Abstracts

GENERAL

Doménech-Carbó, A., Mödlinger, M. & Ghiara, G. (2024), Determining of the composition of the metallic core of historical objects from surface XRF spectrometry data, *Spectrochimica Acta Part B: Atomic Spectroscopy 220, 107030.* https://doi.org/10.1016/j.sab.2024.107030

A method for estimating the composition of the metal cores of historical and archaeological artifacts, using surface X-ray fluorescence (XRF) data is described. It is based on the combination of fluorescence data recorded at points of the object with different degrees of corrosion, exploiting the general phenomenon of demetallation of the less noble components of the metal alloy. A theoretical approach is provided using the Johnson–Mehl–Avrami–Erofeev-Kolmogorov (JMAEK) formalism to describe demetallation. Experimental data for binary Zn-Cu brass and Pb- and Sn-containing brass from Hofkirche in Innsbruck agree satisfactorily with the model.

Jiang, X., Zhang, J., Huang, F., Xie, H., Li, Q. & Fang, C. (2024), A mechanism study of type I corrosion on the surface of ancient tin rich bronzes, *Heritage Science* 12(1), 349. https://doi.org/10.1186/s40494-024-01472-2

The surface patina of ancient tin rich bronze was compared with pure hydrothermally synthesised SnO_2 nanoparticles, using various analytical techniques, including metallographic microscopy, scanning electron microscopy, transmission electron microscopy, energy dispersive spectroscopy, X-ray diffraction, Fourier transform infrared spectroscopy, X-ray photoelectron spectroscopy, and high-angle annular dark-field scanning transmission electron microscopy. The primary crystalline component of the patina consists of approximately 5 nm SnO_2 nanoparticles, which closely resemble pure SnO_2, indicating their comparability. Cu was also detected in the patina; however, it did not form crystalline structures. The X-ray diffraction results showed a shift in the patina's peak, suggesting the infiltration of Cu into the SnO_2 lattice, which compromised its crystallinity. In comparison to synthetic SnO_2, the X-ray photoelectron spectroscopy spectra of the patina revealed novel peaks corresponding to both Cu and O, indicating the presence of Cu−O−Sn bonding—a characteristic feature of type-I patina. This suggests that the primary structure of type-I patina consists of crystalline SnO_2 nanoparticles, with a limited amount of Cu integrated into its lattice configuration. The concentration of Cu within the SnO_2 crystal units is restricted, leading primarily to the formation of amorphous Cu_2O in conjunction with Sn. The presence of Sn enhances the structural stability of Cu_2O, facilitating its incorporation, while inhibiting the crystallization of Cu_2O. However, when the Sn concentration is insufficient, an inadequate Cu–O−Sn amorphous phase may form, allowing the potential crystallization of Cu_2O.

Tan, P., Yang, J. & Ji, J. (2024), Experimental simulation of the ancient production of gold granules, *Heritage Science* 12(1), 363. https://doi.org/10.1186/s40494-024-01475-z

Granulation is an ancient and sophisticated decorative technique. The production of gold granules is a crucial part of this process but has rarely been studied. Three techniques were investigated: pouring, heating and a crucible method. The success ratio of granule formation, granule surface morphology, microstructure, and formation were analysed to identify the techniques used in archaeological objects. The cooling medium significantly influenced small granule formation, microstructure, and grain size. Both heating and crucible methods controlled the granule formation but produced distinct microstructures. Based on these experimental granules, the probable production methods of ancient gold granules were identified and provide microscopic information for determining ancient gold granule production techniques.

Vieri, J., Crema, E. R., Uribe Villegas, M. A., Sáenz Samper, J. & Martinón-Torres, M. (2025), Beyond baselines of performance: Beta regression models of compositional variability in craft production studies, *Journal of Archaeological Science* 173, 106106. https://doi.org/10.1016/j.jas.2024.106106

Chemical analyses of archaeological artefacts are often used for provenance studies and for assessing whether specific performance characteristics were targeted by craftspeople in the past. Traditionally, the answers to these questions were sought by identifying compositional averages and by studying their correlations with either the geochemical signatures of candidate raw material sources or the corresponding physical or chemical properties of the studied materials. However useful, this approach only exploits part of the potential information locked inside the chemical compositions of archaeological artefacts. Different levels of compositional dispersion were observed within and across archaeological assemblages, especially in relation to changes in the size, function, or recovery location of the objects. To gain insights into both types of variability (averages and dispersions) simultaneously, we introduce variable dispersion beta regression models for the archaeological sciences. This shows how adopting the beta distribution provides a significantly improved alternative to previous solutions to modelling compositional data within

