Identification of technological methods of manufacturing bronze jewellery from the Teishebaini burial site (Armenia) by means of X-ray analysis

Hakob Simonyan [1], Vardan Margaryan [2], Yury Cherepennikov [2,3], Arus Shahverdyan [2], Nikolay Filatov [3], Vahan Kocharyan [2]

[1] Yerevan State University, Alek Manukyan 1 Building, Armenia, 0025, Yerevan - haksimon@gmail.com
[2] Institute of Applied Problems of Physics NAS RA, Hr. Nersessian Street 25, Yerevan, 0014, Armenia
[3] National Research Tomsk Polytechnic University, Lenina Avenue 30, Tomsk, 634050

Keywords: Micro-Computed Tomography, X-ray Fluorescence, Bronze Jewellery, Culture Heritage, Teishebaini.

Abstract

Urartian metallurgy remains a critical area of study for understanding the production of metal artefacts in the Ancient Near East during the first half of the first millennium BC. Excavations conducted between 2013 and 2016 by the Research Center for Historical and Cultural Heritage of the Ministry of Culture of the Republic of Armenia (scientific director: Professor Hakob Simonyan) at the newly discovered necropolis of Teishebaini (Karmir Blur)—the northern "capital" of the Urartian Kingdom—uncovered over 280 burials and yielded several hundred metal artefacts. These include bronze jewellery, weapons, horse harness and chariot fittings, seals, and various personal and ritual items. Published studies have primarily focused on the most artistically refined metal objects of the Van Kingdom, often commissioned by Urartian royalty and nobility and produced in court workshops by highly skilled artisans. However, to gain a comprehensive understanding of Urartian metalworking traditions, it is essential to examine a broader spectrum of artefacts that were in everyday use among the vast empire's diverse population. To address this gap, we selected a representative set of metal artefacts from a "closed" context—jewellery items found together in a single burial (Burial No. 12). These artefacts were analysed to investigate their manufacturing techniques and elemental composition using X-ray-based methods. Specifically, two bronze bracelets and a necklace were examined through X-ray fluorescence (XRF) and X-ray micro-computed tomography (μCT). The XRF analysis revealed significant heterogeneity in the distribution of copper and tin, indicating variations in alloying practices or manufacturing processes. μCT imaging provided high-resolution visualizations of internal structures, offering valuable insights into the production techniques and craftsmanship employed by Urartian metalworkers.

1. Introduction

The Teishebaini necropolis, located in the southwestern district of modern Yerevan, Armenia, represents a key archaeological component of the ancient Urartian city of Teishebaini (Karmir Blur). Excavations conducted between 2013 and 2016 by the Scientific Research Center of Historical and Cultural Heritage uncovered over 280 burials, largely contemporaneous with the city's occupation in the 7th century BC. The site had been preserved beneath 2–3 meters of later construction debris.

Situated on a plateau overlooking the Hrazdan River—referred to as the Ildaruni in Urartian cuneiform sources—the necropolis lies south of the city's citadel, which once stood on a promontory at the river's edge. The ancient city itself, characterized by rectilinear streets and planned architecture, extended southward from the citadel. Beyond the unfinished southern fortification walls, in what is now a built-up area containing modern infrastructure and an active cemetery, the extensive necropolis once served the population of Teishebaini. Figure 1 shows a photograph of the excavated city with various sections of the urban layout marked.

Burial No. 12 is situated between tombs No. 5, 7, 8, and 21, in the central section of the excavated necropolis. Figure 2 shows the plan of the necropolis; Figure 3 presents a photograph of the excavated site. The preserved oval cromlech arch, constructed from medium-sized river stones, measured 246 × 200 cm. This structure was partially destroyed by the construction of later cromlechs, suggesting that this area was a prestigious burial zone characterized by a dense arrangement of tombs and repeated burial activities over time.

Archaeological analysis of the burial inventory in the vicinity of Burial No. 12 indicates that new interments were conducted after relatively short intervals – within a span of several years. The graves were typically filled with small river stones and sealed at the top with a clay-based mortar.

Burial No. 12 contained the skull of a female child, estimated to be approximately 8 years old based on dental and cranial measurements. The lower jaw was absent. Additionally, eight tubular bones from a sacrificed lamb were discovered within the burial.

At a depth of 55.5 cm, positioned beneath the skull, a jagged bronze torc (necklace) made of bronze rod (23 × 19 cm) was recovered. Inside the torc 17 small and one large barrel-shaped bead made of carnelian, two beads of black amber (geshir), and two cylindrical gold beads crafted from thin sheet metal was found.

