SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 10, No. 3, (2024), pp. 39-55
Open Access. Online & Print

DOI: 10.5281/zenodo.11251260

ARCHEOMETRIC ANALYSIS OF A GROUP OF GOLD ARTIFACTS IN BURDUR MUSEUM (TURKEY)

Soslu S.[1] and Soslu A.[2]

[1]Burdur Mehmet Akif Ersoy University, Faculty of Science and Letters, Department of Archaeology, 15000 Istiklal Yerleşkesi, Burdur, Turkey
[2]Aydın Adnan Menderes University, Social Sciences Institute, Department of Archeology, 09000, Efeler, Aydın, Turkey

Received: 15/04/2024
Accepted: 21/06/2024

Corresponding author: Soslu, S (ssoslu@mehmetakif.edu.tr)

ABSTRACT

In this article a catalog and archeometric analysis of a group of eleven artifacts of jewelry gold artifacts from the Burdur Museum are examined. The artifacts were brought to the museum through purchase. They were graded based on their forms: head jewelry, hand jewelry, neck jewelry, and bust. Two artifacts (earring, necklace pendulum) from the Iron Age and Classical Period; Two artifacts (earrings) from the Hellenistic Period; Six artifacts from the Roman Period (three earrings, two rings, busts); There is an artifact (ring) from the Late Roman-Early Byzantine Period. They are produced by different construction techniques: casting, wire, filigree, repousse, engraving and granulation. The earliest artifact dates from the Iron Age; Late period artifacts date back to the Early Byzantine Period.

Since it is not allowed to take pieces from the artifact and use destructive methods in the analysis of the artifacts, the analyzes were carried out using non-destructive methods. Three analytical methods were applied: portable energy dispersive XRF (P-EDXRF), X-ray Radiography and μ-PIXE. Such microanalytical techniques are widely used in alloy characterization studies. Additionally, statistical SPSS analyzes of the artifacts were performed.

In these analyses we are dealing with the use of pure gold and gold ore, the chemical components of alloys, the color difference caused by the combination of gold with silver and copper alloys, the alloy used in plating, and the copper ratios used in soldering. Among others some issues concerning manufacturing defects occurring during the production phase, artifacts that are recycled or secondary production, and distortions caused by overheating during soldering, are discussed.

KEYWORDS: Burdur museum, gold jewelry, earring, ring, necklace pendulum, bust, archaeometry, P-EDXRF, X-ray Radiography, μ-PIXE.

1. INTRODUCTION

With the Burdur Museum's formal approval, dated January 31, 2023, and with the number E-51544244-155.01-3441393, a group of gold jewelry was investigated for this study. The museum holds about 60,000 historical objects from the settlements and cities in the Pisidia Region. It was determined that some of these artifacts were obtained as a result of excavations and surface surveys in the region, while some were seized through purchase, confiscation and illegal excavation. The gold jewelry that was the focus of the investigation was purchased and added to the inventory of the museum. Significant issues arose throughout the dating stage since these artifacts were not context finds. This problem was solved by dating the artifacts with typological and analogical examples. It is debatable, nevertheless, if the artifacts are indigenous to the area.

The P-EDXRF method was selected due to its features, such as being able to measure from he surface and determine chemical components by using it in non-destructive analysis of artifacts (Potts and West 2008). The chemical elements and alloys of the artifacts were identified and quantified using XRF analysis. X-ray radiography was used to analyze the alloys of the artifacts as well as the images of these alloys (Schreiner et al., 2004). We were able to determine the manufacturing state and technique by identifying the variations in the visual inspection, namely the alloys, of some of the artifacts that were the focus of the investigation. The artifacts' minor and trace elements were attempted to be identified using the μ-PIXE method (Halden et al., 1995). In ore characterization research, these kinds of microanalytical techniques are rather widely used. These methods provide very useful information with high accuracy and precision (Janssens and Van Grieken, 2004).

The goals of this study are to identify the chemical alloys in gold jewelry, calculate the primary alloy to component ratios, and identify the pure alloy ratio; to get information about the silver to copper ratio, which preserved the long-term preservation of the artifacts' usefulness and aesthetic appearance; to detect deterioration resulting from the manufacture and repair of artifacts; determine the soldering process; the learning the component and its ratio used in soldering; to determine whether artifacts are recycled by identifying alloys; to understand whether there is a relationship between the diversification of alloys and jewelry technology; to examine the connection between alloy ratios and historical process; to learn how the manufacturer uses his technique, knowledge and alloys in the field of jewelery; determine if there is a manufacturing defect; to compare the techniques used with the same techniques in other artifacts; is to question the relationship between jewelry technology and production techniques and forms, and the role of alloys in this relationship. These artifacts are significant because it provided insights on the Anatolian antique gold jewelry culture by analyzing a group of gold jewelry from the Burdur Museum the first time with micro analytical and non-destructive analysis techniques like μ-PIXE, X-ray radiography, and P-EDXRF. Because of this, such studies and research of archeometric analyses will not only improve the quality of gold jewelry studies but also yield insights into the historical process of jewelry technology throughout a long history (Liritzis et al., 2020).

2. MATERIALS - CATALOGUE

All of the artifacts this study examined were used as jewelry, with the exception of the bust. The six of the artifacts are gold; three are gold-plated on bronze; one is gold-plated on green matte glass, and one is gold-plated on silver. Six earrings, a bust, three rings, and a necklace pendulum are among the artifacts. These date historically from the Early Byzantine Period to the Iron Age. The catalogue is given below (2.1- 2.4) with associated photos and in Table 1.

2.1. Earring

Cat. No.: 1 (Purchasing), **B.M. Inv. No.:** K.53.32.93

H.: 1,5 cm **O.D.:** 1,5 cm **I.D.:** 1,3 cm **T.:** 0,2 cm

Gold. Casting and engraving technique. Hoop earrings. Round cross section-circular shaped. The middle part of the ring is thicker than the ends. The ends of the earring rings are rounded and made facing each other. The two rings are spaced apart for easy insertion into the ear hole. The inner surface is decorated with grooves made with the scraping technique.
Date: Iron Age.

Cat. No.: 2 (Purchasing), **B.M. Inv. No.:** K.247.19.73

L.: 4,8 cm **W.:** 1,2 cm **T.:** 0,9 cm

Gold. Casting and filigree technique. Four spiral wires are twisted in the ring section. One end of the ring ends by tapering; the other end goes into the lion's neck. The head is made in casting technique; eye sockets are empty. Rings and spiral-shaped decorations made in filigree technique on the nape and neck of the lion.

Date: Hellenistic (4nd - 3nd century BC).

Cat. No.: 3 (Purchasing), **B.M. Inv. No.:** K.88.39.89

L.: 3,4 cm **W.:** 2,8 cm **T.:** 0,6 cm

Gold. It is gold plated over bronze. Repousse, filigree ve granulation tekniği. The ring was created with the repousse technique. One end of the ring becomes thinner and flatter and has a hook shape. At the thick end of the ring, two rows of beads made with the granulation technique are placed between two rows of horizontal bands made with the filigree technique. Semicircular decorations made with the granulation technique on the upper part and spheres in a single row above it. Then there is a series of six rows of leaves made with the filigree technique.

Date: Hellenistic (3nd - 2nd century BC).

Cat. No.: 4 (Purchasing), **B.M. Inv. No.:** K.1164

L.: 4,2 cm **W.:** 1,7 cm **T.:** 0,7 cm

Gold. Wire, engraving and granulation technique. The round cross-section wire is thick in the middle and becomes thinner towards the ends. Grooved decoration made with engraving technique on the ring made with granulation technique at the tip (nine pieces). After one end of the ring is wrapped around the middle part of the hook-shaped wire, it ends by winding on itself (12 times); small ring decoration.

Date: Roman (1nd - 2nd century AD).

Cat. No.: 5 (Purchasing), **B.M. Inv. No.:** K.28.23.77

L.: 1,7 cm **W.:** 1,3 cm **T.:** 0,3 cm

Gold. Wire and granulation technique. Hoop earrings without a pendulum. One end of the thin wire is wrapped once, forming a short loop; The other end, tapering towards the attachment point, has a short hook. The outer surface of the middle part of the ring is decorated with spherules made in the granulation technique; large cluster (one) in the middle; small globules (two in number) on each side.
Date: Roman (2nd century AD).

Cat. No.: 6 (Purchasing), **B.M. Inv. No.:** 4336

L.: 1,9 cm **W.:** 1,5 cm **T.:** 0,3 cm

Gold. Wire and engraving technique. Hoop earrings without a pendulum. One end of the thick wire is wrapped around itself (twice) to form a small double loop. The end of the loop is wrapped around the body (twice). The other end, tapering towards the attachment point, is wrapped (once) around the short hook loop. The body is grooved (32 pieces).

Date: Roman (1nd - 3nd century AD).

