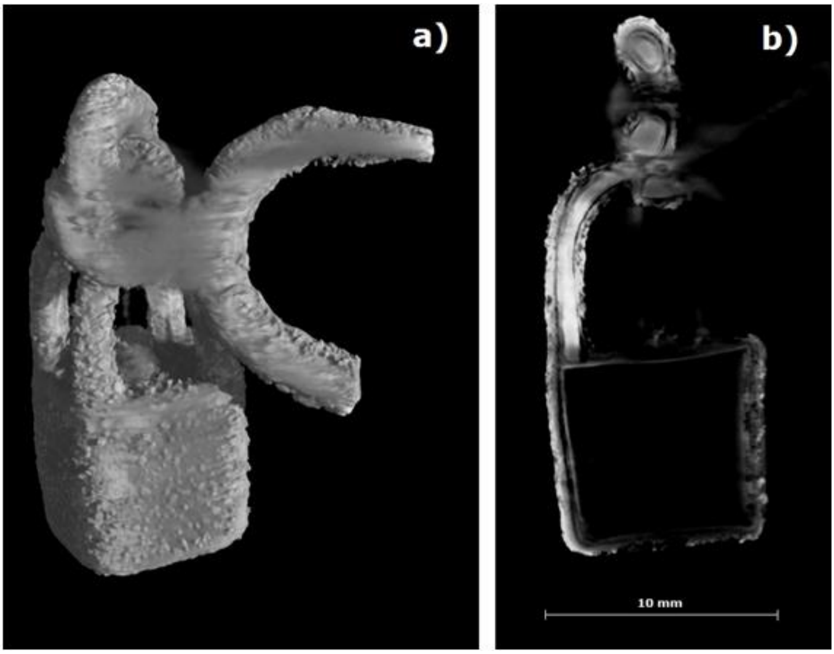


Fig. 15. CT images of basket-shaped pendant no. 56: a) 3D rendering; b) vertical section of the basket showing the rather thin internal metal sheet and the thicker corrosion layer on the outside

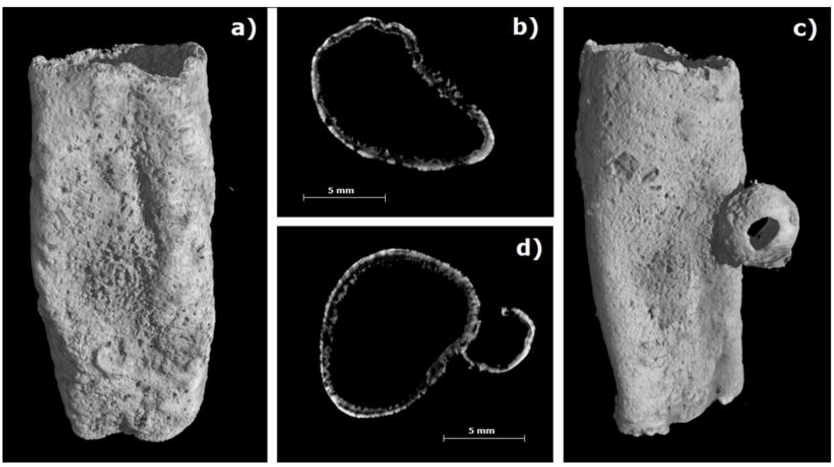


Fig. 16. CT images of cylindrical elements nos. 62 and 63:
a) 3D rendering of find no. 62; b) axial section of the tubule showing the external lamina and the corrosion inside; c) 3D rendering of find no. 63; d) axial section at the interface between the cylindrical element no. 63 and the spherical object outside. There are no constructive elements of union between the two

Cylindrical element no. 62 shows extensive external and internal corrosion (Fig. 16a). The CT axial section displays the thicknesses of the different layers, separated by a thin gap as in the case of find no. 50 (Fig. 16b). The external layer, which is the original metal sheet and has a higher density, has a thickness ranging from 0.2 to 0.4mm; the internal corrosion layer from 0.1 to 0.4mm; the cavity ranges from 0.1 to 0.3mm. Find no. 63 is an internally hollow cylindrical element, with a strong corrosion both outside and inside (Fig. 16c). It is possible to measure the thickness of what presumably must have been the original lamina, now very degraded, from one of the axial sections (Fig. 16d). The thickness of this layer is between 0.15 and 0.3mm. A corrosion layer is also visible on the inside, varying in thickness from 0.27 to 0.35mm and having a lower density than the outer layer. A spherical object appears attached to one side of the tubule. The tomographic sections show a contact area but the laminae of the two objects probably joined together in the degradation process appear distinct (Fig. 16d).