Beneath one end of the necklace lay a bronze bracelet (Inventory No. 12018, Bracelet #1). To its north, a second bronze bracelet (diameter: 4 cm; Inventory No. 12019, Bracelet #2) was found. Two additional bronze bracelets (each with a diameter of 6 cm), featuring thick bands that tapered into serpentine ends, were located to the south (Inventory Nos. 12020 and 12021, Bracelets #3 and #4, respectively).

The grave itself measured 110 cm in length, 65 cm in width, and 60–85 cm in depth. The burial inventory included six black-polished jugs, one necklace, four bronze bracelets, 17 carnelian beads, two geshir beads (black amber), a terracotta bead

covered in blue glaze (likely of Mesopotamian origin and later imported), and two gold beads.

The burial rite is notably distinctive: only the skull, without the lower jaw, of the child was interred – suggesting a unique funerary practice.

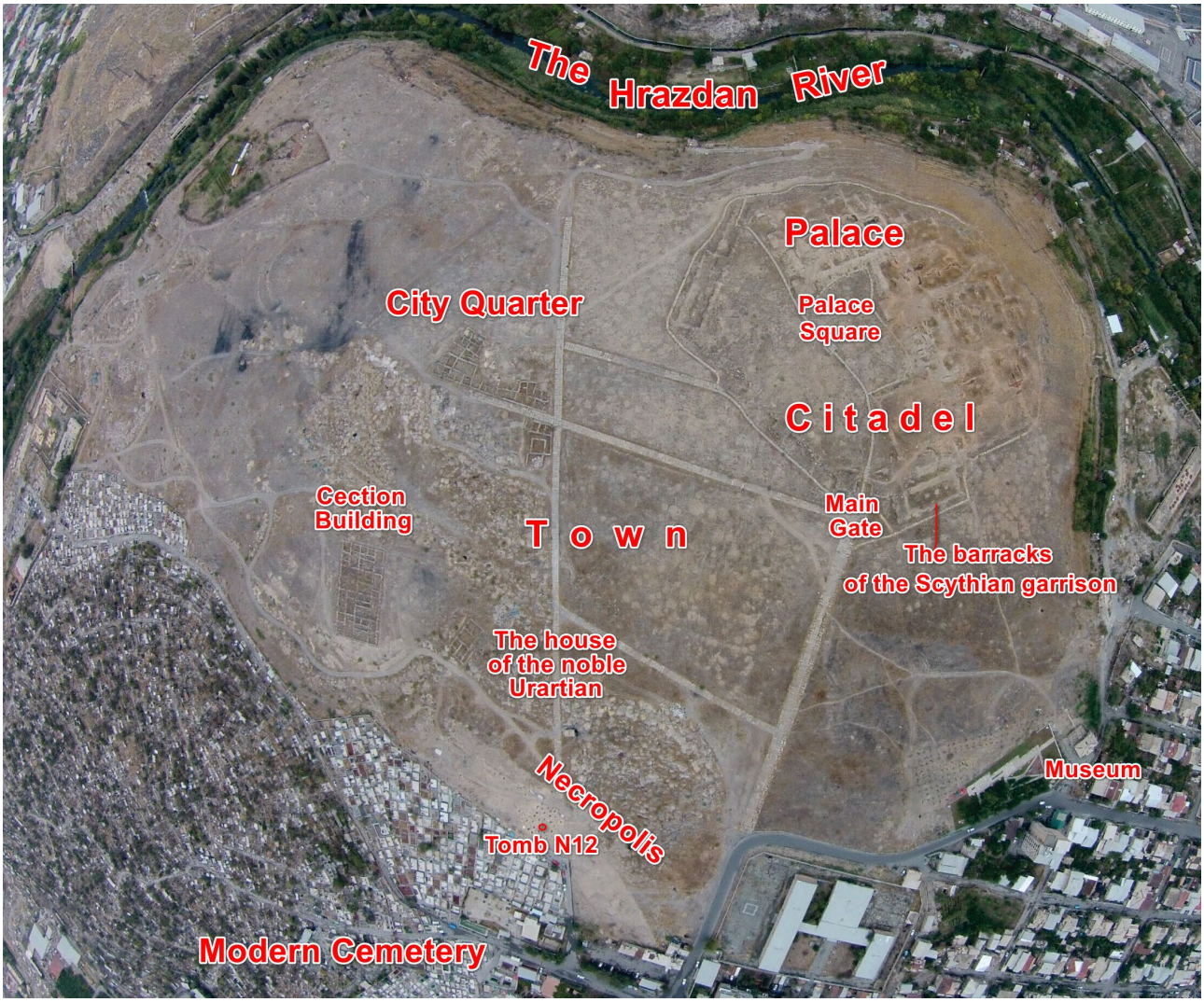

Figure 1. Appearance of the bronze bracelet.