2.2. *Necklace Pendulum*

Cat. No.: 7 (Purchasing), **B.M. Inv. No.:** E.9222

L.: 3,8 cm **W.:** 3 cm **T.:** 3 cm

Glass, gold. Repousse, filigree and granulation technique. It is made of thin gold plate. Conical shaped. It has a round-matte green glass stone inside. The tip is decorated with a single row of bands made with filigree technique. The pendulum is formed by connecting a wide ring to the body.

Date: Classical (5nd century BC).

2.3. *Ring*

Cat. No.: 8 (Purchasing), **B.M. Inv. No.:** K.209.64.75

H.: 1,9 cm **O. D.:** 1,6 cm **I. D.:** 1,3 cm **T.:** 0,3 cm **E.L.:** 0,7 cm **E.W.:** 1,2 cm

Bronze, gold. It is gold plated over bronze. Repousse and engraving technique. The ring has a "rectangular" cross-section. The ring has a circular shape It is connected to the eyebrow with a shoulder flat inward. Flattened oval shaped eyebrow socket; Line decoration made in the engraving technique.

Date: Roman.

Cat. No.: 9. (Purchasing), **B.M. Inv. No.:** K.52.44.82

H.: 1,8 cm **O.D.:** 1,8 cm **I.D.:** 1,4 cm **T.:** 0,4 cm **E.L.:** 1,3 cm **E.W.:** 0,8 cm

Gold. Casting and engraving technique. The ring has a "D" section. The ring is elliptical in shape; It rises upwards, becomes round, and connects to the eyebrow with a wide shoulder. The ring cavity is circular. Flattened oval shaped eyebrow socket; it is depicted with a figure made with engraving technique.

Date: Late Roman (4nd - 5nd century AD).

Cat. No.: 10. (Purchasing), **B.M. Inv. No.:** K.38.72.86

H.: 1,7 cm **O. D.:** 1,5 cm **I. D.:** 1,2 cm **T.:** 0,3 cm **E.L.:** 0,9 cm **E.W.:** 0,9 cm

Bronze, gold. It is gold plated over bronze. Repousse and engraving technique. The ring has a "circular" cross-section. The ring has a circular shape. Flattened circular shaped flat eyebrow socket; Depicting a human head made in the engraving technique.
Date: Late Roman-Early Byzantine (4nd - 8nd century AD).

2.4. *Bust*

Cat. No.: 11. (Purchasing), **B.M. Inv. No.:** K.140.34.03

H.: 4,5 cm **W.:** 3,6 cm

Silver, gold. Casting, filigree, engraving and granulation technique. A small section on the edge is intact and missing. Round-based, symmetrical disorder in the part where the chest sits. Bust of a woman (empress) made with the hollow casting technique, (with golden eyes and crown). The eyes and crown are gold. The round base is also decorated with floral rosettes and braid.

Date: Roman (2nd century AD).

Table 1. Historical features of the artifacts.

Inventory Number	Artifacts Name	Period	Sources used in dating the artifacts andmform, decoration and style features
K.53.32.93	Earring	Iron Age	Koçar 2011, 81, Cat. No. 20
K.247.19.73	Earring	Hellenistic (4nd - 3nd century BC)	Higgins 1961, 47, No. H; Ogden 1982, Pl. 9; Ergil 1983, 25, No. 27; Kasapoğlu 2012, 204, Fig. 254; Kayalar 2019, 39, Fig. 18
K.88.39.89	Earring	Hellenistic (3nd - 2nd century BC)	Ergil 1983, 30, No. 38
K.1164	Earring	Roman (1nd - 2nd century AD)	Higgins 1961, 54, No. F; Ergil 1983, 44, No. 117
K.28.23.77	Earring	Roman (2nd century AD)	Higgins 1961, 54, No. F; Ergil 1983, 44, No. 117; Sezgin 2014, 89, No. 82
4336	Earring	Roman (1nd - 3nd century AD)	Marshall 1911, LIII, 2486; Ergil 1983, 32, No. 45; Özgülnar 2007, 84, Cat. No. 10-11; Facsády 2008, 239, Fig. 1(a); Uygun 2000, 101, Lev. 23, K13
E.9222	Necklace Pendulum	Classical (5nd century BC)	Baran Çelik and Kiraz 2007, 121
K.209.64.75	Ring	Roman	Form
K.52.44.82	Ring	Late Roman (4nd - 5nd century AD)	Lima 2008, 224, No. 359.
K.38.72.86	Ring	Late Roman-Early Byzantine (4nd - 8nd century AD)	Dimitrov 2011, 70, No. 183
K.140.34.03	Bust	Roman (2nd century AD)	Style features

3. METHODS

The analyses were carried out using non-destructive methods since it is not allowed to take pieces from the artifact and study them using destructive methods. Three analysis methods were applied: Portable Energy Dispersive X-ray Fluorescence Spectrometry (P-EDXRF), X-ray Radiography and proton-induced X-ray analysis μ-PIXE (Proton Induced X-ray Emission, μ-PIXE). Studies on the characterisation of ore frequently employ these microanalytical techniques. These techniques, which are effectively used in the characterization of gold ores, especially refractory gold ores, provide very useful information with high accuracy and sensitivity.

Because of the P-EDXRF method's sensitivity to PPM in non-destructive artifact analysis, its capacity to measure from the surface, and its capacity to identify chemical components, it was selected (Leucci 2019; Afifi et al., 2020; Demortier 2021). Instantaneous analysis results are displayed by this technology, which allows for in-situ analysis without destroying any artifacts during the analysis process (Potts and West 2008; Liritzis and Zacharias 2011; Otsuki et al., 2023). The analysis of the artifacts was carried out with the X-MET 8000 Smart brand portable XRF. This device is small and compact, with a library of 1600 alloy standards. The spectrometer has an energy of 40 eV. Analysis time was determined as 40-60 seconds. The chemical elements and alloys of the artifacts were identified and quantified using XRF analysis. In this way, a single study's many different points were analyzed to obtain data.

X-ray radiography was used to analyze the alloys of the artifacts as well as the photographs of these alloys. The instrumentation of this type of research is very simple. Next to the X-ray source, an object for detecting transmitted radiation, and an X-ray sensitive material; film (translucent plastic) is required (Schreiner et al., 2004; Troalen et al., 2009). Because of the varying absorption of X-ray radiation, the material distribution could be visualized thanks to the different alloys used. This method uses analytical tools to determine the material composition of a small area. By finding discrepancies, i.e. alloys, in the visuals of some of the artifacts under examination, we were able to gain an understanding of the production state, technique and process.

The artifacts' few and lower trace elements were made to determined using the μ-PIXE method. The quantitative and visual outputs obtained during this examination constitute the study's micro-analytical data. In this method achieves lower detection limits by employing protons, which are heavier than electrons. The proton beam generated by the nuclear microprobe (NMP) enters the sample, causing electrons to bounce from the atoms' inner orbits, and analysis is performed by counting the scattered beams with a detector (Halden et al., 1995; Paktunç 1996; Celep 2018).

4. ARCHEOMETRIC ANALYSIS

While ten of the analyzed items are utilized as jewelry, one of them is a bust. The artifacts were grouped according to their forms. The P-EDXRF method was used to determine the alloy and its chemical components. In the artifacts contain Au (gold), Ag (silver), Cu (copper), Fe (iron), Cd (cadmium), Ti (titanium), Ni (nickel), Pb (lead), Si (silicon), Zn (zinc) and Sn (tin) elements have been detected (Table 2). The basic elements are gold, silver and copper (Figure 1). The gold average of all artifacts is 77.7%, the silver average is 11.1% and the copper average is 31.7%. Iron, cadmium, titanium, nickel, lead, and silicon are all trace elements with low abundance (Figure 2).

Table 2. P-EDXRF analysis data (%) and descriptive information of the artifacts.

Inv. Num. / Artifact[1]	Au	Ag	Cu	Fe	Cd	Ti	Ni	Pb	Si	Zn	Sn	Notes
K.53.32.93	97,1	2,8	ND	ND	ND	ND	ND	ND	ND	ND	ND	
K.247.19.73	97,3	1	2,2	0,7	0,9	ND	ND	ND	ND	ND	ND	
K.88.39.89	82,3	11,9	87,2	0,5	ND	ND	0,025	1,9	0,2	8,9	4,1	Bronze raw material and gold plating
K.1164	95,1	2,4	2,1	ND	ND	ND	ND	ND	ND	ND	ND	
K.28.23.77	81,2	4,8	13,8	ND	ND	ND	ND	ND	ND	ND	ND	
4336	96,3	2,3	1,2	ND	ND	ND	ND	ND	ND	ND	ND	
E.9222	84,2	3,1	12,4	ND	ND	ND	ND	ND	ND	ND	ND	Green matte glass and gold plating
K.209.64.75	51,3	1,6	83,3	0,8	0,6	ND	0,4	2,1	0,4	12,9	4,3	Bronze raw material and gold plating
K.52.44.82	86,3	10,7	2,8	0,7	ND	ND	ND	ND	ND	ND	ND	
K.38.72.86	68,2	1,2	82,4	0,8	ND	ND	0,3	2,2	0,8	9,8	6,8	Bronze raw material and gold plating
K.140.34.03	16,3	96,7	1,2	0,6	0,8	1,9	ND	ND	ND	ND	ND	

[1] Artifacts; They were examined according to their forms: head jewelry (six earrings), hand jewelry (three rings), neck jewelry (necklace pendulum) and bust.