Typological study of silver pendants (ACF)

The curved pendant no. 47 (height 2.9cm; length 2cm; thickness 2mm) (Fig. 7) shows a granulated decoration within the arched frame. Inside the relief frame, an «Egyptian throat» altar base with a sun disk in the middle and short rectangular feet can be easily recognised; two uraeus snakes with sun disc above the altar frame the so-called «bottle-shaped idol», granulated on the surface and with a well-attested feature in the Carthaginian context [4, 18]. CT images of the disc pendant no. 48 (width 1.1cm; height 1.6cm; thickness 2mm) (Figs. 8 and 9), hardly distinguishable even after restoration, show two decorated faces: on one face, a granulated line delimits the crescent moon that inscribes a circular shape; on the other face, the crescent moon demarcated by granulation surmounts a disc filled with three granulated triangles. The two metal sheets are welded and profiled by granulation. The pendant recalls some gold and silver specimens already documented in Carthage and in Tharros itself [19].

The cylindrical elements nos. 49-50 and 62-63 (Figs. 10-11 and 16), made by rolling technique (height between 2.2 and 2.5cm; width 0.9-1.0cm; thickness 0.5mm), can be classified as necklace beads; they are already documented in the repertory of Tharros' silver jewellery in models of similar size [19]. Artefact no. 50 (Fig. 11) was entirely covered in calcareous concretions; CT allowed identifying two objects cast together: a hollow cylindrical vague and a concave semi-circular pendant with a spool suspension element. The material fused to the hollow cylinder can be interpreted as a small crescent moon (h. length. 0.9cm, thickness 3mm) with the ends pointing downwards. The hollow bezel of the pendant was probably originally filled with an insert of glass paste, amber or hard stone that has been lost. In Tharros, as in other central Mediterranean contexts, the type with a crescent moon inscribed with a sun disc is more frequently documented [19]. CT has revealed that the object has no fracture or gap on the underside, which evidently did not contemplate the insertion of the sun disc. On the other hand, the single crescent moon type can be compared to the Carthaginian context [18], where the bezel is sometimes decorated with a turquoise insert.

A case with no precise matches is represented by artefact no. 51 (9mm; diam. 4mm; thickness 1.0mm). CT analysis (Fig. 12) showed that it is a small, slightly truncated cone-shaped cloche, hollow inside, with a spool-shaped clasp, perhaps corresponding to a miniature bell or to a mount of the type already documented in Carthage [18], perhaps completed by a further element in a different material.

Regarding the basket-shaped pendants, tomographic images acquired on finds nos. 55, 56, 58 (Figs. 13-15) show the recurring detail of three or four overlapping spheres inside the small baskets, which are difficult to see under visual examination. The small spheres are arranged to form a small pyramid; this detail is supposed to render, in Levantine symbolism, the first fruits offered in the basket. The hollow baskets show a systematic homogeneity of size (1.6 h and 0.8cm the side; 1.0mm thickness) and a simple clasp, consisting of a ring attached to the basket handles and a thickened oval wire of slightly more than 2cm in length fitted with a further ring. The pendants appear to be made using the technique of rolling, drawing and granulation, probably in addition to the use of moulds and dies. The morphological and dimensional uniformity certainly allows us to trace them back to a single production process.

However, the difficulty of tracing the precious materials back to a univocal and traditional functional interpretation should be noted [19, 20]. The occurrence, inside the tomb, of a single gold necklace and twelve baskets, together with six cylindrical elements and several small beads, could suggest the presence of necklaces or a pectoral collar decorated with various pendants. In other words, the basket-shaped jewellery would not necessarily be read as earrings. In addition to these considerations, it should be noted that such a find is not isolated in the Sardinian-Punic world and in general not even in North Africa and Punic Sicily. The closest comparisons include an archaic inhumation tomb from the necropolis of Monte Sirai (Carbonia-Iglesias, South Sardinia), which had ten silver basket-shaped pendants in association with other valuable objects, which is why the discoverers called it the «priest's tomb» [21] and in a Punic cremation burial of Motya (Marsala, West Sicily) [4]. The way the artefacts were 'offered', placed inside the plate in TB 18, seems to suggest that the value of the funerary deposition lies in the way jewellery was hoarded, placed in the grave as markers of *status*, as elements of protection for the known religious value of the jewellery [22], but also as a treasure of the deceased.

