Abstracts

GENERAL

Bourgarit, D., Bassett, J., Bewer, F. B., Heginbotham, A., Lacey, A., & Motture, P. (Eds.) (2025). Guidelines for the technical examination of bronze sculpture. Los Angeles: J. Paul Getty Museum. https://www.getty.edu/publications/resources/virtuallibrary/9781606066928.pdf

This illustrated volume offers a new framework for advancing the understanding of bronze sculpture, explaining how to identify the evidence of process steps, metals used, casting defects, surface work and alterations before moving on to address analytical techniques ranging from visual examination to imaging, material analyses, and dating.

Ashkenazi, D., & Cvikel, D. (2025). The use of advanced technologies and novel processes for the metallurgical study of metal objects retrieved from shipwrecks. *Metallography, Microstructure, and Analysis*. https://doi.org/10.1007/s13632-025-01185-3

The metallurgical characterisation of artefacts from shipwrecks requires a multidisciplinary approach. Advanced non-destructive testing (NDT) rather than destructive techniques is preferred to minimize any potential damage. Innovative techniques were developed for NDT of copper-alloy and ferrous artefacts retrieved from shipwrecks. Included are advanced methods of multifocal light microscopy, field multifocal metallography, and chemical cleaning and conservation techniques. Details of composition, microstructure, and manufacturing processes were revealed which also contributed to their dating. The results from NDT methods were consistent with those obtained by destructive methods.

Lin, J., Liu, S., Zou, G., & Cui, T. (2025). Unveiling diverse copper trace element profiles from a single smelting site through laser ablation-inductively coupled plasma-mass spectrometric analysis. *Archaeometry*. https://doi.org/10.1111/arcm.13077

Trace element profiling has been widely used to reveal the origin and mixing history of archaeological bronzes. However, due to the lack of chemical charactersation of raw copper from smelting sites, there has been little understanding of the variation of trace element concentrations within a single copper source. This has significantly confined discussion on copper circulation in prehistoric societies. A method was developed to analyse copper prills embedded in smelting slag based on laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) and tests showed that a relative error of less than 20% can be achieved for most elements with an appropriate choice of analytical parameters and reference materials. The method is used to analyse the Early–Middle Shang (1500–1200 BC) period copper smelting slag from the site of Tongling in northern Jiangxi province, China. The results show that the copper smelted with different ores from the same site has systematically different trace element characteristics. Copper prills from this site are highly varied in terms of Ag, Ni, Co, As, and Bi content. When plotting Tongling prills together with the bronze artifacts from the Panlongcheng site, also in the Middle Yangtze River valley, it is found that the trace element concentrations of these two sites correspond well with each other, and the Panlongcheng bronzes, with highly varied trace element profiles, could have been manufactured with copper from one source. This analysis demonstrates the potentially heterogeneous nature of the copper trace element profiles produced at a single smelting site and calls for more analyses of copper prills using LA-ICP-MS to establish a new foundation for future discussions on copper provenance based on trace element data.

DeCasien, S., Dostal, C., & Grieco, G. (2025). An experimental archaeological project in recreating an ancient bronze naval ram. *Journal of Archaeological Science* 178, 106217. https://doi.org/10.1016/j.jas.2025.106217

Ancient bronze naval rams were used in Mediterranean naval warfare to destroy, swamp, or sink enemy vessels for nearly a millennium (c. 500 BCE–500 CE). This study utilised experimental archaeological methods to reconstruct a ram using shipbuilding and casting techniques reflective of those from Greek and Roman cultures. It represents the first successful casting of a ram in over 1500 years, informed by textual, iconographic, and archaeological evidence. The findings challenge the prevailing assumption that rams were manufactured using sand-casting or indirect lost-wax casting techniques. Instead, this study supports the theory that rams were produced using the direct lost-wax casting method, employing standardized processes, customised to accommodate the specific dimensions of each ship and the appropriate ram size. Furthermore, this experimental project provides critical insights into the process, labor, time, and materials required for ram production, offering a deeper understanding of the socio-economic dimensions of naval warfare in the ancient Mediterranean.

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Haubner, R., & Strobl, S. (2025). Investigations of microstructural changes in tin bronzes during cremation. *Metallography, Microstructure, and Analysis*. https://doi.org/10.1007/s13632-025-01195-1

During the late Bronze Age (ca. 1300–800 BC), cremations took place in Inzersdorf ob der Traisen and bronze artefacts in the urns were heat-treated during the process. Experimental archaeology was used to recreate cremations so that the various microstructural changes in the bronze could be identified. For comparison, ancient bronze artefacts from Inzersdorf ob der Traisen were examined and similar structural changes to those found in experimental cremations were detected. To obtain more precise information about the effects of heat treatment, bronze sheets containing 10 wt.% Sn were annealed in a laboratory furnace at different temperatures and for different times. The heat-treated sheets were examined by metallography, light optical microscope (LOM) and scanning electron microscope (SEM) with energy-dispersive X-ray analysis (EDX). The newly formed microstructures, produced by these experiments, were compared with those of ancient artefacts as well as those from the experimental archaeology samples. It was found that up to 500 °C no visible changes in the bronze structure occurred. At about 800 °C recrystallization of the bronze occurred. Initial melting occurred at 950 °C, which was even more pronounced at 1000 °C.

Smith, R. A., Euser, V. K., Thrun, M., Harvey, M., & Mueller, J. J. (2025). Microstructure, processing, and properties of early twentieth century wrought iron. *Metallography, Microstructure, and Analysis*. https://doi.org/10.1007/s13632-025-01207-0

Wrought iron is known as a material of antiquity, with archaeological evidence of production dating back approximately 5000 years. In the second half of the eighteenth century, wrought iron was produced by a transient liquid phase processing method, known as *puddling*. The historical process of puddling to produce wrought iron and the effects of the process on the microstructure are discussed. Microstructural analysis and mechanical testing were performed on a wrought iron boiler stay-bolt from a steam locomotive built in the early twentieth century. State-of-the-art characterisation techniques revealed the composition, anisotropic microstructure, and chemical distribution in the ferrite and slag. Mechanical testing and fracture analysis indicated anisotropic mechanical performance reflecting the microstructure and processing technology used to produce the wrought iron.