ISSN 0142-3304 (print)
ISSN 2755-0249 (online)

the field. This involved applying simple linear regression to log-transformed data, often resulting in numerically impossible predictions. Beta regression restricts the model predictions between the upper and lower compositional bounds, accounts for the inherently inconsistent variances of compositional data, and permits the modelling of compositional dispersions as a function of covariates. Finally, the toolset is expanded by showing how using a hierarchical model specification within the framework accounts for both local variation and more widely shared practices of material processing and procurement, and alleviates issues of sampling uncertainty. We demonstrate the proposed approach with a study of Muisca gold procurement practices (AD 600–1600) in the Eastern Highlands of Colombia, based on a dataset of 243 elemental analyses. The results suggest intra-regional movement of fresh geological gold imported from a variety of distant sources. We suggest these movements could result from contributions of gold by people converging into the same location for festivities. The approaches taken to modelling compositional data are readily applicable to other sub-disciplines of the archaeological sciences, such as compositional studies of ceramics and glass, or modelling the variability of diets in isotopic studies. An extensive summary in Spanish is included as Supplementary Material S0.

Festa, G., Caliri, C., Botticelli, M., Fatuzzo, C. G., Ferraris, E., Auenmüller, J. & Romano, F. P. (2025), Studying ancient Egyptian copper-alloy objects via X-ray diffraction and machine learning, *Journal of Cultural Heritage* 72, 48–58. https://doi.org/10.1016/j.culher.2025.01.002

The paper reports a novel approach to studying the manufacturing techniques of ancient Egyptian metal objects. It was applied to 12 copper-alloy objects, the majority of which are vessels. They were part of the burial assemblage of the Theban Tomb (TT) 8, belonging to the 'overseer of works at the Great Place' Kha and his wife Merit, that was found undisturbed in 1906 in Western Thebes (Egypt). The funerary assemblage, dating to the mid-18th Dynasty (ca. 1425–1352 BCE) is currently kept at Museo Egizio, Turin (Italy). The investigation aimed to gather information on the manufacturing processes and methods employed to produce the copper-alloy objects selected for analysis. The bronze vessels and stands are among the best and most sophisticated metal artefacts from New Kingdom Egypt in terms of their technology and preservation. Here, non-destructive X-ray fluorescence (XRF) data is reported, and X-ray diffraction is coupled with machine learning which allows the definition of specific data clusters which are compared with the overall role of the objects from a historical perspective and its macroscopic features. We identified four main groups as a function of the metalworking methods, from highly homogeneous microscopic structures induced by a high thermal treatment, such as annealing, to extremely nonhomogeneous microscopic structures, resulting from cold metalworking. This classification from a microscopic point of view is successfully integrated with a macroscopic classification by shape, demonstrating a particular processing method for each intended design type and use.

BRITAIN AND IRELAND

Willmott, H., Thompson, L., Lundy, J. & Crichton-Turley, C.-E. (2024), From Roman table to Anglo-Saxon grave: An archaeological biography of the Scremby cup, *European Journal of Archaeology* 27(4), 507–525. https://doi.org/10.1017/eaa.2024.12

Recent excavations at Scremby in Lincolnshire have revealed a complete Roman copper-alloy enamelled drinking cup in a 6th century AD female burial. Not only is such a Roman vessel a very rare find, but its inclusion in an early medieval grave makes it a unique example of the reuse of an antique object in a funerary context. The typological and metallurgical analyses of the cup and selected comparative examples from England and France are discussed. The context of deposition and the role the cup played as a burial container for animal fat are examined, as are the mechanisms that lay behind the cup's continued life several centuries after its manufacture.