Conservative intervention (IR-KD)

The fragility of the finds, affected by fractures and cracks, with elements sometimes held together by the layer of silver chlorides identified by SEM-EDS analyses, alongside the occurrence of applied decorative elements, highlighted by X-rays TC, led to the choice of a carrying out a cautious, minimal restoration intervention (documentation of the finds before and after the intervention is provided in Table S1).

To minimise the risk of breakage and damage to the surface of the finds, a controlled chemical cleaning with selective agents was opted for, alternated with microscope-aided mechanical intervention. Before cleaning procedures, the surface of the finds was protected with Japanese paper, cut to size and adhered using the same product and the same dilution with which the pack was made.

To soften and remove the layer of alteration products, repeated applications of localised compresses were made, whose shutter speed was based on the tenacity of the encrustations. First, alteration products were treated with surfactant to remove incoherent deposits, then a low concentration complexing agent was applied. The application of both products was supported by rigid gel, as the gelation process of the aqueous solutions allows to release the chemicals in a more controlled way and to retain the material removed from the surface of the products. 3% Agar Agar gel was used, for the first phase with Tween 20, and subsequently with 5% Rochelle salts; deionized water was used for both solutions and rinsing [23–25].

After treatment, the softened concretions were mechanically removed; a rinse was then carried out to eliminate the residues of the products used, followed by a dehydration with acetone and a passage in a ventilated stove.

A meticulous search of the attachments under the microscope was performed among all the available fragments, which allowed the reassembly of several basket-shaped pendants. Paraloid B72 acrylic resin in acetone (1: 1.62) was used as adhesive. Last, the surface of the artifacts was protected with nitrocellulose paint (Zapon in 50% ethyl alcohol).

Conclusions

Archaeometric analyses made it possible to improve the readability of the objects that could be typologically studied and classified. The interdisciplinary study has also made it possible to bring the deposition back to the Carthaginian cultural horizon with certainty.

Considering the compromised state of conservation, the restoration work carried out on the finds was extremely respectful of the original surfaces. Based on the semi-quantitative chemical composition obtained by SEM – EDS analyses, a meticulously controlled cleaning operation allowed achieving good results without resorting to the use of strong chemical agents for prolonged contact times. A good level of cleaning has been reached for the majority of the artefacts, making it possible to obtain a fair readability of the shape and, in some cases, of the decorative elements.

The understanding of manufacturing techniques and the study of decorative features of the jewellery pieces, achieved through CT analyses, allows to assume that the jewellery was produced as part of a sophisticated "élites' media", albeit made in series. The so-called "basket earrings", in silver and gold, are widespread throughout the Phoenician and Punic Mediterranean, with a particular frequency between the 7th and 6th century BC and very few morphological variations from one settlement to another [26]. Pendants with arched tops and "disc" pendants with astral motifs are more common in the Carthaginian context, in both silver and gold, although they are also found in other sites in Punic Sardinia, Sicily and Spain. The crescent moon pendant with a hollow bezel, accidentally fused to the cylindrical pendant no. 50 - which is exclusive to Tharros and does not appear elsewhere - seems to be a North African type [20]. The evidence from tomb 18 is therefore an important innovation in the typological study of astral pendants, but also further evidence of the cultural proximity between Carthage and its colony on the Sinis' Peninsula.

The association of many different "pendants" in a single funerary outfit, also witnessed in Carthage [18], seems to provide further confirmation of the ideological and religious orientation of the first generation of Tharros inhabitants, fully aligned with the North African cultural perspective also from the point of view of the preservation of the traditions of the motherland in the cult of the dead.