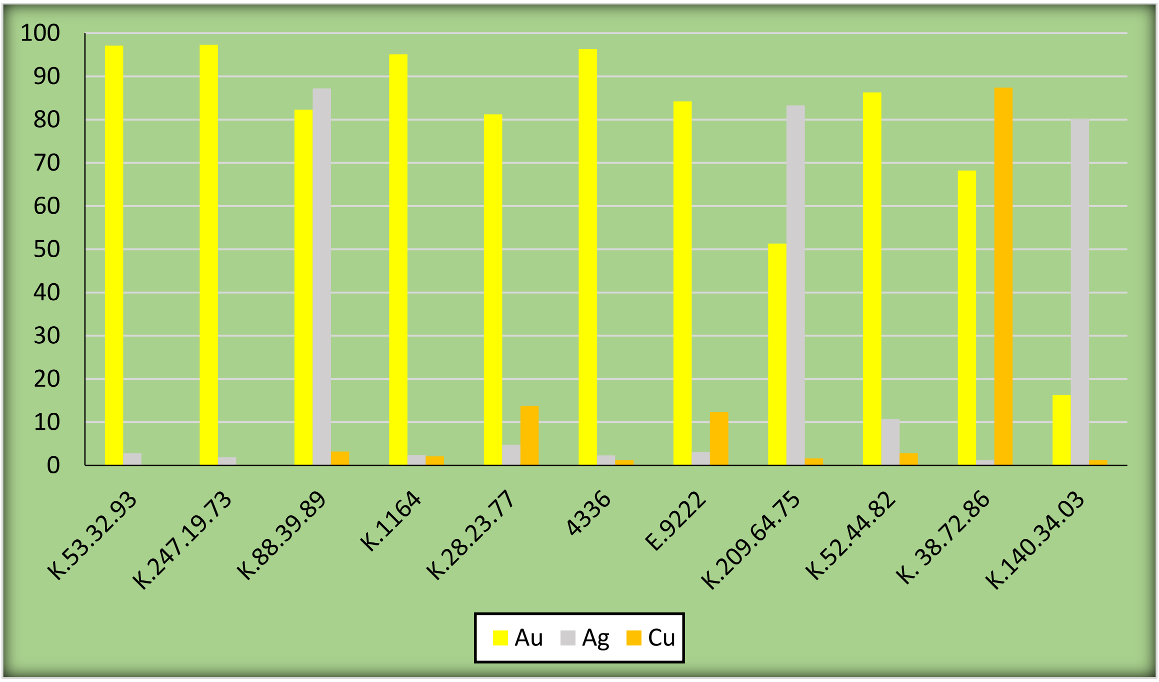

Figure 1. The basic alloys detected in the artifacts by the P-EDXRF method (%)

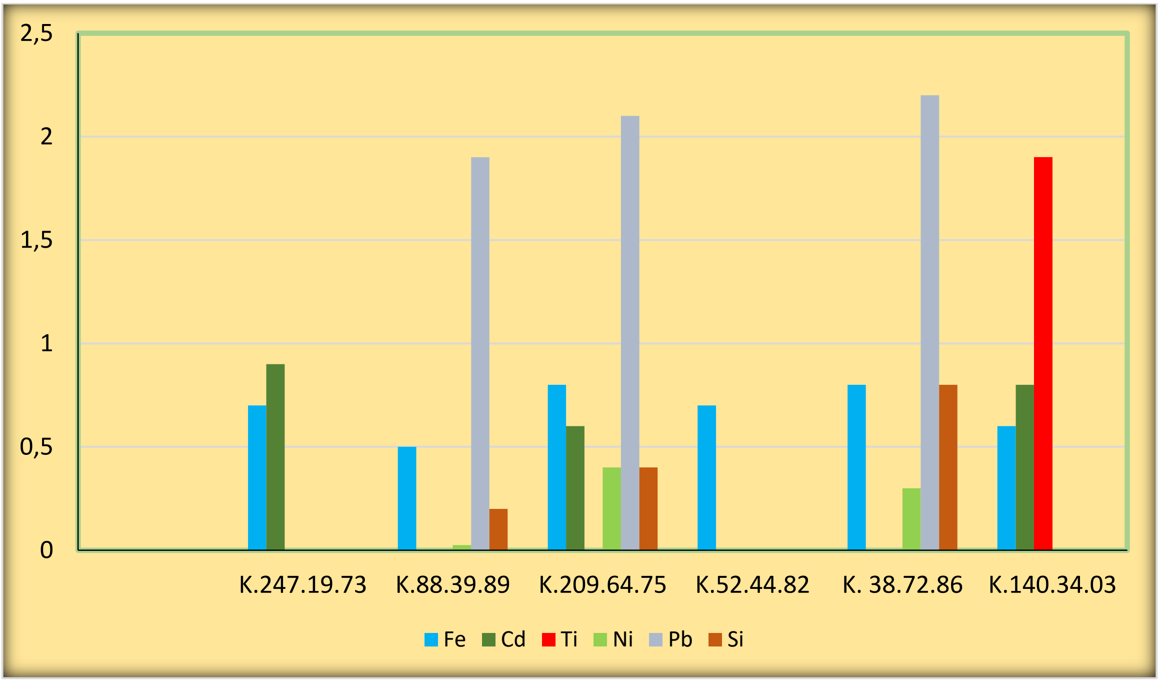

Figure 2. The few and low trace elements detected in the artifacts by the P-EDXRF method (%)

Techniques like casting, engraving, wire, filigree, and granulation were applied in the artifacts. The developments that occurred during the craftsmanship of decorations made with filigree and granulation techniques include important analysis results. Thanks to P-EDXRF, X-ray Radiography and µ-PIXE methods, the intense and different elements used in melting and soldering on the artifacts and the color change caused by these elements are remarkable. It has been determined that the ornaments created made this techniques are soldered using alloys of copper and silver. These two techniques (filigree and granulation techniques) are achieved by joining decorations to a metal sheet using soldering techniques or copper salt (Lilyquist 1993; Köroğlu 2004). The condition of the solders and the alloy ratio employed in the study's subject artifacts were ascertained by using the µ-PIXE analysis method (Figure 3). According to the analysis results, it was revealed that copper alloy was mainly used in soldering: 2.2% in the artifact numbered

K.247.19.73 (earring); 9.8% in the artifact numbered K.88.39.89 (earring); 1.6% in the artifact numbered K.1164 (earring); 10% in the artifact numbered K.28.23.77 (earring); 10.4% in the artifact numbered E.9222 (earring); 2.4% in artifact numbered K.38.72.86 (ring). The average proportion of copper used in soldering is 6.06%.

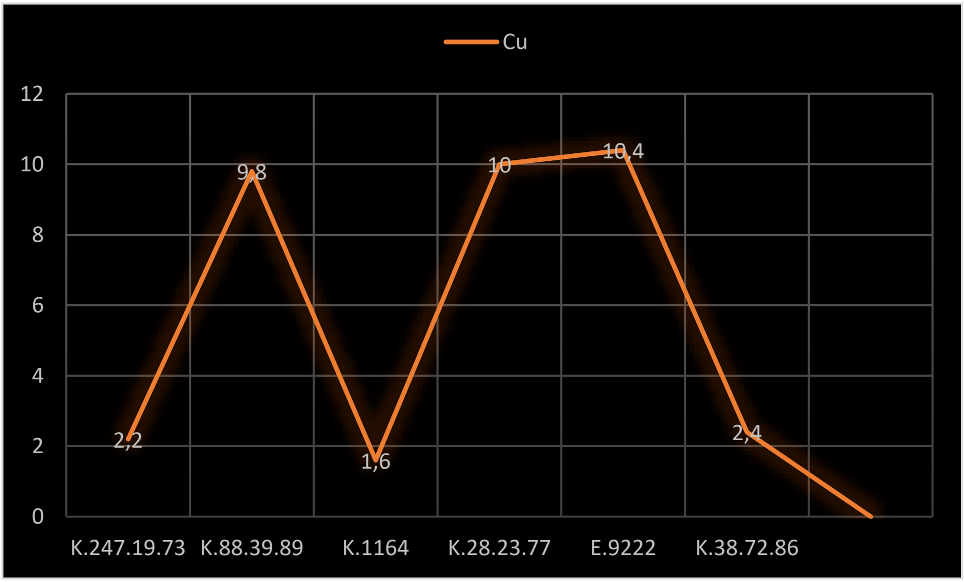

Figure 3. The proportional detection of copper solder in artifacts using the μ-PIXE analysis method (%)