Adams, S., Craddock, P., Hook, D., La Niece, S., Meeks, N., O'Flynn, D. & Perucchetti, L. (2024), The Pulborough gold torc: a 4th to 3rd century BCE artefact of European significance, *Internet Archaeology* 67, 16. https://doi.org/10.11141/ia.67.16

Two fragments of a decorated buffer terminal torc were found in 2019 near Pulborough, West Sussex. The simplicity of the design belies the complexity of the construction of this hollow, gold alloy neck-ring. The overall shape is that of the 4th to 3rd century BCE buffer terminal torcs found in western Europe, particularly France, Germany and Belgium. The terminal and neck-ring are decorated with filigree made from block-twisted wire soldered to the surface of the sheet metal parts. Filigree ornament is unusual in this shape of torc but is known from other varieties of torc and contemporary gold objects found on the Continent. The location of this find, towards the south coast of England along ancient routes of Atlantic and cross-channel contact and trade, is intriguing, given the disparate influences seen in the design. This is not the first buffer terminal torc discovered in England; its discovery is preceded by both gold and copper-alloy versions, but it stands out for its individual style and decorative effect. After its discovery and reporting to the Portable Antiquities Scheme, the torc was subject to analysis and examination, confirming it qualified as Treasure under the stipulations of the Treasure Act 1996. The Sussex Archaeological Society acquired the torc in 2023 for the Barbican House Museum, Lewes, Sussex. Further detailed technical examination of the torc was carried out on their behalf at the British Museum and is described here.

Andrews, M., Polcar, T., Sofaer, J. & Pike, A. W. G. (2024), Establishing life trajectories for British and Irish Middle Bronze Age palstave axes, *Journal of Archaeological Science: Reports* 60, 104811. https://doi.org/10.1016/j.jasrep.2024.104811

The results of chemical characterisation, metallography, metalwork wear-analysis, and damage assessment conducted on 102 British and Irish Middle Bronze Age (*c.* 1500–1000 BCE) tin-bronze palstave axes are presented. There is uncertainty regarding the role of palstave axes; they probably facilitated ongoing forest clearances, but in hearsay, their condition on recovery is

often expressed as 'pristine'. A better appreciation of underlying metallurgy, combined with insight from prior experimentation with replica palstave axes, permits a more nuanced evaluation of wear characteristics and use-intensity. This, alongside available contextual data, suggests that preservation was sometimes favoured over destruction at deposition. There appears to have been considerable variability within their life histories, however.

Stodolová, K., La Duc, E., Millett, M. & Martinón-Torres, M. (2025), Beyond tools and weapons: A study of iron supply and nail manufacture in Roman Aldborough, Britain, *Journal of Archaeological Science: Reports* 61, 104910. https://doi.org/10.1016/j.jasrep.2024.104910

Our understanding of Romano-British iron metallurgy is mainly based on smelting remains and the analysis of bladed tools and weapons. Complementing previous research, this study examines iron nails from the Roman town of Aldborough, Yorkshire (*Isurium Brigantum*), where a blacksmith's workshop featuring extensive remains of coal, a fuel not commonly documented in Roman metallurgy, was excavated. The research investigates the manufacturing technology of the nails, contextualised within broader Roman ironworking, along with potential sources of metal and possible alterations attributable to the use of coal as smithing fuel. The manufacturing technology is explored via metallography while scanning electron microscopy with energy dispersive spectroscopy (SEM-EDS) is employed for elemental analysis of the slag inclusions. The study reveals that the nails from Aldborough are examples of typical Roman nail production with no advanced techniques such as quenching or piling being used. Carbon content shows no discernible pattern across the dataset, varying from zero to 0.8% C in spots, suggesting a lack of deliberate metal selection. Attempts to determine the origin of the metal through multivariate statistical methods (HCA, PCA, and LDA) applied to slag inclusion compositions suggest a very diverse origin of the metal spanning various regions of Roman Britain. While there is no conclusive evidence indicating the utilisation of coal in the smithing process, we suggest the elevated sulphur content in the slag inclusions may provide an indirect indicator, which should be further investigated in future work.