As far as the places of production are concerned, there are two levels of problem. One concerns the supply of raw materials; the other concerns the location of the manufacture, whether centralised (in North Africa: i.e. in Carthage or in the Punic hinterland) or decentralised (in Tharros). The analyses carried out do not allow us to establish with certainty the origin of the silver used, nor do they allow us to establish whether the jewellery was made in Tharros or in other metallurgical workshops in the central-western Mediterranean [27]. The richness of the Sardinian silver-lead mines is well known, so much so that Sardinia is known as the "island of silver veins" by ancient authors. It also seems that even before the colonisation of the island, the technique of cupellation, necessary to separate non-native silver from lead, was in use [28, 29]. On the other hand, isotopic analyses conducted on silver artefacts found in Palestinian context, in sites of high antiquity, document the use of Sardinian and Atlantic metal in the Southern Levant since the First Iron Age [30], as well as silver imported from Attica [31] and Anatolia [32]. These data testify to the existence of commercial connections between the two Mediterranean basins, not attributable only to the "Phoenician" carriers, given the difficulty of reconstructing the ethnic and identity characteristics of the crews of the ships plying the same routes at this stage. Furthermore, the findings in the Southern Levant concern a limited area, very peripheral and subsidiary to the main Phoenician city states.

We know that it was precisely the search for silver that was one of the reasons behind the first surveys in the West Mediterranean and then the Phoenician colonisation of some settlements in South Sardinia and Spain from the 9th century BC. However, this does not justify the assumption that the metal found at Tharros came from the Sardinian mining basins. The chronological distance between the first experiments in cupellation on the island and the manufacture of TB 18 jewellery is several centuries. In addition, the possibility that the role of Carthage as a market for the reception and Mediterranean redistribution of Iberian silver is not negligible. In central-western Sardinia, however, the working of silver ore seems to be documented only for a much later chronology (4th-3rd century BC) compared to the Archaic Punic period in which the jewellery examined here is placed and there is no documentation of an earlier use of cupellation [33]. At the same time, the use of this technology in the manufacture of silver is attested since the 8th century in the Iberian Peninsula, where native silver is also present [30]. Further silver reserves located near Utica are also exploited by the Carthaginians at least from the 4th century BC, in connection with the need to mint silver coins to pay the mercenary armies in war [34]. On the other hand, recent hypotheses place the activity of silver cupellation in Carthage as early as the 7th century BC [35].

In the case of the artefacts analysed in this work it is therefore possible that the silver, regardless of its Sardinian or Iberian provenance, was worked both in Tharros and in Carthage itself, without excluding, in this case, the further export of the finished materials to Sardinia. It is certainly likely, in fact, that in Tharros the silver manufactures were used by members of the Carthaginian ruling class, as a social emblem for themselves and their families [2], as is the case with scarab seals.

Finally, from the point of view of the interpretation of the tomb context, it is possible to imagine that the abundance of silver jewellery in a single burial was intended to constitute a sort of treasure trove, as suggested by some scholars for lots of silver in other archaic tombs in Punic Sardinia [21]; but it is equally likely that the large number of jewellery of the same type in a single burial, as also verified in Carthage and Motya [4], is due to the original composition of the pendants into a single necklace or pectoral. It is also possible to see in this large batch of silverware an ex voto offering to an underworld deity, in line with the hypothesis that the punic jewellery had a particular funerary purpose [22].

Acknowledgements

Authors would like to kindly acknowledge Dr. Maura Picciau, former Head of the Superintendence of Archaeology, Fine Arts and Landscape for the metropolitan city of Cagliari and the Provinces of Oristano and South Sardinia – Cagliari and the General Directorate for Archaeology, Fine Arts and Landscape of MIC for having granted the authorization for the transfer of materials, study and restoration. Dr. Georgia Toreno and Dr. Maura Vargiu (Superintendence of Archaeology, Fine Arts and Landscape for the metropolitan city of Cagliari and the Provinces of Oristano and South Sardinia – Cagliari) are warmly thanked for their active collaboration during the project. We would like to also thank Prof. C. Del Vais, director of the Cabras' "Giovanni Marongiu" Civic Museum, for her assistance to organise the temporary transfer of the materials. Authors are grateful to Dr. Fabrizio Tarterini (Laboratory technician at the Department of Industrial Chemistry - University of Bologna) for his kind collaboration on SEM-EDS analyses.