The artifact numbered K.53.32.93 (earring) (Fig.1) is an earring and belongs to the Iron Age. The gold rate is 97.1%, the silver rate is 2.8%. The artifact numbered K.247.19.73 (earring) is an earring and belongs to the Hellenistic Period. The gold rate is 97.3%, the silver rate is 1%, the copper rate is 2.2%, the iron rate is 0.7% and the cadmium rate is 0.9%; the iron and cadmium are few and trace elements. The artifact numbered K.88.39.89 (earring) is an earring and belongs to the Hellenistic Period. It is gold plated over bronze. The gold ratio is 82.3%, silver ratio is 11.9, copper ratio is 87.2, iron ratio is 0.5%, nickel ratio is 0.025, lead ratio is 1.9%, silicon ratio is 0.2, zinc ratio is 8.9 and tin ratio is 4.1%; the iron, nickel, lead and silicon are few and trace elements. The artifact numbered K.1164 (earring) is an earring and belongs to the Roman Period. The gold rate is 95.1%, the silver rate is 2.4% and the copper rate is 2.1%; the silver and copper are few and trace elements. The artifact numbered K.28.23.77 (earring) is an earring and belongs to the Roman Period. The gold rate is 81.2%, the silver rate is 4.8% and the copper rate is 13.8. The artifact number 4336 (earring) is an earring and belongs to the Roman Period. The gold rate is 96.3%, the silver rate is 2.3% and the copper rate is 1.2%; the silver and copper are few and trace elements. The artifact numbered E.9222 is a necklace pendulum and belongs to the Classical Period. Green matte glass is gold plated. The gold rate is 84.2%, the silver rate is 3.1% and the copper rate is 12.4. The artifact numbered K.209.64.75 (ring) is a ring and belongs to the Roman Period. It is gold plated over bronze. The gold rate is 51.3%, silver rate is 1.6%, copper rate is 83.3%, iron rate is 0.8%, cadmium rate is 0.6%, nickel rate is 0.4%, the lead rate is 2.1%, the silicon rate is 0.4%, the zinc rate is 12.9% and the tin rate is 4.3%; the silver, iron, cadmium, nickel, lead and silicon are few and trace elements. The artifact numbered K.52.44.82 (ring) is a ring and belongs to the Late Roman Period. The gold rate is 86.3%, the silver rate is 10.7%, the copper rate is 2.8% and the iron rate is 0.7; the iron is a few and trace element. The artifact numbered K.38.72.86 (ring) is a ring and belongs to the Late Roman-Early Byzantine Period. It is gold plated over bronze. The gold rate is 68.2%, silver rate is 1.2%, copper rate is 82.4%, iron rate is 0.8%, nickel rate is 0.3%, lead rate is 2%, the silicon rate is 0.8%, the zinc rate is 9.8% and the tin rate is 6.8%; the silver, iron, nickel, lead and silicon are few and trace elements. The artifact numbered K.140.34.03 (bust) is a bust and belongs to the Roman Period. The gold rate is 16.3%, the silver rate is 96.7%, the copper rate is 1.2, the iron rate is 0.6%, the cadmium rate is 0.8% and the titanium rate is 1.9%; the copper, iron, cadmium and titanium are few and trace elements. The artifacts are composed of gold, silver, and copper. This alloy is similar to the results of archaeometric analyses of gold jewelry from the Hellenistic and Roman periods (Buccolieri et al., 2017).

According to the analyses, especially when looking at the chemical components of the artifacts numbered K.53.32.93 (earring), K.247.19.73 (earring), K.88.39.89 (earring), K.1164 (earring), K.28.23.77 (earring), 4336 (earring), E.9222 (necklace pendulum), and K.52.44.82 (ring), the gold ratio appears to be high. The artifacts with gold content of 97.3% (K.247.19.73), 97.1% (K.53.32.93), 96.3% (4336), and 95.1% (K.1164) are close to pure gold. It is thought that the artifacts containing especially 97.3% (K.247.19.73) and 97.1% (K.53.32.93) gold were made of natural gold ore. Historically, artifact numbered K.53.32.93 belongs to the Iron Age, artifact numbered 4336 belongs to the Classical Period, artifact numbered K.247.19.73 belongs to the Hellenistic Period and artifact numbered K.1164 belongs to the Roman Period.

The characteristics of the following samples as pure gold or natural gold ore are closely related to the artifacts that are our subject of study. Similar features were discovered in the analysis results of gold objects dated to the second half of the 7th century BC and the first half of the 6th century BC recovered from the excavations of the Temple of Artemis in Ephesus, as well as gold jewelry in Ephesus (Melcher et al., 2009). The earring from the 7th century BC in Diyarbakır Museum (Inv. No. 15.35.75, gold rate 97.2%) and Roman Period (Ring, Inv. No. 23.1.09, gold rate 99.5%; Earring, Inv. No. 10.30.97, gold rate 99.1%) were found to be made of pure gold, similar to the examples mentioned above (Gündem and Aydın 2021). Archaeological museums at Milas, Bodrum, Izmir, Çanakkale, Tekirdağ, and Istanbul have artifacts from the Hellenistic and Roman periods with similar alloy ratios of pure gold (Gündem and Aydın 2021; Aydın's Unpublished Databank). There are also artifacts made of pure gold in the Taranto Museum in Italy (Buccolieri et al., 2017). The gold artifacts unearthed during the studies carried out in Ephesus regarding pure gold in Anatolia are remarkable. The fact that the gold purification process was not yet known at the time these artifacts were created prompted scientists working in the temple to speculate that Ephesos may have had a gold purification refinery. However, no evidence of the refinery has been discovered in ongoing investigations to far. This situation increases the likelihood that gold separation is accomplished through salt cementation (Melcher et al., 2009). It is also possible to use gold ore found in pure form in nature. The discovery of the purification of the gold ratio, which was done at Sardis in the 6th century BC, disclosed the control of the golden ratio and the determination of additional alloy elements (Ramage and Craddock 2000).

The silver and copper alloys were used as additives in artifacts numbered K.53.32.93 (earring), K.247.19.73 (earring), K.1164 (earring), K.28.23.77 (earring) and 4336 (earring). The silver average of these artifacts is 2.66% and the copper average is 4.825%. Considering that the artifacts are made of gold and have concave-convex shapes, it is extremely difficult to maintain the form / shape generated without alloys (copper or silver), as gold is a soft and easily malleable substance. It is known that silver and copper alloys harden and strengthen the alloys to which they contribute. Therefore, the amount of silver and copper alloys found in these artifacts indicates that they were utilized to assure the artifacts' durability. In particular, increasing the amount of silver in the alloy composition increases the artifacts' chemical reactivity with the external environment, which will promotethe gold surface enrichment process (Araújo et al., 1993). The amount of silver and copper alloys used in these artifacts is not at a level that would cause the color of the main alloy, which is gold. However, the same situation is not the for the the artifacts numbered K.52.44.82 (ring) and K.28.23.77 (ring).

X-ray radiography examinations have documented that different alloys in these artifacts can be distinguished by the color factor (Figure 4). The silver rate of the first artifact is 10.7%, while the copper rate of the second artifact is 13.8%. Due to the mixture of these alloys, it was determined that the first artifact had a greenish color and the second artifact had a reddish color. The same colors were determined using a similar analysis procedure on the Taranto Museum's gold earrings numbered Inv. No. 12294A and Inv. No. 12294B, which include silver and copper alloy additions (Buccolieri et al., 2017).