BRITAIN AND IRELAND

Martin, T. F., & Ponting, M. J. (2025). Quality from Kent: Preliminary results from the analysis of fifth- to seventh-century silver alloys. *Archaeometry*. https://doi.org/10.1111/arcm.13092

Early results from the chemical and lead isotope analysis of 30 silver-alloy objects from southeast England dating to between the fifth and seventh centuries CE are reported. The main analysis included a comparison of the results of surface X-ray fluorescence (pXRF) values with the microwave-plasma atomic emission spectrometry (MP-AES) of drilled samples, considering their methodological implications. Proportions of silver, gold and lead derived from the MP-AES results will be investigated in order to model the basic characteristics of the bullion used to create these objects and the recycling practices to which it was subjected. Third, results from stable lead isotope analysis (LIA) will permit some comments on the most likely sources of the silver and the possibility of refinement processes. We offer some preliminary perspectives on the socio-economic implications of these results, insofar as the control and management of precious metals are concerned.

Williams, R. A., Montesanto, M., Badreshany, K., Berger, D., Jones, A. M., Aragón, E., Brügmann, G., Ponting, M., Roberts, B. W. (2025). From Land's End to the Levant: Did Britain's tin sources transform the Bronze Age in Europe and the Mediterranean? *Antiquity* 99(405), 708–726. https://doi.org/10.15184/aqy.2025.41

Bronze Age–Early Iron Age tin ingots recovered from four Mediterranean shipwrecks off the coasts of Israel and southern France can now be provenanced to tin ores in south-west Britain. These exceptionally rich and accessible ores played a fundamental role in the transition from copper to full tin-bronze metallurgy across Europe and the Mediterranean during the second millennium BC. The application of a novel combination of three independent analyses (trace element, lead and tin isotopes) to tin ores and artefacts from Western and Central Europe also provides the foundation for future analyses of the pan-continental tin trade in later periods.

EUROPE

Tomczyk, C., Bernat, A., Belmon, J., & Larousse, N. M. (2024). Geochemical and documentary topography of a medieval silver valley: Detection of workshops and identification of their function. *Archaeological Prospection* 32(2), 345–374. https://doi.org/10.1002/arp.1963

This paper presents the interdisciplinary investigation (archaeology, geochemistry, history) of a medieval silver and lead production site located in southern France, in the Minier valley (Occitanie, Aveyron, Le-Viala-du-Tarn). To identify the production sites, in situ geochemical surveys were carried out using a portable X-ray fluorescence spectrometer and differential GPS, guided by the analysis of medieval archival sources. The cartographic representation of the metal concentrations in the surface horizons indicates significant enrichment of zinc and lead in the vicinity of the mines. This first type of enrichment makes it possible to highlight the activities of the separation of sphalerite and silver-bearing galena. The galena, thus isolated on the hillsides, is then transported to the vicinity of watercourses, where it is crushed, washed, and smelted. These secondary activities result in a last type of enrichment in which only lead is found in large quantities. The cross-referencing of the information made it possible to overcome the challenges related to the location of the mineral processing workshops, which were often invisible on the surface. The medieval workshops have been located and a function suggested, outlining the first trends in the spatial and social division of labour and providing a solid corpus for future archaeological excavations. Finally, this study highlights the per-

sistence of significant metal contamination in the soils of a rural valley and encourages the consideration of former mining areas when examining the environmental impact of metal production.

Jambon, A., Bielińska, G., Kosiński, M., Wieczorek-Szmal, M., Miśta-Jakubowska, E., Tarasiuk, J., & Dzięgielewski, K. (2025). Heavenly metal for the commoners: Meteoritic irons from the Early Iron Age cemeteries in Częstochowa (Poland). *Journal of Archaeological Science: Reports* 62, 104982. https://doi.org/10.1016/j.jasrep.2025.104982

The Częstochowa-Raków and Częstochowa-Mirów cemeteries in S Poland (Hallstatt C period) yielded several dozen iron objects, very few of which have been previously analysed. The pXRF analysis of 26 specimens and SEM-EDS analyses of 3 revealed that three bracelets, an ankle ring and a pin contain meteoritic iron. The other objects were made of smelted iron. This is one of the biggest collections of meteoritic iron products found at one archaeological site worldwide. The presence in the same context of both meteoritic and smelted irons enables us to discuss the role of slag incorporation vs. contamination. The composition of the specimens containing meteoritic iron is quite variable, even in a single specimen, which can be explained by an association with smelted iron. Extensive examinations suggest that a single meteorite was used, possibly a contemporary fall rather than an import, which would confirm that the inhabitants understood the working of iron and also that meteoritic iron no longer had the considerable symbolic value it had in the Bronze Age before the discovery of iron smelting. It was simply used as an iron ore. We suggest that meteoritic iron was deliberately used to produce a specific pattern on iron jewelry a millennium before the supposed invention of wootz and Damascus steel.

Heredia, C., Guédron, S., Gourlan, A. T., Helly, B., Delile, H., Calzolari, L., Campillo, S., Santenac, S., Audin, L., Telouk, P., Albarede, F. (2025). Provenance of lead ores used for water pipes production in the ancient Roman Gaul (Vienne, France). *Quaternary Science Reviews* 353, 109227. https://doi.org/10.1016/j.quascirev.2025.109227

The urban fabric of Roman cities developed through the installation of water supply networks, mainly made of lead (Pb). In Gaul, the city of Vienne (France) was central to the manufacturing of Pb artifacts, including large volumes of Pb water pipes. Roman-period stamps often indicate the location of manufacture but information on the provenance of the Pb ores and how they were imported is limited. In this study, Roman-period artifacts were analysed for Pb isotope signatures to document the source of Pb ore used in Vienne's manufactories. The Pb isotope signatures were compared with new local Pb ores data and an updated Pb isotope database using a new algorithm to identify the provenance of Pb. Results indicate that the lead used at Vienne originates mainly from a single source. Data treatment with the new algorithm identifies the Rhenish Massif and the Pennines mining regions as the primary and most probable sources, but some artifacts exhibit a similar isotope composition to that of local Pb ores. The similarity of the Pb isotopic signatures of the Vienne artifacts with those of Mainz pipes and lead ingots from the Rhenish massif, as well as the synchronicity of the mining periods in this region, support the Rhenish Massif as the most likely source of Pb for Vienne. The Rhine and Saone Rivers are the most probable routes to convey Pb ores to Vienne during the Roman Period.