Authors' contributions

ACF directed the field work (Concession of archaeological research and excavations DG-ABAP Prot. 9426, Class. 34.31.07/15. 3, 27/03/2017), co-ordinated research and the preparation of the manuscript; SF designed the manuscript and performed OM and SEM-EDS analyses - with data elaboration and interpretation; MPM and MB performed CT analyses – with data elaboration and interpretation; IR and KD carried out the restoration intervention; MV supervised archaeometric data interpretation and made Laboratory's facilities available. All authors read and approved the final manuscript.

References

[1] R. Secci, *Cartagine oltre Cartagine tra VIII e VI sec. a.C.: una retrospettiva storiografica*, **Byrsa Cartagine fuori da Cartagine Mobilità nordafricana nel Mediterraneo centro-occidentale fra l'VIII e il II sec a.C, Atti del Congresso Internazionale**, Ravenna 30 novembre – 1 dicembre 2017 (Editors: A.C. Fariselli and R. Secci), 2018, pp. 351–364.

[2] A.C. Fariselli, *Tharros the coastal cities of Punic Sardinia and the Carthaginian geopolitics from the 5th to the 3rd century BCE*, **Transformations and Crisis in the Mediterranean – III "Identity" and Interculturality in the Levant and Phoenician West During the 5th-2nd Centuries BCE** (Editors: G. Garbati and T. Pedrazzi), CNR Edizioni, Roma, 2021, pp. 231–243.

[3] A.C. Fariselli, M. Silani, M. Vandini, *Ricerche a Capo San Marco (Penisola del Sinis - OR). Nuove indagini dell'Università di Bologna nel quartiere funerario meridionale di Tharros fenicia e punica*, **From the Mediterranean to the Atlantic: People, Goods and Ideas Between East and West 8th International Congress of Phoenician and Punic Studies Italy** (Editor: M. Guirguis), Sardinia Carbonia, Sant'Antioco 21th-26th October 2013, Folia Phoenicia 1, 2017, pp. 308–313.

[4] A.C. Fariselli, S. Fiorentino, M.P. Morigi, M. Bettuzzi, I Rimondi, K. Doppiu, **Oro, argento e fuoco: nota multidisciplinare su una cremazione arcaica dalla necropoli meridionale di Tharros - Capo San Marco**, Byrsa, 2021, pp. 31–85.

[5] R. Secci, *Il ruolo di Cartagine nel Mediterraneo centrale: nuovi dati e prospettive alla luce della documentazione ceramica,* **L'Africa Romana Atti del XVII Convegno internazionale di studi Le ricchezze dell'Africa Risorse, produzioni, scambi,** Sevilla, 14-17 dicembre 2006. Rome, 2008 (Editors: J. González, P. Ruggeir, C. Vismara and R. Zucca), Rome, 2008, pp. 135–150.

[6] L.A. Feldkamp, L.C. Davis, J.W. Kress, *Practical cone-beam algorithm*, **Journal of Optical Society of America A-Optics Image Science and Vision, 1**(6), 1984, pp. 612–619. https://doi.org/10.1364/JOSAA.1.000612

[7] V. Costa, *The deterioration of silver alloys and some aspects of their conservation*, **Studies in Conservation, 46**(1), 2001, pp. 18–34, https://doi.org/10.1179/sic.2001.46.Supplement-1.18.

[8] L. Selwyn, **Metals and Corrosion: A Handbook for the Conservation Professional,** Canadian Conservation Institute, Ottawa, 2004.

[9] L. Selwyn, *Corrosion of metal artifacts in buried environments,* **ASM Handbook Corrosion: Environments and Industries**, ASM International, Ohio, 2006, pp. 306–322.

[10] H Águas, R.J.C. Silva, M. Viegas, L. Pereira, E. Fortunato, R. Martins, *Study of environmental degradation of silver surface,* **Physica Status Solidi C - Current Topics in Solid State Physics, 5**(5), 2008, pp. 1215–1218, DOI: 10.1002/pssc.200777842.

[11] G. Marchand, E. Guilminot, S. Lemoine, L. Rossetti, M. Vieau, N. Stephant, *Degradation of archaeological horn silver artefacts in burials*, **Heritage Science, 2**(1), 2014, Article Number: 5, https://doi.org/10.1186/2050-7445-2-5.

[12] R.J.H. Wanhill, *Brittle archaeological silver: A fracture mechanisms and mechanics assessment,* **Archaeometry, 45**(4), 2003, pp. 625–636.