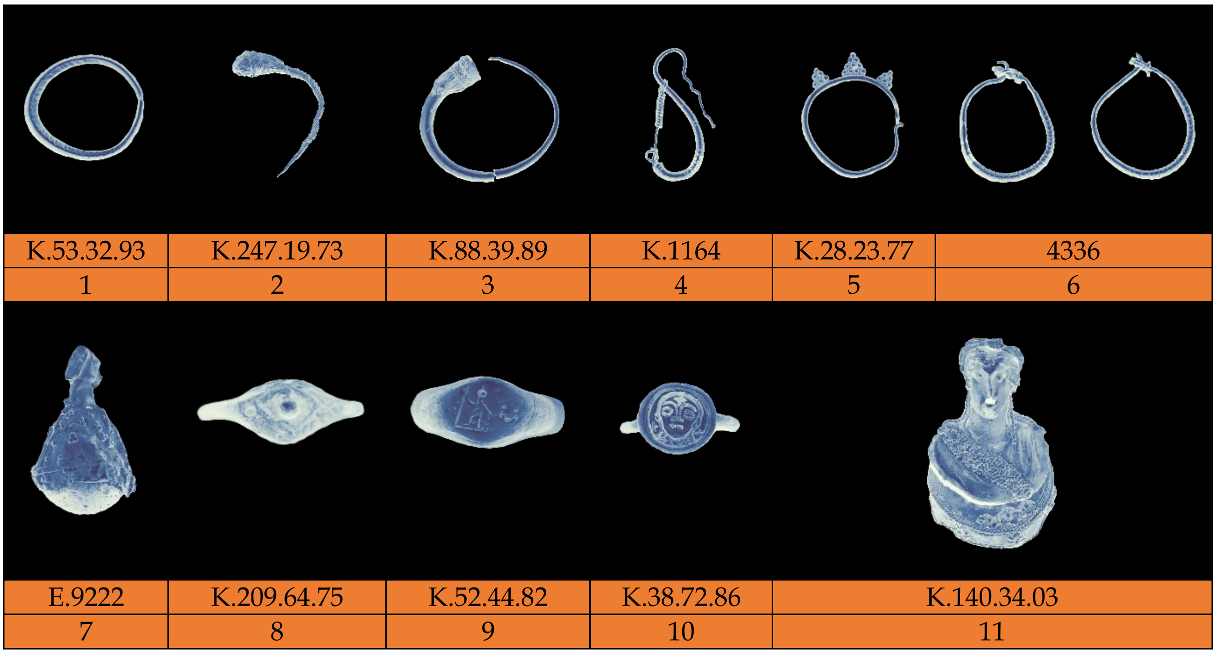

Figure 4. X-ray Radiography of the artifacts.

Using the X-ray radiography method, it was determined that red color was predominant in the cluster decoration / ornament created from spherules made in the granulation technique in the artifact numbered K.28.23.77 (earring) (Figure 5 a). The main reason for this is the copper alloy used at a rate of 13.8%. X-ray radiography showed that the color intensity altered in the area containing the spherules. Therefore, since the spherules were determined to be gold, it was seen that copper was used as solder to fasten them together. According to the µ-PIXE analysis method, the proportion of copper used as solder is 10%. The gold has a lower melting point than copper. For this reason, soldering has been performed with an alloy that has a lower melting point than the alloy to be soldered (Maryon 1949). The hard soldering technique was not used to connect the spherules. If this were done, melting of the spherules would be observed. The technique is mostly seen in Egyptian jewelry. It was determined that the ancient earrings, which were identified as belonging to a child in Qurneh, melted owing to overheating during soldering (Troalen 2009). It is known that the beads found in the Wah tomb were hard soldered by combining copper with the main alloy (Schorsch 1995). In the artifact numbered K.28.23.77 (earring), a very important addition detail was detected by X-ray radiography method (Figure 7b). It was determined that there was a gap in the part of the earring that was concave from the front and convex from the back, and this place was filled by adding a small piece of gold. Because this place is close to both ends of the earring ring and causes sensitivity when the earring is worn, an attempt was made to reinforce it by soldering an additional component. This is a very important repair trace.

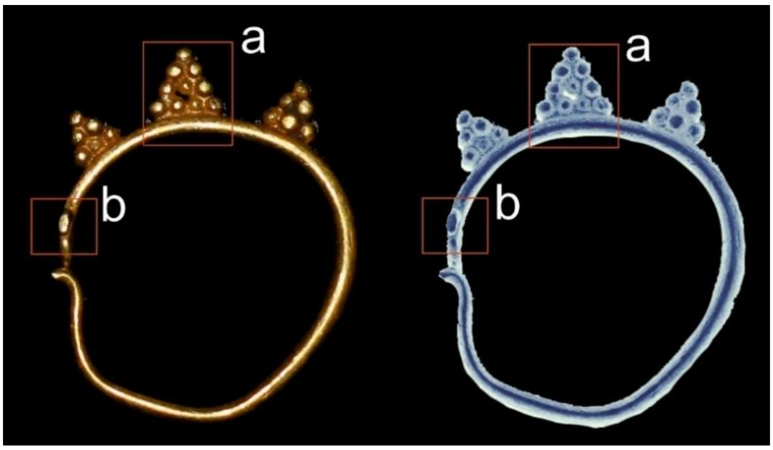

Figure 5. a-b. µ-PIXE analysis, X-ray radiography, and soldering traces (K.28.23.77, earring)

The lion shaped earring numbered K.247.19.73 (earring) was made with hard soldering due to the use of filigree technique. According to μ-PIXE analysis, the copper rate used for solder in this artifact is 2.2%. The area created by combining (repair) two gold pieces of different sizes on the lion's head is remarkable. The degradation or missing portions that were most likely caused by casting were repaired using the soldering process (Figure 6).

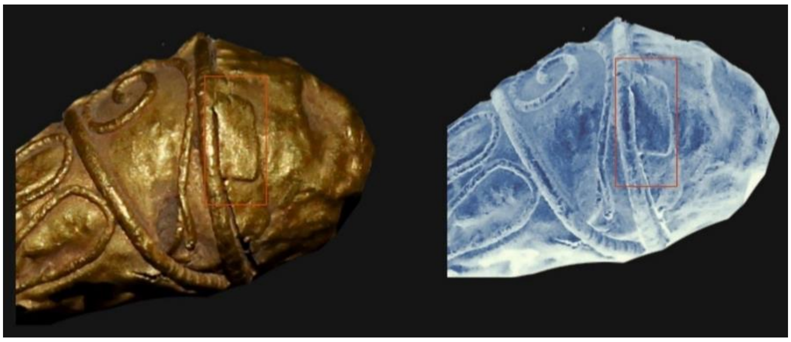

Figure 6. 8. μ-PIXE analysis, X-ray radiography, and soldering traces (K.247.19.73, earring)

It was discovered that soldering occurred where the double-loop hook of the earring number K.1164 (earring) meets the lower section of the hoop. According to μ-PIXE analysis, the copper rate used for solder is 1.6%. It has been determined that melting occurs due to overheating during the soldering process (Figure 7 9).

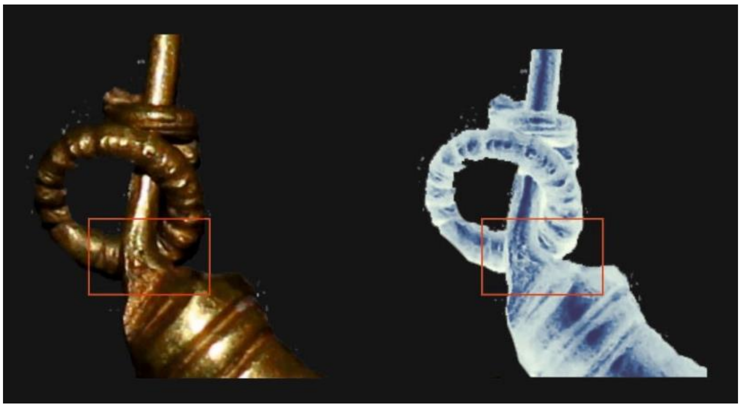

Figure 7. 9. μ-PIXE analysis, X-ray radiography, and soldering traces (K.1164, earring)

Artifacts numbered K.247.19.73 (earring), K.209.64.75 (ring) and K.52.44.82 (ring)contained few and low trace elements; these are cadmium and iron. The low proportions of these elements may be due to the tools used during the mechanical cleaning of the artifacts rather than the alloys utilized in their manufacture. Iron and cadmium were found in artifacts numbered Inv. No. 5.2.03, Inv. No. 10.30.97, Inv. No. 38.6.08, and Inv. No. 21.9.84 from the Roman Period in the Diyarbakır Museum. These are thought to be the outcome of mechanical cleaning (Gündem and Aydın 2021). Soil residues were discovered in the artifacts with the numbers K.247.19.73 (earring), K.1164 (earring), and K.28.23.77 (earring) because of their form and technical attributes. Iron and calcium traces were found in the earring with the number K.247.19.73. These traces, however, are insufficient to indicate that the manufacturer's activities throughout the production phase are to blame.

The necklace pendulum with the number E.9222 is a piece of Classical Period. Green matte glass is gold plated. The additives of glass are silicon, soda, lime and copper. The gold rate is 84.2%, the silver rate is 3.1% and the copper rate is 12.4%. It is possible to say that the reddish hue is more noticeable because of the copper used. In the examination made by X-ray radiography method that some decorations created using the granulation technique had color variations surrounding them. While this change is slight in some places, it is intense in others. Thus, based on the copper ratio in this instance, it is considering that the ornaments were soldered onto the gold plating. According to the μ-PIXE analysis, 10.4% copper rate is used in solder. At the junction of the gold employed as the glass's covering, dense solder traces were detected. It was found that the soldering was quite basic and careless; the mastery is not very good. Because at this stage, the artifact's aesthetics have been superseded by the solder's appearance (Figure 8).