Valério, P., Monge Soares, R., Monge Soares, A. M., Sousa Gomes, S., & Fátima Araújo, M. (2025). Early Iron Age metal trade networks of the workshop of Cabeço Redondo (southern Portugal). Tracing the origin of lead of ternary bronzes. *Journal of Archaeological Science: Reports* 62, 105045. https://doi.org/10.1016/j.jasrep.2025.105045

Recent research has identified two regions for the supply of copper to the 5th century workshop of Cabeço Redondo (Moura), namely Sardinia and Los Pedroches Batholith complex (Central Iberian Zone). The metal debris recovered by archaeological surveys includes not only copper and bronze ingots and lumps, but also leaded bronze examples, which can help to provenance lead in ternary bronzes. A fragment of a possible ingot and two lumps were characterised by SEM-EDS, ICP-QMS and MC-ICP-MS to establish microstructural features, trace elemental compositions and Pb isotope signatures. The leaded bronze samples show similar microstructural compositions, with a dendritic morphology and $\alpha + \delta$ eutectoid and Pb-rich and Cu-S inclusions. Trace element profiles indicate a higher Ni and As content in the "ingot" and the Pb isotope signature is also significantly different from that of the two lumps, but all of them overlap with lead sources from different regions bordering the Mediterranean Sea. The determination of the nearest Euclidean neighbours and geologic parameters, combined with archaeological and historical data, was used to find the most likely sources of lead of these ternary bronzes. As the lead sources could correspond to regions in the Iberian Peninsula (Ossa-Morena Zone and Alcudia Valley) and the Eastern Mediterranean (Greece and Anatolia) and considering the copper sources of the Cabeço Redondo metallurgical workshop, these new results evidence a complex metal supply system that includes both intra and extra-peninsular trade networks covering both the Western and Central Mediterranean and also Eastern Mediterranean regions.

Moreno-Padilla, M. I., Gutiérrez-Rodríguez, M., Molinos-Molinos, M., Fernández-Casado, R., & Gea Guillén, G. de (2025). Dealing with the archaeological invisibility of the Iberian mints: A technological and contextual analysis of the first stone mould for blank coin production found in Hispania. *Journal of Archaeological Science: Reports* 63, 105083. https://doi.org/10.1016/j.jasrep.2025.105083

Between the 2nd and 1st centuries BCE, a significant number of mints emerged in the Iberian Peninsula, producing coins either continuously or on an ad hoc basis. Despite the large number of workshops, we have little material evidence of their locations beyond the coins themselves, of the mint locations in the ancient towns, the *chaîne opératoire*, or the social organisation around the workshops. In this study, we present a stone mould for blank coin production found in excavations carried out in the Iberian oppidum of Obulco, modern-day Porcuna (Jaén, Spain). Petrographic analysis has documented the local origin of the raw material. Use-wear analysis has shown technical marks associated with its use as a coin mould. μ-XRF analysis of the metallic traces on its surface confirmed that it was used in casting a binary Cu-Pb alloy. This observation fits previous elemental analytical studies of Obulco coins. The metric analysis of the metallic impressions

leads us to propose the production of bronze asses dated to the 2nd century BCE, more specifically between 189/165–146 BCE. The blank coin mould presented in this paper is the only one found so far in the Iberian Peninsula, and also, it is one of the few coin production tools documented in archaeological context. This has implications for the understanding of coinage production processes and locative decisions of mints in ancient Hispania, which are traditionally defined by their archaeological invisibility.

Clemenza, M., Fiorini, E., Marchegiani, F., Nisi, S., Rendeli, M., Trincherini, P. R., & Villa, I. M. (2025). Geochemical and Pb isotopic constraints on the provenance of the Lupa Capitolina bronze statue. *Archaeological and Anthropological Sciences* 17(4), 85. https://doi.org/10.1007/s12520-025-02176-9

Newly re-analysed samples from the bronze statue of the Lupa Capitolina have provided lead isotope and trace element data. The lead isotope results coincide with those previously reported in the literature, but are approximately 20 times more precise. The high-resolution lead isotope analyses and the compositional data, especially lead concentrations higher than those found in copper ores, clearly reveal a mixing trend during the casting process. The addition of lead as a flux makes the lead isotopic composition unsuitable for determining the provenance of the bronze. However, comparisons with available data on bronze artifacts from the same epoch as the Lupa Capitolina statue (11th–12th centuries AD) support evidence of the monopolistic copper trade during the early Frankish and later Germanic imperial periods. Furthermore, element zoning in the Lupa Capitolina highlights details of successive melting within the metallurgical *chaîne opératoire*. Lead and other trace metals may have become enriched at the statue's surface due to slow cooling after casting.

Stróżyk, M., Pospieszny, Ł., Belka, Z., Garbacz-Klempka, A., Silska, P., & Wardas-Lasoń, M. (2025). Tracking bronze age "itinerant smiths" in western Poland: Insights from Nd and Sr isotope data. *Archaeometry*. https://doi.org/10.1111/arcm.13085

The neodymium (Nd) isotope compositions of stone casting moulds found in graves of Bronze Age 'itinerant smiths' in western Poland were analysed to determine the provenance of their raw materials. For the first time in archaeological research, the Nd model age—a highly useful parameter in studying the provenance of geological materials—has been applied. Nd data revealed that the material for making casting moulds came from the Sudetes. Additionally, the results of strontium (Sr) isotope analysis in human remains indicated that the metallurgists were neither born nor spent their early childhood in the areas where they were buried.