To gain a deeper understanding of the craftsmanship of jewellers and blacksmiths in Ancient Armenia, particularly the Urartian Kingdom period, natural science methods, especially those from physics, are increasingly being employed. X-ray studies have revealed the technical expertise of Urartian craftsmen involved in the creation of bronze jewelleries found in burial No. 12. During this period, a variety of materials and methods were utilized in the creation of jewellery and luxury items, highlighting the existence of diverse local industries. Urartian burials, in particular, contain a wide range of objects made from copper and copper-based alloys, including beads, pins, knives, daggers, harpoons, rings, axes, spears, bracelets, and other artefacts. The study of the materials used in ancient Armenian technology, along with an analysis of the methods employed to process these materials, is crucial for a comprehensive understanding of ancient history (Simonyan et al., 2023). Such studies provide valuable insights into the emergence and development of both technology and the economy of Ancient Armenia. Therefore, determining the chemical composition of these materials and understanding the methods of their processing grounded in physical analysis are essential for constructing a clear and objective picture of the evolution of ancient Armenian technology.

Radiation-based techniques for the non-destructive analysis of cultural heritage are garnering increasing attention from researchers worldwide. In particular, X-ray fluorescence (XRF) and micro-computed tomography (μCT) are commonly employed to obtain detailed information on the structure and composition of various ancient artefacts (Brunello et al., 2021; Morigi et al., 2010; Ruvalcaba Sil et al., 2010' Vaggelli et al., 2012; Dabagov et al., 2020; Simonyan et al., 2024; Bertrand et al., 2021; Ceccarelli et al. 2022). It is important to note that, compared to conventional destructive methods, X-ray-based analyses offer a more effective and reliable approach. These techniques provide greater potential for obtaining accurate and insightful results, while also preserving the integrity of the original sample.

This study presents an overview of the results obtained from XRF and μCT investigations of a set of bronze jewelleries from the Teishebaini Necropolis (Armenia).

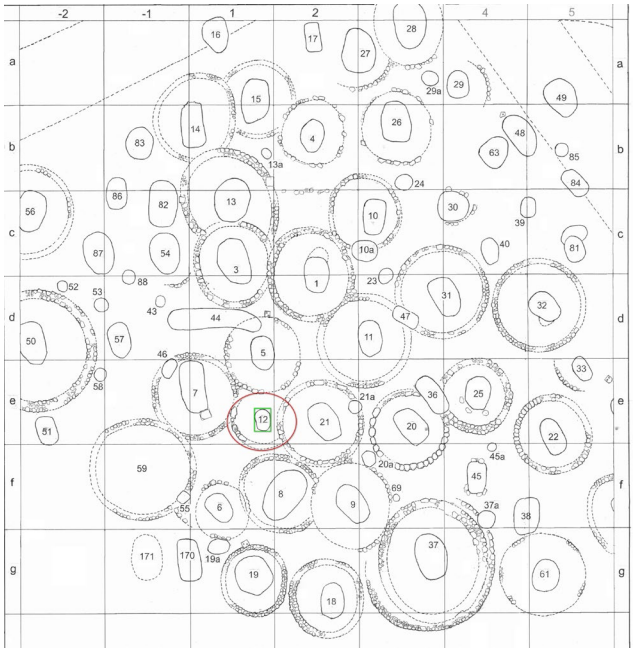

Figure 2. The plan of the Teishebani necropolis

Figure 3. A photograph of the excavated site

2. Experimental studies

Experimental studies were conducted at the Institute of Applied Problems of Physics (Yerevan, Armenia). Two bronze bracelets and a bronze necklace, excavated from burial No. 12, were investigated. Figure 4 shows the appearance of one of the bracelets, while Figure 5 shows a necklace. As seen in Figure 4, this bracelet is decorated with serpentine heads at both ends of the metal rod. The surface of the bracelet is heterogeneous, with varying thicknesses of the patina (coating), a characteristic shared by all the samples examined. However, the roughness differs among the jewellery pieces, which may suggest that blacksmiths of varying skill levels were involved in their production. For instance, a necklace demonstrates particularly fine craftsmanship, with intricate details decorating its outer edge. Nonetheless, the patina layer also varies across this item.