EUROPE

Mozgai, V., Villa, I. M., Bajnóczi, B. & Szenthe, G. (2024), The early medieval origins of copper ore extraction in the Carpathian mountains, *Archaeological and Anthropological Sciences* 16(10). https://doi.org/10.1007/s12520-024-02060-y

The study addresses the early medieval revival of copper production in Europe, focussing on the Carpathian Basin which is located on the eastern periphery of the zone influenced by European early medieval processes. The research into where and when early medieval metal production started in the region also provides answers to the question of how the region was linked to the European continental economic network, which was an unresolved problem, until recently. Ore extraction and the production of various non-ferrous metals (copper, silver, gold) had important centres in the Carpathian Mountains throughout the Middle Ages until the Modern Era. Our study comprises lead isotope and chemical analyses of 'Late Avar' (*c.* 8th century AD) copper rivets, used for certain purposes alongside the copper alloys predominant in the period. As rivets were selected from the entire Avar cultural area, including all the lowland and hilly areas in the Carpathian Basin, the results are representative of the entire region and show that Avar craftsmen were producing large quantities of copper alloy objects in the 8th and the early 9th century and were supplied with copper from a single mining district, that is the ore deposits of the Slovak Ore Mountains in present-day Central Slovakia, a region which became an important metal-processing centre in the 11th century AD.

Hanel, N. & Pfeffer, I. (2024), The making of Roman lead ingots: casting by experiment and the archaeological evidence, *METALLA* 28(1), 23–40. https://doi.org/0.46586/metalla.v28.2024.i1.23-40

Casting experiments in Brilon-Hoppecke (North Rhine-Westfalia, Germany) in 2011, 2012 and 2015 aimed to reconstruct the production of Roman lead ingots with the help of archaeological experiments. Traces of the moulding process on the Roman lead ingots themselves and epigraphic evidence provided further information on the production process. The results of this research suggest that most of the lead ingots were very likely cast in clay sand moulds which almost completely disintegrated after the ingots had been removed. In a few cases, wood could be verified as the material for the moulds. Finally, all known artefacts associated with the casting of lead ingots have been critically examined and reinterpreted.

Longman, J., Veres, D., Ersek, V., Tamas, C. G., Haliuc, A., Magyari, E. & Papadopoulou, M. (2024), Central-eastern Europe as a centre of Middle Ages extractive metallurgy, *Journal of Archaeological Science* 172, 106093. https://doi.org/10.1016/j.jas.2024.106093

Central-eastern to southeastern Europe, from Bohemia to Greece is home to some of the richest ore deposits on earth, with archaeological evidence suggesting a long history of metal use. However, the exact timing and extent of past metal processing activities remains unclear. The Middle Ages and Early Modern period (*c.* 500–1800 CE) in Europe saw the continent-wide expansion of metal use at an unprecedented scale. Rates of past atmospheric lead (Pb) deposition in six peat bogs from Romania, Serbia and Greece were analysed which showed that after 1000 CE, the redevelopment of the central European mining industry was synchronous with lead pollution in southeastern Europe, while the onset of metal pollution had occurred prior to that in central Europe. Therefore, southeastern Europe may have led regional mining developments, with technological advances rapidly shifting from east to west through the Middle Ages. This emphasises that southeastern Europe should be included in future discussions of Middle Age metallurgy not simply as a contributor, but at times as a leader in metal production.

Paulina, B., Wim, D. C., Elisa, B., Patrick, B., Duncan, M. L., Rick, H. & Johan, D. G. (2024), Fuelling the blacksmiths furnace: A multidisciplinary study into the use of "smithy" coal in the ironworking industry of a late medieval harbour system, Bruges (Belgium), *Archaeometry*. https://doi.org/10.1111/arcm.13036

Large amounts of iron slag were discovered during archaeological excavations in the late medieval harbour of Hoeke (Municipality of Damme, Belgium), one of the main outer harbours of Bruges. This waste product indicates the presence of 13th- to 14th-century pre-industrial metalworking activities, including blacksmithing, which involved the production of iron objects and the repair of ships, as historically documented on this site. Besides iron working waste, fragments of coal were also discovered within the same deposits, both as separate pieces and also in the slags, suggesting that coal was used as a fuel during these activities. A multidisciplinary study, applying geochemical, palaeontological, and historical analyses identified the provenance of the coal (Northumberland-Durham Coalfield) and provided new insights into maritime coal trade during this period.