[13] R.J.H. Wanhill, *Embrittlement in archaeological silver artifacts: Diagnostic and remedial techniques*, **Journal of Miner Met Mater Soc, 55**, 2003, pp. 16–19.

[14] N. North, I. MacLeod, *Corrosion of Metals,* **Conservation of Marine Archaeological Objects**, (Editor: P. Butterworth), Canberra, 1987, pp. 91–95.

[15] M. McNeil, B. Little, *Corrosion mechanisms for copper and silver objects in near-surface environments,* **Journal of American Institute for Conservation, 31**, 1992, pp. 355–366.

[16] B. Bozzini, G. Giovannelli, C. Mele, F. Brunella, S. Goidanich, P. Pedeferri, *An investigation into the corrosion of Ag coins from the Greek colonies of Southern Italy. Part I: An in situ FT-IR and ERS investigation of the behaviour of Ag in contact with aqueous solutions containing 4-cyanopyridine,* **Corrosion Science, 48(**1), 2006, pp. 193–208.

[17] M. Jaro, *Re-Corrosion of Silver and Gilt Silver Threads on Museum Textiles After Treatments,* **Proceedings of the 7th International Restorer Seminar, Conservation of Metals,** (Editor: M. Jaro), National Centre of Museums, Veszprem, 1990, pp. 95–98.

[18] B. Quillard, **Bijoux carthaginois III. Les colliers. Apports de trois décennies (1979-2009),** Éditions De Boccard, Orient & Méditerranée, 13, Paris, 2013.

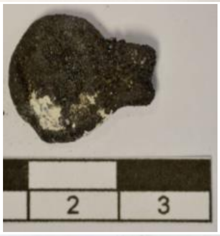
[19] G. Quattrocchi Pisano, *I gioielli fenici di Tharros nel Museo Nazionale di Cagliari,* **Collezione di Studi Fenici**, vol. 3, Rome, 1974.

[20] B. Quillard, **Bijoux carthaginois I. Les colliers d'après les collections du Musée National du Bardo et du Musée National de Carthage**, Publications d'histoire de l'art et d'archéologie de l'Université Catholique de Louvain, 15. Louvain-la-Neuve, 1979.