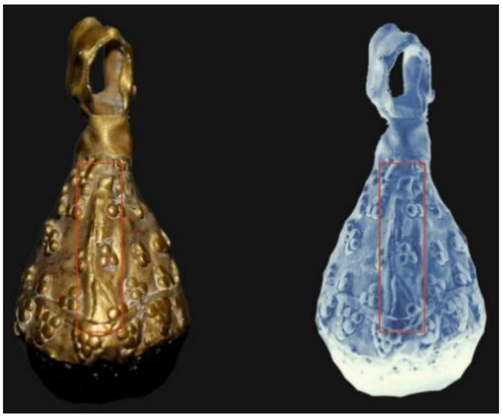

Figure 8. μ-PIXE analysis, X-ray radiography, and soldering traces (E.9222, necklace pendulum)

The artifacts numbered K.88.39.89 (earring), K.209.64.75 (ring) and K.38.72.86 (ring) belong to the Hellenistic, Roman and Byzantine periods, respectively. Especially the use of tin and lead alloys together with copper is an important feature of Roman and Byzantine bronzes (Facsády and Verebes 2009). These artifacts are crafted from bronze that has been gold-plated. The artifacts numbered K.88.39.89 (earring), K.209.64.75 (ring) and K.38.72.86 (ring) are gold plated on bronze. According to analysis data, the artifacts have gold plating with a thickness of 0.7, 0.9 and 1.0 microns, respectively. It will be observed that, in comparison to other gold artifacts under investigation, the color of the gold employed as the plating alloy has lost its original color and taken on a matt appearance. The main reason for this is the mixture of copper, zinc and tin that forms the main body of the artifacts. The plated gold ratios of the artifacts are 82.3%, 51.3%, and 68.2%, while the copper ratios are 87.2%, 83.3%, and 87.4%, respectively. In the examination of the artifact numbered K.88.39.89 using X-ray radiography, it was observed that the 11.9% silver alloy created a greenish hue. In addition, it was determined that the ornaments created using granulation and filigree techniques were soldered with copper thanks to this analysis approach. The gold used as coating in the artifact numbered K.209.64.75 (ring) has been greatly corroded. Using X-ray radiography, traces of copper solder were found on the artifact's ring portion. In this regard, it is understood that the wax cylinder method was not used to create the ring. The depiction on the ring stone of the artifact numbered K.38.72.86 (ring) was made by engraving. It was determined using X-ray radiography method that the area where the ring joins under the ring stone had changed color, and that this was a copper alloy that ensures the integration, or soldering, of the metal. It was determined that hard soldering was done here. According to the μ-PIXE analysis, 2.4% copper rate is utilized in solder (Figure 9).

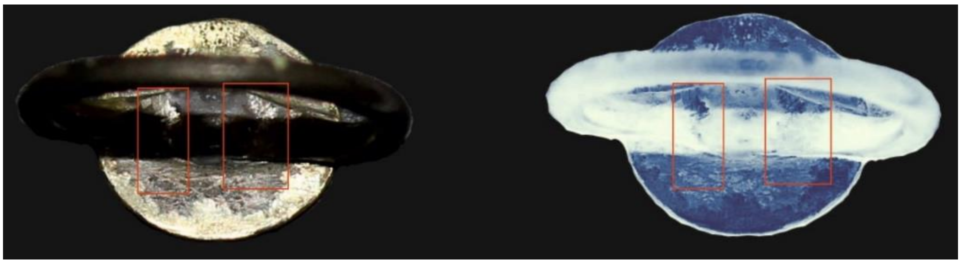

Figure 9. μ-PIXE analysis, X-ray radiography, and soldering traces (K.38.72.86, ring)

These artifacts contain few and low trace elements. These are iron, cadmium, nickel, lead and silicon. These elements were mostly encountered in the parts of the artifacts that employed engraving and granulation techniques. The elements' ratio suggests that they were most likely passed through the mechanical cleaning chemicals and instruments used to clean the artifacts. It is also possible that these elements originate from intercrystalline corrosion. Traces of iron oxide and calcium carbonate were also found in the analysis. It is also thought that iron may only exist as an impurity or perhaps due to corrosion. It doesn't appear that these three artifacts can be directly dated to a particular era. Because the possibility of the material being recycled is always a question mark. However the amounts of alloy revealed in the study of the research done on these artifacts appear to provide some insight into this matter. While the copper content of the artifacts is 87.2%, 83.3% and 82.4%, respectively, the zinc rate is 8.9%, 12.9% and 9.8%. The difference between copper and zinc is approximately 80%. The average of zinc and tin alloys of the same artifacts is approximately 15%. The data here shows that recycling metal allows the use of cheaper alloys produced by adding copper and then using these alloys with other alloys to produce artifacts. So it can be said that there is a secondary production. Examining the lead, zinc, tin, and copper alloys in the artifacts, we find that the copper rate stays high and this rate does not dropping below 80%. However, the actual ratios in which metals alloy vary. This circumstance can be shown as another evidence for recycling. We can give the findings in the Aquincum Museum as the most important and explanatory example on this subject (Facsády and Verebes 2009); the copper-based jewelery pieces from Augsburg have a similar composition and are interpreted as being produced from recycled scrap metal (Facsády and Verebes 2009). Lead was used for casting and connecting complex shapes. This may be partially valid for the part of the earring numbered K.88.39.89 made with the granulation technique. However, when the rings numbered K.209.64.75 and K.38.72.86 are examined, it will be seen that the artifacts were produced in a very simple way, despite the use of lead as the alloy. The increasing demand for inexpensive rings and other jewelry has been satisfied by technological advancements, but these advancements have not been able to create new forms, which explains this situation.

The artifact numbered K.140.34.03 (bust) is silver. The gold rate is 16.3% due to the crown on her head and the beads in her eyes. In this artifact, casting, filigree, engraving and granulation techniques were used together. With this analysis method, it was observed that the decorations, particularly those created using filigree and granulation techniques, were soldered. It is possible to see this soldering process in various parts of the artifact. It has been determined that overheating, particularly when soldering, causes the hair strands at the back of the head to melt (Figure 10).

Figure 10. Workmanship and soldering traces on the head of the artifact numbered K.140.34.03 (bust).

The artifact’s crown was found traces of transparent paste on it. Although this material initially appeared to be the material used by the manufacturer, our research has revealed that the artifact was cleaned using a paste-like solution made in Paraloid B-72 (Figure 11).

Figure 11. Remains of paste used in mechanical cleaning on the gold crown of the artifact numbered K.140.34.03 (bust).

As an example of the material used by the manufacturer; During the examination of an earring (Inv. No. 117 628) in the Taranto Museum, traces of blue glass paste were found. This is associated to the material used by the manufacturer (Buccolieri et al., 2017). There are few and low trace elements. These elements are cadmium, iron, titanium, and copper. It is thought that these such low-rate metals were not added to the alloy consciously and are a part of the chemical materials that were utilized to restoration and conservation the artifact. Even though 1.9% titanium is a member of the few and low trace element group, it can still be used to guarantee that the artifacts are resistant to corrosion and oxidation.

The statistical analysis of the alloys of the artifacts was performed using the SPSS method. Accordingly, when gold and copper data are examined, as well as gold and silver, a negative change stands out. It was observed that when the gold rate was reduced, silver + copper alloys began to be used instead. It was determined that the proportion of gold in the alloys decreased in some Roman and Byzantine artifacts, while the proportion of silver and copper increased in some artifacts. In other words, while silver and copper rates increased, the gold rate decreased. This correlation change was fully revealed by the analysis method (Table 3).

Table 3. Statistical analysis of artifacts with SPSS.