Sarah, G. (2024), Melle but not melle? A mine's mint as a hub for Carolingian silver coinage recycling, *Archaeometry*. https://doi.org/10.1111/arcm.13041

The mines at Melle in Deux-Sèvres, France, are known as the only significant source of silver for the early Middle Ages until the 10th century. Though it was not a major locality, the settlement possessed a mint in the Merovingian period that became one of the major centres of coin production under the Carolingians in the ninth century. Following the decrease in Carolingian power and increase in the autonomy of local authorities from *c.* 900, the Counts of Poitou started minting a coinage in the name of Melle which remained with the same typology for the next 200 years. Nearly 2000 silver coins covering four centuries of the Merovingian, Carolingian and Feudal periods were examined by laser ablation and inductively coupled plasma mass spectrometry (LA-ICP-MS) to determine the trace elements (including Au and Bi). The study has two main objectives: first, identifying the patterns of trace elements for the coinages attributed to Melle and comparing them with those of the same periods from other mints; and second, establishing the general evolution of the trace elements in coins from Poitou and other areas to evaluate the contribution of fresh silver from Melle, in order to identify the silver stocks available. One main result shows that part of the silver minted at Melle in the ninth century does not present the pattern of trace elements that characterise Melle silver, suggesting the use of the Melle mint as a hub for coining not only local silver from the mines, but also for recycling and refining silver from elsewhere.

Szczurek, G., Kowalski, Ł., Stos-Gale, Z. A., Kaczmarek, M., Maas, R. & Woodhead, J. (2025), The Kaliska II hoard: Interconnections and metal trade between Pomerania and the Nordic zone during the north European Bronze Age, *Journal of Archaeological Science: Reports* 61, 104877. https://doi.org/10.1016/j.jasrep.2024.104877

This paper discusses the results of a provenance study of nine *phalerae* from the recently discovered Kaliska II metal hoard, in order to evaluate the role of the Pomerania region (northern Poland) in the metal exchange networks of the North European Bronze Age. We relate Pb isotope and chemical data, supported by archaeological and typological information, to patterns of metalwork movement and consumption in the region. Our results suggest the metal used in making the domes of the *phalerae* could be sourced from copper mines in Cornwall, Great Orme, the Italian Alps and South Tyrol, indicating that the region of northern Poland was involved in a metal trading network that connected much of Europe in the 8th century BCE, providing further evidence for interconnections between Pomerania and the Nordic zone in the North European Bronze Age.

Nerantzis, N. & Matsas, D. (2024), Copper of the Kabeiroi: Bronze age metallurgy at *Mikró Vouní* on Samothrace and its Minoan connections, *Archaeological and Anthropological Sciences* 16(12), 205. https://doi.org/10.1007/s12520-024-02110-5

The prehistoric settlement of Mikró Vouní lies on the southwestern coast of the island of Samothrace in the northeastern Aegean. The site's stratigraphic sequence spans from the beginning of the Late Neolithic to the end of the Middle Bronze Age. Its importance has been emphasised by the finding of Minoan pottery and clay mini-documents with Linear A inscriptions, indicating active links with a Cretan palace (Knossos) in the 18th century BCE. The excavation yielded important finds related to Bronze Age metallurgy, including furnaces, moulds, tuyères, crucibles and pieces of slag from several contexts from EBA II to MBA III. The metallurgical finds of the MBA II-III periods come from contexts with Minoan or Minoanising pottery and clay mini-documents, suggesting a Minoan administration at the site. Crucibles and slags were sampled and optical microscopy and SEM/EDS analysis were used to investigate metal production with the aim of reconstructing the processes employed at the site during the Early and Middle Bronze Age. Crucial information emerged on the technical intricacies of arsenical copper production in the early stages and the introduction of tin bronze technology most probably associated with the Minoan interaction on site. Evidence for cementation and co-smelting of Cu and Sn ores represent the earliest examples so far reported for the north Aegean. As the iconography of the Minoan clay documents' seal impressions indicates, the religious ideology of the Minoan palatial administration appears to have encouraged metal manufacturing and trading in the north Aegean and beyond. Samothrace appears to have been well incorporated into long-distance exchange networks for the procurement of tin to sustain bronze working practices, as the findings from Mikró Vouní suggest. Metallurgical technology seems to resonate in mythic accounts of the well-known smith deities, the Kabeiroi, who were essentially the same divinities as the Great Gods of Samothrace.