To determine the composition of the jewellery, XRF analysis was conducted using a custom-designed setup featuring a BSV-25 X-ray tube and a silicon drift detector (AMPTEK-SDD). X-ray beam was shaped with two thin slits (vertical and horizontal). The results revealed that the distribution of the two primary components of the bronze alloy (tin and copper) varied significantly, even within a single piece of jewellery. For instance, the tin content could fluctuate dramatically, ranging from 0% to more than 30%, supporting the findings of previous studies (Cherepennikov et al., 2025).

Figure 4. Appearance of the bronze bracelet.

Figure 5. Appearance of the bronze necklace.

Two examples of XRF spectra acquired from different points on a single bracelet are presented in Figures 6, 7. These spectra were corrected for background by subtracting the signal

obtained from our XRF setup in the absence of the investigated object (Figure 8). However, a few parasitic characteristic lines – originating from components of the setup and the X-ray tube anode – are still present in the experimental spectra, likely due to scattering within the analyzed object.

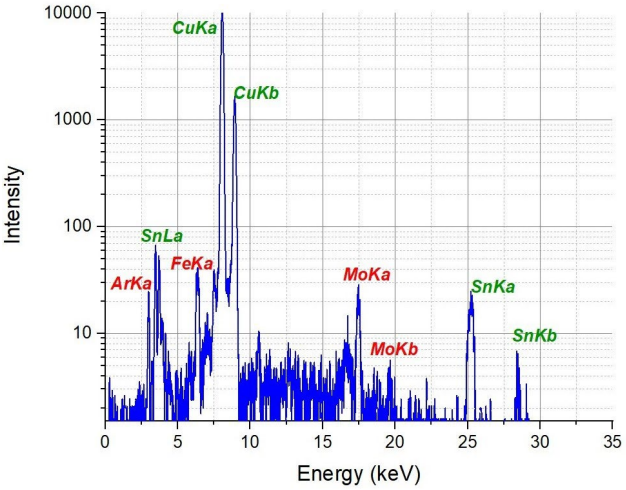

Figure 3. XRF spectrum acquired from the point of the sample with high concentration of tin.

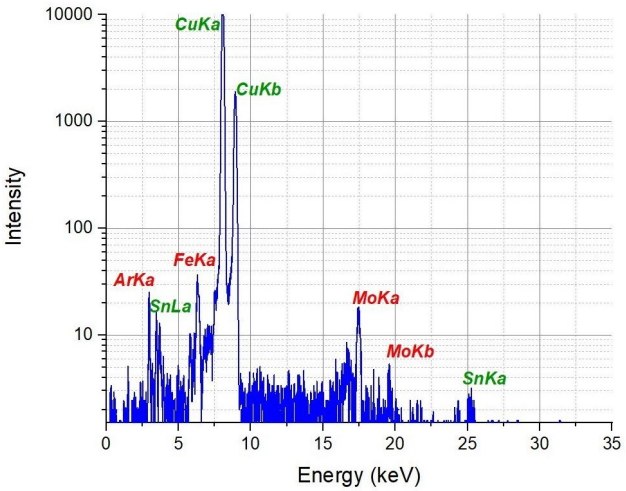

Figure 4. XRF spectrum acquired from the point of the sample with low concentration of tin.

The spectra in Figures 3 and 4 clearly show differences in the intensities of characteristic lines between the two measurement points. At these locations, the tin content was determined to be 28.3% and 3.8%, respectively. It should be noted that, in general, a high concentration of alloying elements such as tin reduces the toughness of metal, making the artifact more brittle. Nevertheless, elevated tin content is not uncommon in archaeological metal artefacts. For example, items with tin concentrations exceeding 27% were found in Scythian-period burials at Ak-Dag (Mitko et al., 2015).