Minvielle Larousse, N., Brodie, E., Geltner, G., Gopnik, H., Sanna, F., & Tomczyk, C. (2025). A geochemical survey of the Antas Valley, Sardinia: Medieval metallurgy and modern slag recycling? *Journal of Archaeological Science: Reports* 64, 105114. https://doi.org/10.1016/j.jasrep.2025.105114

Geochemical surveys of the Antas Valley in Sardinia, Italy, have revealed significant zinc and lead concentrations along the Antas River floodplains, suggesting the presence of medieval ore-processing workshops which are otherwise hard to detect. While the zinc concentrations were found to be dispersed and probably related to the erosion of zinc-rich dolomite, the lead concentrations were more localised on the banks of the river, suggesting an anthropogenic origin. Three large concentrations of lead were found to coincide with deposits of black glassy slag, a by-product of ore processing. Analysis of the slag revealed a high lead content (around 75%) and very low zinc content, which along with historical research suggests either medieval ore processing for silver and/or 19th-century slag recycling. The near absence of zinc in the slag supports the 19th-century recycling hypothesis, as this period saw an increased demand for silver, lead and zinc and the development of processes to extract it from older slag. Further research, including dating of the slag and excavation of the lead-enriched areas, is required to confirm the origin of the slag deposits.

Guerra, M. F. (2025). Goldworking in Mycenaean Thessaly: Technological study of the gold objects from the four *tholos* tombs in the bay of Volos. *Journal of Archaeological Science: Reports* 64, 105129. https://doi.org/10.1016/j.jasrep.2025.105129

A first comprehensive analytical study of Mycenaean gold working in the context of the Bay of Volos is offered, based on over 165 gold items from the four *tholos* tombs excavated at Dimini and Volos, including the intact tomb of Kazanaki. Using XRF, PIXE, optical microscopy, SEM and radiography, this work investigates the composition of the alloys and the production techniques used in this significant region of Thessaly. The results indicate regional workshop practices, with uniform production techniques and consistent alloys, probably using alluvial gold. The standardised gold sheet funerary ornaments, showing no wear, were produced in batches. Objects which showed signs of wear were made with the same type of alloys, but using different technologies, suggesting that the gold sheets may have been supplied by centralised workshops. To explore the potential influence of cross-cultural exchange, a comparative analysis with objects from the Argolid was conducted. The 34 gold items analysed in this work and in previous studies reveal distinct differences in alloy composition and production processes. At Prosymna, the reddish-toned gold beads, some repaired, may reflect either direct trade or regional adaptation influenced by external, perhaps Egyptian, aesthetic and skill. Despite some similarities in gold working practices across Mycenaean and Egyptian workshops, Egyptian objects show unique features, such as the presence of visible PGE inclusions, the use of hard-soldering techniques and a broader range of gold hues, which highlight the regional specificity of Mycenaean gold working traditions, particularly in the Bay of Volos.

Tarbay, J. G., Maróti, B., & Braun, M. (2025). Comparative PGAA and LA-ICP-MS analyses of late Bronze Age weapons and armour. *Journal of Archaeological Science: Reports* 64, 105151. https://doi.org/10.1016/j.jasrep.2025.105151

The paper presents the results of elemental composition analyses conducted on Late Bronze Age weapons, armour, and sheet metal objects from Transdanubia (western Hungary). This series of unique bronze objects has been analysed using the bulk, non-invasive Prompt Gamma Activation Analysis (PGAA), and the invasive Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS). Their combined results reveal correlations with previously found and analysed artefacts. A similar amount of Sn was observed in typologically similar finds. The

deliberate use of Sb and Pb is also noted in some of the finds dated between the Ha A and Ha B periods. These elements appear in alloying proportions in spearheads from Budakeszi and Ság Hill, dated to the Ha B1 and Ha B2 periods.

Virág, Z. M., Villa, I. M., Nisi, S., Bajnóczi, B., Mozgai, V., Solnay, E., Kraus, D., Szilas, G., Tóth, F. M., Csippán, P., Siklósi, Z. (2025). The beginning of copper metalworking in the Copper Age of the Carpathian Basin – new data on the provenance of Early and Middle Copper Age copper finds from Western and Central Hungary. *Journal of Archaeological Science: Reports* 64, 105130. https://doi.org/10.1016/j.jasrep.2025.105130

The Carpathian Basin played a crucial role in spreading metallurgical technology across Europe. The significance of the region is exemplified by its abundant copper finds in the Early and Middle Copper Age (4500–3700 cal BCE). On a typological basis, the Great Hungarian Plain was linked to the Southeastern European metallurgical circle, while Transdanubia was linked to the Central European metallurgical circle, thus forming an essential link between the two areas. The provenance of the raw material of the copper artefacts was investigated through the lead isotope and chemical composition analyses of Early and Middle Copper Age copper artefacts from Transdanubia and Central Hungary. The sites were dated using radiocarbon dating. The earliest evidence of local metalworking was identified in Early Copper Age material as tuyères. Artefacts typologically related to the Central European metallurgical circle – specifically, copper discs and spectacle spiral pendants – were manufactured from raw materials sourced from the Northwestern Carpathians. The slag remnants discovered within a Middle Copper Age crucible also originated from this region. During the Middle Copper Age, the use of flat axes crafted from arsenical copper emerged. In addition to the Northwestern Carpathians, the possible exploitation of ore deposits in Northeastern Hungary and the Bihor region has also been proposed.

Kałaska, M., Recław, J., Sierpień, P., Karasiński, J., & Kamenov, G. (2025). Determination of the origin of lead objects from Risan and Riječani (Montenegro) based on lead isotope analysis. *Journal of Archaeological Science: Reports* 64, 105161. https://doi.org/10.1016/j.jasrep.2025.105161

The determination of the origin of raw material is an important aspect of archaeological research. This study attempts to identify the sources of lead ores used to produce lead objects by communities inhabiting the Bay of Kotor and its surroundings between 3 BC and the Middle Ages. The objects come from archaeological sites in Risan and Riječani (Montenegro). Samples were taken from joins of columns and pedestals. One sample was identified as probably recycled, indicated by a significantly increased Sn content. Pb isotopes were measured and the results were compared with literature data for Roman mines from the areas of present-day Algeria, Austria, Bosnia and Herzegovina, Bulgaria, Cyprus, Egypt, France, Germany, Greece, Israel, Italy, Montenegro, Morocco, North Macedonia, Portugal, Romania, Spain, Serbia, Tunisia and Turkey. The results indicate the use of mainly Greek and/or Serbian or Bulgarian deposits. However, a good match to the North Macedonia deposits is also visible. There are also matches to individual deposits from Italy, Romania, Turkey and Tunisia. However, these directions seem less promising due to the long distances and the availability of closer deposits.