Alexandrescu, C.-G. & Bode, M. (2024), Roman lead finds from Troesmis (Turcoaia, Tulcea county, Romania) and its surroundings – an investigation based on lead isotopes and trace element analyses, *METALLA* 28(1), 41–65. https://doi.org/10.46586/metalla.v28.2024.i1.41-65

Lead samples and one leaded bronze sample from five identifiable objects (*e.g.* large-scale bronze statues, lead pipes) and three lead chunks from the area of the ancient center of Troesmis, in the

Moesia Inferior province, have been investigated by elemental and lead isotope analyses. Four samples, dated into the 2nd to 3rd centuries AD, were found in the civil settlement near the fortress of the *legio V Macedonica* and the municipium of Troesmis. Another was uncovered in the nearby rural settlement, of Horia, in a context dated to the 2nd century AD. A fifth object is a fragmented lead pipe from a private collection in Bucharest, from Carnuntum, according to the seller, but bearing a maker's stamp relating it to Rome. Three lead chunks, presumably used in hanging objects on wall (like the bronze plates with the lex of the municipium), were also analysed. The investigations into the provenance of the nine Troesmis finds point to two different lead sources - the Central Balkans (Serbia/Kosovo) and the Cévennes (Massif Central) in France, while the lead source for the pipe fragment in Bucharest might be Yorkshire in Britain.

Davis, G., Blichert-Toft, J., Gentelli, L., Gore, D. B., Sheedy, K. A. & Albarède, F. (2025), Identifying silver ore sources for the earliest coins of Athens, *Archaeological and Anthropological Sciences* 17(2), 45. https://doi.org/10.1007/s12520-024-02120-3

This study investigates the ore sources used in the first series of coins of ancient Athens known as the *Wappenmünzen* (*c.* 540–500 BCE) by combining comprehensive numismatic data on 22 coins (16 new and 6 legacy analyses) with lead isotope and surface analysis (MC-ICP-MS and XRF). Ores from Spain to Romania and Türkiye and frequent mixing were identified. This upends current thinking based on a (mis)interpretation of historical sources which argues that the tyrant Peisistratos and his sons, who ruled Athens during the period, sourced most silver from the districts of Mt Pangaion and Strymon River in northern Greece and that silver did not flow from the western Mediterranean into their coinage. However, the data suggest that the domestic 'Lavrion' mines of Athens did not contribute to the ore stock of the *Wappenmünzen* until the subsequent production of the 'owl' series when it was also used in some *Wappenmünzen* fractions and also show that there is no correlation between coin types and ore sources. These new findings force a reappraisal of numismatic and historical perceptions of the period of the Athenian tyranny in the lead up to democracy, not least because the multiple silver sources point to trading relationships with a greater variety of regions than previously contemplated.

Mödlinger, M., Fera, M. & Utz, J. (2025), Chemical analysis of the 5th and 12th century metal doors in the Lateran, Rome, *Archaeological and Anthropological Sciences* 17(3), 59. https://doi.org/10.1007/s12520-025-02165-y

The three bronze doors of the Lateran Baptistery and Cloister of the Archbasilica of St John Lateran in Rome were studied to determine their chemical composition and to obtain information about their manufacture. One door was made by an unknown master in the 5th century and now leads to the Oratory of St John the Baptist in the Lateran Baptistery. The other two doors were made at the end of the 12th century by Pietro and Uberto from Piacenza, Italy. One of these doors is now in the Chapel of St. John the Evangelist, whilst the other is in the cloister of the Archbasilica. High-resolution photographic recording and a 3D model of one of the door wings complete the detailed documentation of all the three medieval doors. Chemical analysis shows that they were all made of leaded tin bronze.

NEAR EAST

Rodzinka, A. E., Fedrigo, A., Scherillo, A., Shortland, A. J., Simpson, S. J. & Erb-Satullo, N. L. (2024), Neutron tomography reveals extensive modern modification in Iron Age Iranian swords, *Journal of Archaeological Science* 171, 106018. https://doi.org/10.1016/j.jas.2024.106018

Early Iron Age Iranian bladed weaponry plays a significant role in discussions of metallurgical development in the ancient Near East. Due to its ubiquity in museum collections, as well as the co-occurrence of bronze, iron, and bimetallic forms, it figures prominently in debates about the early ironworking techniques in the late 2nd and early 1st millennia BCE. However, dispersed collections, often lacking secure archaeological context, have made comprehensive assessment difficult. One major type of bladed weaponry, the so-called split-ear pommel swords have been the subject of much discussion, particularly around the presence of an iron core identified in many examples. Neutron tomography was applied to eight swords of this type to image their inner structure, assess the manufacturing process and determine possible recent modifications—the first time this technique has been applied to bronze Iranian weaponry of any period. The objects were recovered by the Border Force after being seized on entry to the UK and will be repatriated to Iran, providing an opportunity to investigate both ancient manufacture and modern (illicit) modifications. The results reveal extensive modern modification, namely the replacement of original blades—often made of iron —with different (but probably also ancient) bronze blades, conclusively showing that the "iron cores" were not a technological feature in these bronze swords, but a result of modern tampering. Widespread iron blade replacement has masked the true extent of the production of bimetallic weapons and obscured the technological choices of early ironworkers. Given the centrality of unprovenanced objects in discussions of Iranian Iron Age metallurgy, these modifications have negative consequences for efforts to map the process of iron innovation.