	Au	Ag	Cu	Fe	Cd	Ti	Ni	Pb	Si	Zn	Sn
Average	77,7818	11,1636	26,0364	0,37273	0,20909	0,17273	0,06591	0,56364	0,12727	2,87273	1,38182
Standard Error	7,45651	6,98073	11,3758	0,11045	0,10992	0,17273	0,04294	0,29179	0,07757	1,51021	0,74184
Average Value	84,2	2,8	2,8	0,5	0	0	0	0	0	0	0
Standard Deviation	24,7305	23,1525	37,7293	0,36631	0,36457	0,57287	0,14242	0,96775	0,25726	5,00881	2,46041
Sample Variance	611,596	536,037	1423,5	0,13418	0,13291	0,32818	0,02028	0,93655	0,06618	25,0882	6,05364
Kurtosis	3,32656	10,2736	-0,80129	-2,24183	-0,13535	11	2,79111	-0,66807	4,72668	-0,00817	0,92659
Skewed Value	-1,81534	3,17316	1,13575	-0,04723	1,31858	3,31662	2,02056	1,20857	2,21553	1,33243	1,50074
Range Value	81	78,9	87,2	0,8	0,9	1,9	0,4	2,2	0,8	12,9	6,8
Greatest Value	16,3	1,2	0	0	0	0	0	0	0	0	0
Minimum Value	97,3	80,1	87,2	0,8	0,9	1,9	0,4	2,2	0,8	12,9	6,8
Total	855,6	122,8	286,4	4,1	2,3	1,9	0,725	6,2	1,4	31,6	15,2

4. DISCUSSION AND CONCLUSION

By using the P-EDXRF method, it was found that the alloys of the artifacts that belonged to the Iron Age, Classical, Hellenistic, Roman, and Late Roman-Early Byzantine periods were made of gold, silver, and copper. The gold rates of artifacts numbered K.53.32.93 (earring) (97.1%), K.247.19.73 (earring) (97.3%), 4336 (earring) (96.3%) and K.1164 (earring) (95.1%) are close to pure gold. It is thought that the artifacts numbered K.53.32.93 (97.1%) and K.247.19.73 (97.3%) were produced from natural gold ore. When the gold rate was lowered in the tradition of making gold jewelry, silver + copper alloys were utilized in place of the lowered or reduced rate. It has been observed that in certain Roman and Byzantine artifacts, the proportion of gold in the alloys has decreased, whereas in other artifacts, the proportion of silver and copper has increased. This situation was confirmed by the SPSS statistical analysis method. It has also been established that certain artifacts were created by gold plating on glass, gold plating on bronze, and gold decoration on silver. Gold-plated artifacts have a matte color due to the bronze alloy. The thickness of the coating also plays an important role in this (K.88.39.89 (earring), K.209.64.75 (ring) and K.38.72.86 (ring); 0.7, 0.9, 1.0 microns). Therefore, it has been observed that the use of pure gold decreased with the use of different alloys during the Roman and Byzantine periods. The variety in alloys appears to be influenced by the chronology, object type, and use. The range of alloys that are accessible has increased due to the development of technology for producing gold and the deft application of this technology. The variety of alloys shows that different technologies and skills coexisted during the production periods. This situation manifests itself in the diversity of decorations on the artifacts and in the alloy that allows these decorations to be soldered.

Analyzes using X-ray radiography have documented that different alloys can be distinguished by the color factor. The copper content of artifact numbered E.9222 (necklace pendulum) is 12.4% and the copper rate of artifact numbered K.28.23.77 (earring) is 13.8%. It has been determined that the reddish color stands out in both artifacts due to the copper alloy. A greenish color was detected in the artifact numbered K.52.44.82 (ring) since the silver content was 10.7%. When the type, utilization, and technical qualities of the artifacts are investigated, it is understood that the alloys used here harden and reinforce them. According to the X-ray radiography method, while soldering and hard soldering were arried out in artifacts where copper and silver alloys were widely utilized, melting happened in some artifacts due to overheating during soldering. These artifacts were produced using casting, filigree, engraving and granulation technique: K.28.23.77 (earring), K.247.19.73 (earring), K.1164 (earring), E.9222 (necklace pendulum), K.209.64.75 (ring), K.38.72.86 (ring) and K.140.34.03 (bust). It is noteworthy that in the artifacts numbered K.247.19.73 and K.28.23.77, faults, distortions and deficiens caused by technical manufacture were soldered with copper using gold pieces. As a result of the analysis, it was determined that these defects were caused by the manufacturers. The ratio of solder alloys in these artifacts was determined by the μ-PIXE analysis method. The average proportion of copper used in soldering is 6.06%. The rate of copper used in soldering and the traces on the artifacts revealed the function and state of soldering and hard soldering. It has been found that hard soldering occurs, particularly in decorations formed with filigree and granulation techniques, as a result of soldering and overheating. This also demonstrates the manufacturer's masterfully application of gold jewelry making techniques and skills in joining techniques. Working with alloy wires is akin to the technique of ancient Egyptian goldsmiths, who used the granulation technique and expertly applied joining techniques. Gold-plated bronze artifacts numbered K.88.39.89 (earring), K.209.64.75, and K.38.72.86 were analyzed using X-ray radiography and are thought to be recycled jewelrys, that is, secondary manufacturing. The copper content of the artifacts is 87.2%, 83.3% and 82.4%, respectively, while the zinc rate is 8.9%, 12.9% and 9.8%. The difference between copper and zinc is about 80%. The average of zinc and tin alloys of the same artifacts is around 15%. Given that the main alloy of the artifacts is bronze, it proves that this alloy may be combined with different alloys to create jewelry. Because when we examine the copper, zinc, tin, and lead alloys in the artifacts, the copper rate remains high and does not drop below 80%. However, the actual proportions of alloying metals vary. This can be demonstrated as another evidence of recycling. When the rings of the artifacts numbered K.209.64.75 and K.38.72.86 are examined, it will be seen that they are simple manufacturing products. This phenomenon can be explained by the fact that technological advancements have matched the growing demand for low-cost rings and other jewelry, but have been unable to produce new forms. The residues left on the artifacts by the materials used during mechanical cleaning in the museum were determined using the analysis methods described above. These are defined as few and low trace elements. It is noteworthy that the paste-like solution created in Paraloid B-72, which was found to have been employed during the cleaning of the artifact K.140.34.03, was detected. This residue is not related to the material used by the manufacturer during manufacturing.

Historically, these works can be dated from the Iron Age to the Early Byzantine Period. Since the artifacts are recorded in the museum inventory through purchase, it is not possible to say anything definitive about their origin (place of production). However, it is possible to make some comments based on analogical and typological comparison examples. The earrings in Catalog 2.1 are closely similar to the examples in the Pamphylia (Perge), Lycia (Patara), Troas (Parion), Galatia (Ancyra), Cilicia (Silifke), Ionia (Ephesus) regions, as well as the Anatolian Civilizations Museum, the Tokat Museum and the Istanbul Archaeological Museum. It is also similar to the Royal Ontario Museum and British Museum examples. A necklace pendulum similar to the one in Catalog 2.2 is found in Lydia (Sardis). Examples of rings similar to those in Catalog 2.3 have been found in Bulgaria (Chirpan Heights) and Italy (Rome). The bust in Catalog 2.4 is dated according to its stylistic features. In the light of this information, it is possible to think that the works could be produced in Anatolia. Because it is known that gold was intensively processed and turned into various objects during the Roman Period in Anatolia. Of course, it is also possible that the works came to the Pisidia Region from outside Anatolia. In this case, it can be said that political, military and socio-economic developments have a significant impact. Here, the existence of relations between the Mediterranean and Anatolia as well as the Mediterranean and Pisidia constitutes important data. The close similarity of the soldering workmanship in the artifacts to the artifacts in Egypt suggests that they may have been found in the region due to the developments between the Mediterranean and Anatolia.

As a result, it is important to preserve these artifacts in museums, archive them, and display them following archeometric research. It is essential to record the results and create antique jewelry databases. By creating this information, we may learn more about the development of jewelry craftsmanship and the application of period technologies, as well as help curators better comprehend artifacts in museums.

ACKNOWLEDGEMENTS

We would like to thank Burdur Museum Director Murat Kaleağasıoğlu for allowing the gold jewelry in this study to be examined and published. We would like to thank museum staff Uğur Biçer and Mustafa Çidem for their support in laboratory studies at the museum. We would like to thank Prof. Dr. Rıdvan Karapınar (Department of Nanotechnology, Burdur Mehmet Akif Ersoy University, Turkey) and Restorer Yeliz Öztuna (from the Phocaea excavations) for their support in interpreting the analysis of the artifacts. Also, I would like to thank Lecturer Özgür Durmuş (Depatment of Finance-Banking and Insurance Department, Pamukkale University) and Lecturer Tahsin Avcı (Depatment of International Trade and Logistics, Pamukkale University) who conducted the SPSS statistical analysis of the artifacts.

Author Contributions: The contribution rate of both authors to the article is equal. The analysis, data transfer and evaluation of the works of artifacts were carried out by the first author. The second author prepared the catalog of the artifacts.

Conflict of Interest: The authors declare that they have no conflict of interest.

REFERENCES

Afifi, H. Etman, M. Abdrabbo, H., and Kamal, H. M. (2020). Typological Study and Non-Destructive Analytical Approaches Used for Dating A Polychrome Gilded Wooden Statuette at the Grand Egyptian Museum. *Scientific Culture*, 6(3), pp. 69-83. DOI: 10.5281/zenodo.4007568

Araújo, M. F. Alves, L. C., and Cabrai, J. M. P. (1993). Comparison of EDXRF and PIXE in the analysis of ancient gold coins. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, Vol. 75, 1-4, pp. 450-453. DOI: https://doi.org/10.1016/0168-583X(93)95694-Z

Aydın, M., The Portable XRF-Databank of Metal Finds after Various Archaeological Sites and Periods in Anatolia (*Unpublished Databank*).