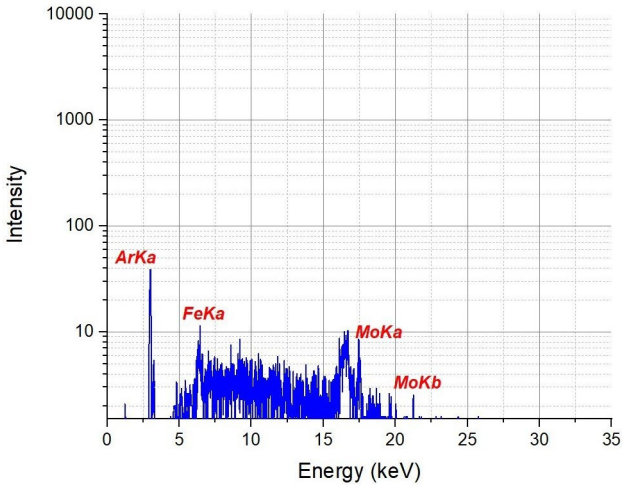

Figure 5. Background spectrum obtained in the absence of the investigated object.

This phenomenon is likely attributable to the relatively low level of metallurgical knowledge of local blacksmith masters, and the lack of precise control over the composition of metal alloys during smelting and alloy preparation.

It is important to emphasize that our experimental setup primarily detects XRF signals generated in the surface and relatively shallow subsurface layers of metal artefacts, due to the high absorption of both primary and secondary X-rays in metallic materials. Furthermore, it should be reiterated that the tin concentration is highly uneven within each of the investigated items, suggesting that ancient blacksmiths likely faced technological challenges during the production of bronze alloys.

MicroCT study was performed using dedicated setup based on X-ray source of XRB150PN6004009 model (Spellman High Voltage Electronics) and CareView 750MT matrix detector (CareRay Digital Medical Technology). The T4 software, developed at Tomsk Polytechnic University, was used to control the MicroCT setup, acquire, and process the experimental data (Information on: https://rsp.tpu.ru/tech/). The obtained results were processed into a series of CT slices, which were then used to create 3D models of the investigated samples (Figure 6). These models enabled a detailed analysis of the structure of the investigated samples. In particular, the bronze bracelets exhibit a distinct layered texture near the surface (Figure 7), which may provide evidence of forging techniques used in the creation of these jewellery pieces.

Performed analysis demonstrates that local blacksmiths also played a significant role in Urartian torievtika (artistic metalwork), in addition to highly skilled court masters. The jewellers made by these blacksmiths was utilised by the common class of the city of Teishebaini. The X-ray analysis of the artefacts' components provides a more comprehensive understanding of the archaeological site, while circumventing the destruction that is frequently associated with traditional methods.

Figure 6. 3D model of bronze bracelet based on CT image.

Figure 7. “Cut” CT image of the bronze bracelet. Layered texture is clearly visible.

3. Conclusion.

During the excavation of burial No. 12, the following assemblage of the burial inventory was recovered: five bronze jewelleries, 19 carnelian beads, one glazed terracotta bead, two black amber (geshir) beads, a lamb sacrifice, and several beads made of a precious metal – gold. This rich burial inventory indicates that the girl interred in this grave belonged to the affluent strata of the urban population of Teishebaini. The ceramic assemblage, characteristic of local, traditional cultural forms, suggests that the deceased was a member of a local ethnic group that had already attained honorary citizenship within the Urartian Empire.

Whereas Urartian toreutics (metalwork) is primarily known from the refined masterpieces uncovered in elite burials and palace contexts, the study of metal jewellery associated with the urban population provides valuable insight into the broader spectrum of metallurgical production within the Urartian Empire. These findings contribute to a more comprehensive understanding of ancient Urartian metal craftsmanship and social stratification.

An X-ray-based study of a set of metal artefacts from a single burial – conducted for the first time – has revealed previously unknown production techniques associated with bronze items, which appear to have been widely employed among the inhabitants of the Urartian state. The metal samples examined were not produced in the royal workshops, but rather by local craftsmen. These artefacts represent a distinct tier of metallurgical production, reflecting the types of objects commonly used by the general population during the second major flourishing of the Urartian Empire under King Rusa II (685–645 BC).

By employing X-ray micro-computed tomography (μCT) and X-ray fluorescence (XRF), we were able to non-destructively examine both the manufacturing methods and material composition of the artefacts. μCT imaging revealed that the artefacts were shaped from forged bronze rods, indicating a specific metalworking practice. XRF results, however, revealed a strikingly uneven distribution of copper and tin – the two primary components of bronze – across the surfaces of the objects. This compositional irregularity suggests a non-homogeneous alloying process and raises important questions regarding ancient metallurgical techniques, trade in raw materials, and technological knowledge within non-elite production contexts. These findings merit further investigation and comparison with materials from both elite and non-elite contexts across the Urartian cultural sphere.