Montes-Landa, J., Pons, E., Rovira, C., Moya, A., Alonso, N., & Martinón-Torres, M. (2025). Towards a new history of bronze making: Explaining the selection of tin bronze alloying techniques across prehistoric N.E. Iberia (2100-200BC). *Journal of Archaeological Science* 178, 106206. https://doi.org/10.1016/j.jas.2025.106206

Copper-tin bronzes can be obtained through different techniques (i.e. natural alloying, co-smelting, cementation, co-melting and recycling). This paper presents a methodology and theoretical framework to explain the selection of bronze alloying techniques in different contexts. Northeast Iberia was selected as a case study, comparing slags and slagged technical ceramics from four sites (Minferri, Vilars, Mas Castellar and Ullastret) dated between 2100-200 BC. The materials were analysed using pXRF, OM, SEM-EDS, and ICP-MS. Patterns of choice are considered in relation to the technical affordances of each alloying technique and contextualised within the relevant environmental and socioeconomic parameters. The results show that bronze-making technique choices were primarily dependent on (1) the (in)stability of raw material procurement networks, and (2) the existent selective pressures on performance characteristics for which each technique offered different trade-offs. Discrete combinations of these two variables can explain instances of different techniques co-existing (e.g. Minferri, Mas Castellar, and Ullastret) and cases of commitment to a single one (e.g. Vilars). This is the first diachronic study of bronze alloying practices investigated through direct analyses of bronze-making residues for a given area. The analytical framework employed and the derived behavioural rules can be applied to other case studies to collectively build a multi-path history of bronze alloying development. This will be fundamental to understand the link between bronze alloying technique selection and social change, to better contextualise metal finds within their production and exchange networks, and to requestion existing models of bronze production organisation and technological diffusion across the world.

Ynsa, M., Viñals, S., Pestana, R., Balduz, B., Corregidor, V., & Barrio, J. (2025). Micro-PIXE analysis of metal archaeological pieces from Torre Monreal necropolis. *Journal of Cultural Heritage* 73, 419–425. https://doi.org/10.1016/j.culher.2025.04.025

In 2019, the Torre Monreal necropolis was discovered in the urban centre of Tudela, in the north of Spain (Navarra). This Islamic necropolis has a great number of graves with rich funeral dowries and is, therefore, of high archaeological and historical interest. A number of mainly metallic pieces such as rings, earrings, necklaces, belt buckles, etc., were analysed by Particle Induced X-ray Emission (PIXE), using the external microbeam line at CMAM (Centro de Microanálisis de Materiales in Madrid). Most of the metallic objects with a gilded appearance exhibit Au concentrations higher than 50%, Ag and Hg levels close to 20%, and low or trace concentrations of other elements such as Cu or Fe. The results have been compared with data from other Islamic pieces from the Andalusian city Qalat-Rabah (Calatrava la Vieja) collection which correspond to the same historic medieval period, 13–15th century.

Santo, A. P., Calandra, S., & Cappuccini, L. (2025). Unveiling hidden details of an Etruscan statue: The power of combined pXRF spot and map approach. *Journal of Cultural Heritage* 73, 536–542. https://doi.org/10.1016/j.culher.2025.04.031

Portable X-ray fluorescence spectrometry (pXRF), a non-invasive technique, is increasingly used in the field of Cultural Heritage for multi-element analysis due to its ease of use and no sample preparation, without damaging the original objects. The combined application of spot and map analyses may shed new light on the composition of the studied material. This dual approach is particularly useful, revealing insights inaccessible through spot analysis alone. In this paper, we demonstrated the validity of this approach by analyzing the eyes of an Etruscan statue housed at the National Archaeological Museum in Florence (Italy). The obtained distribution of chemical elements in the eyes enabled the formulation of a hypothesis regarding their manufacturing process.

NEAR EAST

Douglas, K. A., Al-Jahwari, N. S., Vreeze, M. de, Hesein, M., Weeks, L., & Pracejus, B. (2025). Bronze age cymbals from Dahwa: Indus musical traditions in Oman. *Antiquity* 99(404), 375–391. https://doi.org/10.15184/aqy.2025.23

Understanding the development and use of musical instruments in prehistory is often hampered by poor preservation of perishable materials and the relative rarity of durable examples. Here, the authors present a pair of third-millennium BC copper cymbals, excavated at Dahwa, Oman. Although they are the only well-contextualised examples from Arabia, the Dahwa cymbals are paralleled by contemporaneous examples from the Indus Valley and images in Mesopotamian iconography. Not only do the cymbals add to the body of evidence interpreted in terms of Indus migrants in Early Bronze Age Oman, they also suggest shared musical and potentially ritual practices around the Arabian Gulf at that time.

Pagelson, Y., Farhi, Y., Mevorah, D., & Goren, Y. (2025). Iron keys from the Roman province of Judaea/Palaestina: A typological and technological study. *Archaeological and Anthropological Sciences* 17(5), 111. https://doi.org/10.1007/s12520-025-02227-1

In the early 1960s, Yigael Yadin excavated a number of caves at Nahal Hever in the Judean Desert, containing evidence for the final days of refugees from the Bar-Kokhba Revolt against Rome (132–136 CE). The artifacts they chose to take with them into the wilderness were fantastically preserved, including 10 iron keys. Since then, dozens of iron keys have been found in excavations at the region. In this study, we provide a typological analysis of the keys and argue that the diversity of types relate to chronological periods with evident diachronic changes. It is suggested that elbow keys are a local type of Roman Iudaea, with recognisable spatial boundaries, and possibly used solely by the local Jewish population. In addition, we reconstruct how the keys were produced and why, by applying X-ray radiography and metallography. The local smiths utilized easily workable soft iron, in order to fabricate the artifacts' complex shapes. It was also less likely to break, a timeless benefit when it comes to keys.