Baran Çelik, G., and Kiraz, M. (2007). Metal Objects Collection: Beads, Pendants, Amulets and Statuettes. In Beads: Faith, Power and Beauty. M. Karalom (ed). pp. 23-199. İstanbul.

Buccolieri, A. Castellano, A. Degl'Innocenti, Cesareo, E. R. Casciaro R., and Buccolieri. G. (2017). EDXRF analysis of gold jewelry from the Archaeological Museum of Taranto, Italy. *X-Ray Spectrom*, 46, pp. 421-426. DOI: https://doi.org/10.1002/xrs.2761

Celep, O. Baş, A. D. Yazıcı, E. Y., and Deveci, H. (2018). Altın Cevherlerinin Karakterizasyonunda Kullanılan Mikro Analitik Yöntemler / Micro-Analytical Methods Used in Characterization of Gold Ores. *Bilimsel Madencilik Dergisi*, 57(4), pp. 281-298. DOI: https://doi.org/10.30797/madencilik.479520

Demortier, G. (2021). Non-Destructive Study of Gold Artefacts with Prompt Atomic and Nuclear Methods. *Scientific Culture*, 7(3), pp. 13-40. DOI: 10.5281/zenodo.4916515

Dimitrov, Z. (2011). Трако-римски династичен център в района на Чирпанските възвишения, М. Тонкова (Редактор). Архитектурни детайли от община Братя Даскалови – сведения за античната селищна система в района на Чирпанските възвишения (122-128), София.

Ergil, T. (1983). Küpeler İstanbul Arkeoloji Müzeleri Küpeler Kataloğu. İstanbul: Güzel Sanatlar Matbaası.

Facsady, A. R. (2008). Earings on Stone Monuments frpm Pannonia. In THIASOS Festschrift für Erwin Pochmarski zum 65. Geburtstag. C. Franek, S. Lamm, T. Neuhauser, B. Porod, K. Zöhrer (ed.). pp. 229-242. Wien.

Facsády, R. A., and Verebes, A. (2009). Analysis of Roman Bronze Finger Rings from Aquincum. *Materials and Manufacturing Processes*, 24, pp. 993-998. DOI: https://doi.org/10.1080/10426910902979942

Frantz, J. H., and Schorsch, D. (1990). Egyptian Red Gold. *Archeomaterials*, 4, pp. 133-152. https://www.academia.edu/18045245/Egyptian_Red_Gold

Gündem, E., and Aydın, M. (2021). Archaeometric Characterization of A Group of Gold Jewelry from the Diyarbakır Archaeological Museum. *TÜBA-AR*, 24, pp. 93-103. DOI: https://doi.org/10.22520/tubaked2021.24.005

Halden, N. M. Campbell, J. L., and Teesdale, W. J. (1995). PIXE Analysis in Mineralogy and Geochemistry. *The Canadian Mineralogist*, 33, pp. 293-302. https://www.researchgate.net/publication/266496635.

Higgins, R. A. (1961). Greek and Roman Jewellery. Great Britain: Butler & Tanner Ltd.

Janssens, K., and Van Grieken, R (editors) (2004) Non-destructive Micro Analysis of Cultural Heritage Materials. 1st Edition, Volume 42, Elsevier Science.

Kasapoğlu, H. (2012). Antik Troas'ın Parlayan Kenti Parion 1997-2009 Yılları Yüzey Araştırmaları, Kazı ve Restorasyon Çalışmaları. In Takılar. C. Başaran (ed.). pp. 197-232. İstanbul: Yapıkredi yayınları.

Kayalar, A. İ. (2019). Examination of the Jewelery Found in the Museum of Anatolian Civilizations. Gazi University Institute of Social Sciences, (Unpublished Master Thesis), Ankara.

Koçar, N. (2011). An Analysis on Roman Period Jewelry: Example of Roman Period Jewelry from Antalya Museum. Süleyman Demirel University Institute of Social Sciences, (Unpublished Master's Thesis), İstanbul.

Köroğlu, G. (2004). *Anadolu Uygarlıklarında Takı / Jewelry in Anatolian Civilizations*. İstanbul: Ege Yayınları.

Leucci, G. (2019). Nondestructive Testing for Archaeology and Cultural Heritage. A Practical Guide and New Perspectives. New York: Springer.

Lilyquist, C. (1993). Granulation and Glass: Chronological and Stylistic Investigations at Selected Sites, ca. 2500-1400 B.C.E. *Bulletin of the American Schools of Oriental Research*, 290-291, pp. 29-94. https://doi.org/10.2307/1357319

Lima, M. A. (2008). Ornamenta romana, in Pulcherrima Res 2008: 193-225.

Liritzis, I. Laskaris, N. Vafiadou, A. Karapanagiotis, I. Volonakis, P. Papageorgopoulou, C., and Bratitsi, M. (2020). Archaeometry: An Overview. *Scientific Culture*, 6(1), pp. 49-98. DOI: 10.5281/zenodo.3625220

Liritzis, I., and Zacharias N. (2011). Portable XRF of Archaeological Artifacts: Current Research, Potentials and Limitation's. *In X-Ray Fluorescence Spectrometry (XRF) in Geoarchaeology*. M. Steven Shackley (ed.). pp. 109-142. New York, London: Springer. Online press: DOI:10.1007/978-1-4419-6886-9_6

Marshall, F. H. (1911). Jewellery Greek, Etruscan and Roman in the Departments of Antiquities British Museum. London: Printed by order of the Trustes.

Maryon, H. (1949). Metal Working in the Ancient World. *American Journal of Archaeology*, 53(2), pp. 93-125. DOI: https://doi.org/10.2307/500498

Melcher, M. Schreiner, M. Bühler, B. Pülz, A. M., and Muss, U. (2009). Investigation of Ancient Gold Objects From Artemision at Ephesus Using Porteble μ-XRF. *ArcheoSciences*, 33, pp. 169-175. DOI: https://doi.org/10.4000/archeosciences.2172

Müller, R. (2010). Die Gräberfelder vor der Südm auer der Befestigung von Keszthely-Fenékpuszta, CAs tellum Pannonicum PEL Sonense (1). Budapst: Verlag Marie Leidorf Gmbh.

Ogden, J. (1982). Jewellry of theancient World. London: Trefoil Books.

Otsuki, A. Jose, S. Mohan, M., and Thomas, S. (2023). Non-Destructive Material Characterization Methods. Elsevier B.V.

Özgülnar, N. (2007). Jewelery Found in Perge Excavations. Istanbul University Institute of Social Sciences, (Unpublished Master's Thesis), İstanbul.

Paktunç, D. (1996). Yerbilimlerinde Mikroanalitik Yöntemler / Microanalytical Methods in Earth Sciences. Jeoloji Mühendisliği Dergisi, 46, pp. 41-49. https://www.jmo.org.tr/resimler/ekler/a5c79b1eaf15445_ek.pdf

Potts, P. J. and West, M. (2008). Portable X-Ray Fluorescence Spectrometry Capabilities for In Situ Analysis. Cambridge: RSC publishing. DOI: https://doi.org/10.1039/9781847558640

Ramage, A., and Craddock, P. (2000). Archaeological Exploration Of Sardis-King Croesus' Gold. London: British Museum Press.

Schorsch, D. (1995). The gold and silver necklaces of Wah: a technical study of an unusual metallurgical joining method. In Conservation in Ancient Egyptian Collections. C. Brown, F. Macalister and M. Wright (ed.). pp. 127-135. London: Archetype Publications.

Schorsch, D. (2001). Precious-Metal Polychromy in Egypt in the Time of Tutankhamun. *Journal of Egyptian Archaeology*, 87, pp. 55-71. DOI:10.1177/030751330108700106

Schreiner, M. Frühmann, B. Jembrih-Simbürger, D., and Linke, R. (2004). X-Rays in Art and Archaeology: An overview. *International Centre for Diffraction Data*, 47, pp. 1-17. DOI: https://doi.org/10.1154/1.1649963

Sezgin, N. (2014). Metal Jewelery in the Museum of Anatolian Civilizations. Gazi University Institute of Social Sciences, (Unpublished Master's Thesis), Ankara.

Troalen, L. G. Guerra, M. F., Tate, J., and Manley, B. (2009). Technological study of gold jewellery pieces dating from the Middle Kingdom to the New Kingdom in Egypt. *ArcheoSciences, Revue d'archéométrie*, 33, pp. 111-119. DOI: https://doi.org/10.4000/archeosciences.2095

Uygun, Ç. (2016). Silifke Müzesi'nden Mitolojik Figürlü Kameolar ve Gemmeler. *Cedrus,* 4, pp. 219-242. DOI: 10.13113/CEDRUS/201613