Marussi, G., Pavoni, E., Crosera, M., Gariboldi, A., Verk, G. & Adami, G. (2024), Archaeometric investigations of Sasanian silver drachmas (6th-7th century AD) using X-ray fluorescence analysis, *Journal of Cultural Heritage* 70, 381–387. https://doi.org/10.1016/j.culher.2024.10.007

Micro X-ray fluorescence (μ-EDXRF) analysis was used to study 29 Sasanian drachmas from a private collection at the Department of Humanities, University of Trieste. The coins were issued between 499 and 628 AD, during the reigns of four Sasanian kings (Kawad I, Khosrow I, Hormizd IV, and Khosrow II). This study aimed to determine the elemental composition of the alloy surface, assess the fineness of the coins, and identify potential forgeries or signs of devaluation. Eight XRF spectra were acquired for each sample, revealing a primary composition of Ag, with traces of Cu, Au, and Pb. Semi-quantitative analysis showed the Ag content exceeding 95% in nearly all coins, with two suspected forgeries identified (coin no. 13 minted during the reign of Hormizd IV and coin no. 18 from the reign of Khosrow II). Five drachmas from Khosrow II's reign, marked with the inscription "*afid*", exhibited an Ag content above 99 %, supporting the historical hypothesis of superior quality compared to other drachmas from the same period. Finally, the % Au and the presence of Pb provided further

indications on the origin of the silver, allowing hypotheses on the mineral sources.

Oudbashi, O., Colburn, H. P. & Carò, F. (2025), Sasanian and early Islamic copper-base metalworking at Qasr-e Abu Nasr, south-central Iran, *Archaeological and Anthropological Sciences* 17(1), 28. https://doi.org/10.1007/s12520-024-02123-0

A group of metal objects excavated at Qasr-e Abu Nasr in south-central Iran in the 1930s, now in the collection of the Metropolitan Museum of Art, was analysed to examine metal-working techniques and metallurgical processes. Thirty-three objects were studied and analysed by micro-XRF, SEM-EDX spectroscopy, and metallography. The results show a wide range of copper alloy compositions including impure copper, tin bronze, brass, leaded tin bronze, leaded brass and leaded ternary Cu-Sn-Zn (gunmetal) alloys. Also, two silver-copper and one pewter object were identified. The results of this interdisciplinary study provides new insights onto the archaeology of Qasr-e Abu Nasr and the history and evolution of copper-base metallurgy on the Iranian Plateau during the Sasanian and early Islamic periods.

ASIA

Zhangsun, Y., Wu, X., Liu, L. & Yang, J. (2024), Bronze technology and metal resources in the Zhouyuan area before and after the replacement of Shang and Zhou dynasties, *Archaeological and Anthropological Sciences* 16(10), 164. https://doi.org/10.1007/s12520-024-02059-5

The Zhouyuan site was the largest central settlement in the western Guanzhong Plain during the Shang and Zhou periods; it was once the capital of the Zhou people before the establishment of Western Zhou. Bronzes excavated in the Zhouyuan area from the pre-Zhou to the Western Zhou period were analysed via a field emission electron probe microanalyser for chemical compositions and MC–ICP–MS for lead isotope ratios. Various alloy types were used in the pre-Zhou period, whereas more stable alloy recipes and materials with better performances were used in the Western Zhou. The pre-Zhou bronzes contain highly radiogenic lead and common lead but the Western Zhou bronzes only contain common lead. Both the alloying techniques and metal resources of the Zhouyuan area changed significantly from pre-Zhou to Western Zhou. This could be related to a major transformation of the bronze industry pattern after the Zhou people replaced the dominance of the Shang Dynasty. Zhouyuan also participated in the circulation network of metal resources centered on Yin Ruins during the late Shang. The highly radiogenic lead metal resources were probably obtained from Yin Ruins through the Shang culture in the eastern Guanzhong Plain (Laoniupo). The Zhou people probably acquired bronze smelting and casting techniques from Shang after they conquered Laoniupo. After this, their military equipment, as well as sacrificial vessels, improved considerably, which provided resources and technical support for the forthcoming war against the Shang capital.