Abu-Baker, A. N., & Khalil, L. A. (2025). The microstructure and corrosion characteristics of iron-based artifacts from the Khirbet Yajuz archaeological site, Jordan. *Metallography, Microstructure, and Analysis*. https://doi.org/10.1007/s13632-025-01215-0

This study investigated the microstructure and corrosion behavior of iron-based artifacts from the Khirbet Yajuz archaeological site in Jordan. Scanning electron microscopy with energy-dispersive spectroscopy (SEM-EDS) and optical microscopy were used to analyze the elemental composition of the alloy, corrosion layers, and to reveal the microstructure. Microhardness testing was utilized to assess mechanical properties, while energy-dispersive X-ray fluorescence (ED-XRF) and X-ray diffraction (XRD) were utilized to assess elemental and mineralogical composition of corrosion products. SEM-EDS and elemental mapping revealed the alloy composition, presence of slag inclusions, corrosion stratigraphy, and elemental distribution in the layers. Metallography revealed α-ferrite grains, lamellar pearlite aggregates, and slag inclusions in a nail. Similar features were present in an arrowhead, along with intergranular and spheroidized carbides. A bracelet and coffin corner were fully mineralized. Microhardness tests also validated these findings, revealing a predominance of ferrite with minute traces of pearlite and carbides in the alloy, confirming that the artifacts were made of wrought iron. ED-XRF examination identified chloride-containing corrosion products on the nail and arrowhead. XRD confirmed the presence of magnetite (Fe_3O_4), goethite (α-FeOOH), and lepidocrocite (γ-FeOOH) on all the artifacts analyzed, but identified akaganeite (β-FeO(OH,Cl)) only on the nail, which is consistent with the ED-XRF results. The research helped explain the mechanism and condition of corrosion, which showed the need for dechlorination to stabilize certain of the artifacts. Long-term stability requires improved storage with stable low relative humidity.

ASIA

Tan, P., Li, M., Huang, X., & Yang, J. (2025). Technique and utilisation: Characterisation of copper granulation during the Sui and Tang dynasties (581–907 CE). *Journal of Archaeological Science: Reports* 62, 105000. https://doi.org/10.1016/j.jasrep.2025.105000

Granulation is an ancient decorative technique for metalwork where small metal granules are thermally bonded with each other or onto a metal substrate. Granulation in copper has been relatively under-researched due to the scarcity of archaeological findings. However, the ornaments of a gilt female coronet recently uncovered from tomb M11 of the early Tang dynasty (7th century CE) in the Chadaokou Village of Xi'an, Shaanxi, China, provide new insight into this method. Optical microscopic analysis, X-ray radiography, metallographic investigation, and scanning electron microscopy including energy dispersive spectroscopy (SEM-EDS) were carried out on these granulated ornaments to investigate the granule size and distribution, material and microstructure, granule production method, bonding methods, and manufacturing procedures, for clarifying the manufacturing technique of copper granulation. The results show consistency in technical features of the ornaments with other granulated copper artefacts, reflecting technical standards in the produc-

tion of granulated copper objects. The similarity of granulated copper artefacts discovered so far with granulated gold artefacts suggests that the copper items were imitations. Moreover, these copper artefacts, including the ornaments in the current study, demonstrate a close relationship with the ritual systems of the Sui and Tang dynasties and were probably customised by a central government agency, Jiangzuo Jian. This research enhances our understanding of copper granulation technique.

Liu, T., Liu, Z., & Liu, S. (2025). Unveiling Ming vassal policy through the chemical composition analysis of gold enfeoffment books. *Archaeological and Anthropological Sciences* 17(4), 82. https://doi.org/10.1007/s12520-025-02196-5

The ancestral fief system was a traditional Chinese political practice in which the emperor granted his brothers and sons territories as vassal kings—a process known as enfeoffment—to consolidate national stability. Enfeoffment, a term rooted in feudal governance, refers to the formal act of granting land or titles in exchange for loyalty and service. This system reached its peak during the Ming Dynasty (1368–1644 CE), which introduced specific policies for managing vassal kings. Gold enfeoffment books, physical tokens of this system, reflect the Ming government's stance toward vassal kings. Portable X-ray fluorescence spectroscopy was used to analyse twelve gold books given by the Ming royal court to the Rong vassal state, revealing a diachronic change in their compositional characteristics. They were all found to be ternary alloys of Au, Ag, and Cu but show a significant declining trend in their Au content from the Hongzhi to the Chongzhen eras (1501–1634 CE). The compositional changes coincided with the promulgation of the "Regulations of Clans and vassals" during the Jiajing era (1522–1566 CE) and the implementation of the "Fixed Benefits System" during the Wanli era (1573 -1620 CE). The material characteristics of the gold books evidenced the rise, sustenance, and eventual collapse of the ancestral fief system during the Ming dynasty.

Lian, H., Zeng, X., Liang, P., Liu, S., Ran, H., Guo, J., Zhang, J., Mei, J., Chen, K. (2025). Deciphering the origins of Sanxingdui bronzes through petrographic and elemental analysis of casting cores. *Journal of Archaeological Science* 178, 106212. https://doi.org/10.1016/j.jas.2025.106212

Sanxingdui, one of the most significant Bronze Age sites in China, has yielded unique bronze artifacts with varying styles: some exhibit distinct local characteristics, while others resemble central Shang designs, raising questions about their origins. This study applies semi-quantitative petrographic observations and elemental analysis to 39 casting core samples from Pits 1 and 2 at Sanxingdui. The results reveal distinct differences in production techniques and materials between vessel and non-vessel artifacts. Comparative analysis with local soils, sediment, and casting cores from other Chinese bronze production sites suggests that non-vessel bronzes were likely cast locally near Sanxingdui, while vessel artifacts show connections to the middle and lower Yangtze River region. Our findings indicate that Sanxingdui bronzes were part of a larger, interconnected circulation network for bronze products and ores, reflecting complex cultural, technological, and material exchanges with other regions during the Shang period.