[21] P. Bartoloni, *La tomba 88 della necropoli arcaica di Monte Sirai*, **Archäologische Studien in Kontaktzonen der antiken Welt Veröffenltichungen der Joachim Jungius-Gesellschaft der Wissenschaften**, (Editors: R. Rolle, K. Schmidt, R. Docter), Hamburg, 87, 1998, pp. 353–358.
[22] H. Bénichou-Safar, *De la fonction des bijoux phénico-puniques*, **Alle soglie della classicità. Il Mediterraneo tra tradizione e innovazione**,(Editor: E. Acquaro), Pisa - Rome, 1996, pp. 523–534.
[23] D. Chelazzi, E. Fratini, R. Giorgi, M. Mastrangelo, M. Rossi, P. Baglioni, *Gels for the Cleaning of Works of Art*, **Gels and Others Soft Amorphous Solids ACS Symposium Series,** Vol 1296, ACS, Washington, 2018, pp. 291–314.
[24] A. Dupke, A. Raimon, E. Guilminot, **Nouvelles Utilisations del Gels à Base d'Agar pour le Nettoiage del Métaux.** Vol. 26, AR AAFU CRBC – Cahier technique, 2020, pp. 72–79.
[25] L. Scott, *The use of agar as a solvent gel in objects conservation 2012*, **Proceedings of the Objects Specialty Group and joint Objects Research & Technical Studies Sessions 40th Annual Meeting in Albuquerque,** New Mexico Objects Specialty Group, Vol. 19. Washington: AIC, 2012, pp. 71–83.
[26] G. Pisano, *Considerazioni sui gioielli alla luce delle nuove scoperte,* **Studi di Egittologia e Antichità puniche**, 14, 1995, pp. 63–73.
[27] A.C. Fariselli, M. Vandini, F. Caillaud, S. Zambruno, C. Caputo, M.P. Morigi, M. Bettuzzi, R. Brancaccio et al. *Una laminetta in argento con volto virile dalla necropoli meridionale di Tharros, Note iconografiche, archeometriche e conservative, in L'archeologia punica e gli dèi degli altri*, **Byrsa**, 21-22/23-2:11–28.
[28] A. Valera, P. Valera, A. Rivoldini, *Geology*, **Sardinian ore deposits and metals in the Bronze Age Archaeometallurgy in Sardinia from the Origin to the Beginning of Early Iron Age** (Editors: F. Lo Schiavo, A. Giumlia Mair, U. Sanna, R. Valera, Éditions M. Montagnac, 2005, pp. 43–87.
[29] C. Atzeni, L. Massidda, U. Sanna, A*rchaeometric data*, **Archaeometallurgy in Sardinia from the Origin to the Beginning of Early Iron Age** (Editors: A. Lo Schiavo, F. Giumlia-Mair, U. Sanna, R. Valera), Éditions M. Montagnac, 2005.
[30] J.R. Wood, I. Montero-Ruiz, M. Martinón-Torres, F*rom Iberia to the Southern Levant: The Movement of Silver Across the Mediterranean in the Early Iron Age*, **Journal of World Prehistory (Springer US), 32**, 2019, pp. 1–31, https://doi.org/10.1007/s10963-018-09128-3
[31] T. Eshel, Y. Erel, N. Yahalom-Mack, O. Tirosh, A. Gilboa, *Lead isotopes in silver reveal earliest Phoenician quest for metals in the west Mediterranean*, **Proceedings of National Acadmy of Science USA, 116**(13), 2019, pp. 6007–6012.
[32] T. Eshel, O. Tirosh, N. Yahalom-Mack, A. Gilboa, Y. Erel, *Silver Isotopes in Silver Suggest Phoenician Innovation in Metal Production*, **Applied Sciences, 12**(2), 2022, 741.
[33] T. De Caro, C. Riccucci, E.I. Parisi, F. Faraldi, D.Caschera, *Ancient silver extraction in the Montevecchio mine basin (Sardinia, Italy): Micro-chemical study of pyrometallurgical materials*, **Applied Physics A Materials Science and Processing, 113**(4), 2013, pp. 945–957.
[34] H. Delile, E. Pleuger, J. Blichert-Toft, J. Goiran, N. Fagel, A. Gadhoum, et al., *Economic resilience of Carthage during the Punic Wars. Insights from sediments of the Medjerda delta around Utica (Tunisia)*, **Proceedings of the National Academy of Sciences of the United States of America, 116**(20), 2019, pp. 9764–9769.
[35] R. Secci, *Tra Huelva e Cartagine: possibili testimonianze della coppellazione dell'argento nella Sardegna centro-orientale*, **El Oriente de Occidente fenicio y púnicos en el área ibérica VIII edición del Coloquio Internacional del CEFYP en Alicante** (Editors: F.Prados Martínez and F. Sala Sélles), UN, 2017, pp. 537–546.

Received: March 3, 2022
Accepted: August 26, 2022

Appendix 1.
Synoptic table of the finds under study, with documentation before and after the restoration

Find No.	Description	Before restoration	After restoration
THNM_ 18.S252- 21.47	Curved pendant		
THNM_ 18.S252- 21.48	Circular pendant		
THNM_ 18.S252- 21.49	Cylindrical element		
THNM_ 18.S252- 21.50	Cylindrical element		
THNM_ 18.S252- 21.51	Cylindrical element		
THNM_ 18.S252- 21.52	Basket-shaped pendant		

Find No.	Description	Before restoration	After restoration
THNM_ 18.S252-21.53	Basket-shaped pendant		
THNM_ 18.S252-21.54	Basket-shaped pendant		
THNM_ 18.S252-21.55	Basket-shaped pendant		
THNM_ 18.S252-21.56	Basket-shaped pendant		
THNM_ 18.S252-21.57	Basket-shaped pendant		
THNM_ 18.S252-21.58	Basket-shaped pendant		

Find No.	Description	Before restoration	After restoration
THNM_ 18.S252- 21.59	Basket-shaped pendant		
THNM_ 18.S252- 21.60	Basket-shaped pendant		
THNM_ 18.S252- 21.61	Basket-shaped pendant		
THNM_ 18.S252- 21.62	Cylindrical element		
THNM_ 18.S252- 21.63	Cylindrical element