Obtained results underscore the importance of analysing the full volume of metal artefacts, as surface sampling alone may not reflect internal composition – something not feasible through traditional destructive techniques. The study highlights the clear advantages of X-ray–based methods in archaeological research, offering a more holistic view of artefact production. Moreover, the results suggest that, in addition to elite court artisans, local blacksmiths were actively involved in producing bronze jewellery in Teishebaini. The stylistic and technical characteristics of the pieces indicate that they were likely intended for everyday use by the city’s broader population.

Acknowledgements

We gratefully acknowledge all our colleagues for their assistance in preparing this study, especially archaeologist Levon Mkrtchyan, artist Taguhi Hmayakyan, Elena Atoyants and Liana Zhamagortsyan, who restored the artefacts from the excavated burial mound, and Dr. Alexey Gogolev and Sergey Chistyakov for the useful discussions on CT imaging and processing.

This work was supported by the Science Committee of Republic of Armenia, Research project N◦ 23RL-1C037.

References

Simonyan, H., Areshian, G. 2023: Empire Beyond its Palaces: New Discoveries at the Urartian Necropolis of Karmir-Blur (Armenia). *Proceedings of the International Congress on the Archaeology of the Ancient Near East Proceedings of the 12th ICAANE 2021, Bologna*, 2, 587-602.

Brunello, V., Canevali, C., Corti, C., De Kock, T., Rampazzi, L., Recchia, S., Sansonetti, A., Tedeschi, C., Cnudde, V. 2021: Understanding the Microstructure of Mortars for Cultural Heritage Using X-ray CT and MIP. *Materials*, 14(20). https://www.mdpi.com/1996-1944/14/20/5939.

Morigi, M.P., Casali, F., Bettuzzi, M., Brancaccio, R., d'Errico, V. 2010: Application of X-ray computed tomography to cultural heritage diagnostics, *Appl. Phys.* A 100

Ruvalcaba Sil, J.L., Ramírez Miranda, D., Aguilar Melo, V., Picazo, F. 2010: SANDRA: a portable XRF system for the study of Mexican cultural heritage, *X Ray Spectrom.* 39 (5), 338–345.

Vaggelli, G., Cossio, R. 2012: μ-XRF analysis of glasses: a non-destructive utility for cultural heritage applications, *Analyst* 137 (3), 662–667. http://dx.doi.org/10.1039/C1AN15518K.

Dabagov, S.B., Hampai, D., Guglielmotti, V., Cappuccio, G., Capitolo, E., Gladkikh, Y. 2020: X-ray applications and recent advances@ XLab Frascati, *Rendiconti Lincei. Sci. Fis. Nat.* 31 (2), 443–453.

Simonyan H., Kocharyan V., Margaryan V., Minasyan E., Cherepennikov Y. 2024: XRF and μ-tomography investigations of gold jewellery from the Middle Bronze Age from the Nerkin Naver burial mound (Armenia), *Int. Arch. Photogram. Rem. Sens. Spatial Inf. Sci.* 48, 123–128.

Bertrand L., Thoury M., Gueriau P., Anheim ´E., Cohen S. 2021: Deciphering the chemistry of cultural heritage: targeting material properties by coupling spectral imaging with image analysis, *Accounts Chem. Res.* 54 (13) 2823–2832.

Ceccarelli S., Redi M., Terrei A., Orazi N., Guglielmotti V., Hampai D., Dabagov S., Mercuri F. 2022: Colour characterisation for the restoration of a Japanese handscroll, *SCIRES-IT-SCIentific RESearch and Information Technology* 12 (2), 109–118.

Cherepennikov, Y., Margaryan, V., Shahverdyan, A., Kocharyan, V., Trouni, K., Mkrtchyan, L., Simonyan, H. 2025: X-ray tomography and spectroscopy applications for revealing ancient metalworking techniques. *Nucl. Instrum. Methods Phys. Res. A.*, 1075, 170359.

Mitko, O.A., Panov, V.S., Teterin, Yu.V. 2015: bronze composition of artifacts from the Ak-Dag I burial ground of the Scythian period in Tyva. Vestnik Novosibirskogo gosudarstvennogo universiteta. Seriya: Istoriya. Filologiya, 14(5), 37-41. (in Russian)