Wood, J. R., & Liu, Y. (2025). Trajectories of adoption for silver and bloomery iron in China from the Spring and Autumn periods (c. 770–476 BC). *Archaeometry*. https://doi.org/10.1111/arcm.13088

We examine the number of sites with silver objects in China over a period of 3500 years to suggest that technologies that stimulated the indigenous exploitation of silver-bearing ores were innovated during the Spring and Autumn period (c. 770–476 BCE), and that increased centralisation and bureaucratisation from the Warring States period (475–221 BCE) advanced their adoption. This culture of innovation should have extended to other prestige metals used for decorative objects, such as bloomery iron. However, bloomery iron, although rare prior to the 5th century BCE, disappears almost entirely from the archaeological record in China after this time. The movement of objects and ideas across the Eurasian Steppe was potentially the impetus for both silver- and bloomery iron-production technologies in China, but the adoption trajectory of bloomery iron diverged from that of silver because of the introduction of mass-produced cast iron. In effect, we propose that bloomery iron's status and value diminished when iron became recognised as a utilitarian material; thus, the Chinese invention of cast iron stymied the adoption of the bloomery process and effectively signed the death warrant of iron as a prestige metal.

Hu, P., Wang, Y., Wei, G., Mo, Z., Jiang, C., & Xia, F. (2025). The production of bronze wares of the Changsha state in the Western Han dynasty — a case study of the Fengpengling-Taohualing cemetery in Changsha, Hunan province. *Archaeological and Anthropological Sciences* 17(5), 103. https://doi.org/10.1007/s12520-025-02211-9

Bronze wares, excavated from the Fengpengling-Taohualing Cemetery in Changsha City of the Western Han Dynasty, Hunan Province, were investigated by the scientific and technological analysis of their alloy composition, metallographic organization and lead isotopes. The production and mineral sources of bronze wares in the Changsha State were discussed. Analysis shows that the bronze wares excavated from the Changsha Fengpengling-Taohualing Cemetery are mainly lead-tin bronze and tin bronze, characterised by the alloy technology of high copper, low tin and low lead. All the bronzes had cast structures, some showing signs of heat after casting. No hot forged bronzes are seen. The lead isotope results show that the sources of copper ore in Changsha State in the Western Han Dynasty were diversified. The Xiaoqinling-Yuxi was the most important source, and the Nanling and the Edong-Ganbei regions were also important supplements. After the middle and late Western Han, although the central government centralised the manufacture and distribution of bronze wares, its control over the local fiefdoms may not have been as strict as imagined. The bronze production of local feudal states should still have had a certain degree of autonomy of choice under the unified management of the central government. The Changsha State in Western Han Dynasty may have had its own independent bronze production workshops, with a wide variety of bronze wares and well-developed manufacturing techniques.

Wang, Y., Dai, Q., Li, Z., Liu, F., Yu, H., Gan, Z., & Ma, Q. (2025). Experimental research on the rhombic pattern swords of the Wu and Yue states during the Eastern Zhou period, China. *Journal of Cultural Heritage* 73, 249–255. https://doi.org/10.1016/j.culher.2025.03.010

Bronze weaponry crafted by the Wu-Yue states represents the zenith of weapon-casting technology in China during the Eastern Zhou era. Among these relics, swords and spears with dark rhombic patterns have astonishingly retained their pristine condition after thousands of years of subterranean burial. This remarkable preservation has generated considerable scholarly interest. However, obtaining suitable specimens for in-depth study has long been a challenge. This study utilises metallurgical microscopy, Scanning Electron Microscopy (SEM), and Energy Dispersive Spectrometer (EDS) to analyze two bronze swords with dark rhombic patterns from the Dahan Cemetery in Tengzhou City, Shandong Province. The analysis reveals that the rhombic pattern consists of a dense δ-phase layer, with some areas showing an outer ε-phase layer, indicating a hot tinning technique. Tin-plating experiments were conducted using various methods to simulate this tinning process. The results suggest that when a mixture of tin soap and tin powder is applied to the bronze surface and heated, a dark rhomboid pattern appears, similar to that found on the famous Sword of Gou Jian. A silver-white layer enriched with tin was discovered beneath the dark rhombic pattern through additional surface polishing. The residual tin soap on the bronze swords demonstrated notable resistance to corrosion; however, under acidic conditions, it tended to transform into organic acids, which could erode the α-phase of the bronze, leading to discoloration and darkening of the sword.

Dou, Z., Peng, Q., Liu, Y., Wang, Y., Yang, Y., Chen, G., & Chen, K. (2025). Iron artefacts used at an ancient jade mine in the Hexi corridor: A technical observation. *Archaeometry*. https://doi.org/10.1111/arcm.13093

This paper presents a study of 45 iron objects unearthed from the ancient Jingbao'er jade mining site in the western Hexi Corridor, dating from the Warring States period to the early West Han dynasty (about fourth–first centuries BCE). Metallographic and slag inclusion analyses were conducted to investigate the material features and their potential correlation with intended applications. Of the analysed items, 38 were made of cast iron, some of which had been decarburized or graphitized through annealing treatment to enhance their properties. Seven artefacts were identified as bloomery iron, indicating a distinct iron production tradition, likely localised and small in scale. By the late first millennium BCE, the supply of iron artefacts at the Jingbao'er site was predominantly derived from the cast-iron system, although evidence of regional bloomery smelting highlighted the complexity of iron production during this period. These observations offer new insights into the adoption of iron in the Hexi Corridor and the dynamics of regional technological exchange.

AFRICA

Redon, B. (2025). Iron shackles from the Ptolemaic gold mines of Ghozza (Egypt, Eastern Desert). *Antiquity*. https://doi.org/10.15184/aqy.2025.39

Since 1994, the French Archaeological Mission at the Eastern Desert has excavated more than 20 sites in Egypt, focusing on Roman forts and Ptolemaic mining sites. Rich in natural resources, the region was heavily exploited in the Hellenistic Period (332–30 BC). Recent excavations at Ghozza reveal the harsh reality of mining.

Morel, M., Serneels, V., Robion-Brunner, C., & Kiénon Kabore, H. T. (2025). Efficiency of ancient iron production: A case study from the Kaniasso district, Ivory Coast (11th-19th century). *Journal of Archaeological Science: Reports* 63, 105089. https://doi.org/10.1016/j.jasrep.2025.105089

This study explores the management of two iron smelting sites, KAN1 and KAN3, in the Kaniasso district of northwest Ivory Coast. These two technical traditions present quite different archaeological remains, including furnaces, tuyères, and slag. The KAN1 technique (11th-13th century CE) used smaller furnaces and produced tapped slag with a consistent chemical composition, indicating a selective use of iron ores. In contrast, the KAN3 technique, from a later phase (17th-19th century CE), shows a clear evolution towards mass production with larger furnaces and a more variable slag composition, reflecting the use of a wider range of ore sources. Bulk chemical analyses conducted using X-ray fluorescence (XRF) on slag and ore samples revealed significant differences in ore types and slag compositions between the two techniques. Mass balance calculations were performed to estimate metal production and its evolution according to the techniques. The study introduces a new comparative approach, integrating the technical, economic, and social dimensions to indicate the efficiency of the processes. Based on archaeological examples, this approach underscores the importance of considering the socio-economic context and the smelters' expertise to better understand ancient metallurgical practices.

Stephens, J., Mugabe, B., & Fenn, T. (2025). Archaeological applications of lead isotopic analysis to non-ferrous metals in Africa: A critical review. *Archaeometry*. https://doi.org/10.1111/arcm.13081

Lead isotopic analysis (LIA) has become a powerful tool in archaeology for identifying the geological source, or provenance, of non-ferrous metals and their alloys. Most applications have historically focused on Europe, but there is also a long, and rapidly expanding, history of LIA applications to the archaeological record of Africa. Here we highlight how Africanist archaeologists can apply LIA to understand materials provenance and circulation, and we discuss why this technique works well in Central and Southern Africa but requires a more nuanced approach for applications in North, West, and East Africa.

Kasso, T., Zaggia, C., Pastorelli, G., Ramsøe, M., Collins, M. J., & Brøns, C. (2025). Behind the mask − archaeometric analysis of four gilded romano-egyptian mummy masks from the Ny Carlsberg Glyptotek, Copenhagen. *Journal of Archaeological Science: Reports* 64, 105106. https://doi.org/10.1016/j.jasrep.2025.105106

This study investigates the materials and production techniques involved in the creation of four gilded mummy masks from Ptolemaic and Roman Egypt from the collections of the Ny Carlsberg Glyptotek, Copenhagen. These masks, dating from the 1st to 2nd centuries CE, are an example of the dual existence of a traditional Egyptian style and newly introduced Roman stylistic elements in funerary art. Various analytical methods, including imaging, FTIR, SEM-EDS, and palaeoproteomic analysis, were employed to identify and examine the composition of the materials. The main constructive material for the masks is plaster made of gypsum and calcite. Red and yellow ochre were used for the preparation layers for the gilding, which was made with silver-containing gold leaf. Four masks is not representative of major developments in gilding techniques, but the study does reveal information about the materials and production techniques available in Roman Egypt.

AMERICAS

Oliveira, I. G., Tavares, S. S. M., Correia, J. A. F. O., & Pardal, J. M. (2025). Microstructural characterisation of an ancient iron bridge in Brazil. *Metallography, Microstructure, and Analysis*. https://doi.org/10.1007/s13632-025-01193-3

In this work, two structural components from a railway bridge were analysed. These components were obtained from Brazilian Desengano´s Bridge built in the nineteenth century and today is also used for vehicles and pedestrian transport. The microstructural characterisation revealed that these components are made of puddled iron, a material developed during the Industrial Revolution and produced until the early twentieth century. The puddled iron has a heterogeneous microstructure primarily consisting of ferrite and coarse non-metallic inclusions and is mainly affected by phosphorus and nitrogen elements as a consequence of technological limitations of the time. This research aims to evaluate these microstructural characteristics using light optical microscopy and scanning electron microscopy, allowing a qualitative correlation between the local microstructure and mechanical properties. Energy-dispersive spectroscopy was employed to determine the chemical composition of the inclusions, while computerized microtomography provided insights into their distribution within the material matrix. Computational thermodynamic simulations were conducted to assess the influence of certain elements on these materials properties. The results indicate that a local microstructure analysis can give information about the local hardness, tensile strength, and toughness for this material.

Arano, D., Ciarlo, N. C., Carrasco-González, G., Barba-Meinecke, H., & Bethencourt, M. (2025). Copper-based sheathing and fastenings for wooden ships: An archeometallurgical study of the Carron, Ancla Macuca, RMS Forth, and El Pesquero wreck sites located in the Gulf of Mexico (late 18th to mid-19th century). *Metallography, Microstructure, and Analysis*. https://doi.org/10.1007/s13632-025-01186-2

One challenge in maritime archeology is correlating historical records, archeological findings, and material analysis data to accurately date and establish the provenance of shipwrecks. In the late 18th and early 19th centuries, European naval construction emphasised improvements to the durability of wooden ships, especially for tropical waters. The introduction of metal sheathing was a significant innovation to safeguard ship hulls against wood-boring organisms. Archeometallurgical analysis of copper-based sheathing and fastenings provides crucial insights into shipwreck technology and construction contexts. This study examines copper sheathing and fastenings on wooden ships from the late 18th to mid-19th century, focusing on wrecks in the Gulf of Mexico. Artifact analysis from these sites sheds light on evolving shipbuilding practices during the early industrial period. Additionally, archeometallurgical analysis has provided chronological references that assist in identifying these wrecks, particularly given the absence of ship hulls, which have degraded under tropical marine conditions.

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