Li, Q., Wei, G., Chen, L., Wu, L. & Chen, Y. (2024), Lead isotopes and elemental composition of bronzes excavated from Xiajiang area of Chongqing, China using MC-ICP-MS and SEM-EDS, *Journal of Archaeological Science: Reports* 59, 104774. https://doi.org/10.1016/j.jasrep.2024.104774

The archaeometallurgy of Han Dynasty bronzes is a hot topic of current research and has made great progress, although the archaeometallurgical features of the Han bronzes in the Xiajiang area are not yet fully understood. In this study, bronzes recovered from the Fengxiangbei tomb, in the Xiajiang area were analysed, using optical microscopy (OM), scanning electron microscopy, energy dispersive X-ray spectroscopy (SEM-EDS), and multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS) to study the techniques and the provenance of the raw materials. Metallographic analysis showed that all the bronzes were cast, and only one sample showed signs of post-casting heating, probably due to heating during daily use. Comparison with the available data from different sites and mines reveals that the lead ore used for bronzes in the mid-to-late Western Han Dynasty came from multiple lead sources, and that there may have been an extensive network circulating metal resources. The Xiajiang area has been included in this network.

Yang, F., Chen, S., Liu, S. & Chen, K. (2024), Stay with the green: New insights into ancient copper smelting in the Tonglüshan site, China, *Journal of Archaeological Science: Reports* 59, 104790. https://doi.org/10.1016/j.jasrep.2024.104790

This paper presents new archaeometallurgical analyses from the Tonglüshan site, a famous ancient mining and smelting site in China. Results show that the primary phases in slag samples from two sites (Sifangtang and Lujia'nao) are a vitreous matrix, interspersed with fayalite crystals, wüstite, and hercynite. The trapped metallic particles in the slag are mainly raw copper with few a sulphides present, which indicates a direct reduction process of oxidic ore. The probable addition of iron-rich minerals as flux is implied by the few unreacted inclusions in the slag samples. The extremely low copper content in the slag samples demonstrates a high rate of copper recovery, indicating an advanced level of copper smelting technology in the region. In the meantime, variations in the metal content of slag samples from different periods reveal the diachronic changes in this copper smelting technology. The Tonglüshan site, with its millennia of ancient mining and metallurgical activities, provides an excellent material base for detailed studies on technological evolution.

Liu, S., Sun, Z., Cui, T., Zou, G., Zhong, R. & Rehren, T. (2024), Beyond linear narratives: Complex copper ore exploitation strategies in early bronze age China revealed by geochemical characterisation of smelting remains, *Journal of Archaeological Science* 171, 106092. https://doi.org/10.1016/j.jas.2024.106092

Despite decades of efforts to reconstruct the bronze production and metal distribution systems of the Shang period in Bronze Age China, understanding of the ore choices and smelting practices of the Shang people is still limited. This study addressed this gap by conducting an investigation of Shang period copper ores and smelting remains uncovered at the Tongling site in the Middle Yangtze River valley. The results of lead isotope, copper isotope, trace element, and rare earth element (REE) patterns help to classify the slags from this site into two groups, associated with smelting sulphidic (Group A) and oxidic (Group B) copper ores, respectively. This provides the first physical evidence of the use of sulphidic copper ores in Early Bronze Age China. It also provides pivotal details of the copper resource exploitation

strategies of the Shang people. It challenges the traditional narrative that the Shang people moved to this area solely for the high-grade supergene deposits. The parallel use of both supergene and hypogene ores at the same site complicates the notion of a linear, technological evolution from simpler to more advanced copper sources. Despite the presence of hypogene ores, the study reveals that the Shang people maintained labour-intensive smelting practices, including crushing slag to recover trapped metallic prills, to meet the demands of large-scale bronze casting. This nuanced approach to copper resource exploitation reflects a complex, context-dependent strategy rather than a technological revolution. By highlighting these intricate metallurgical choices, this research contributes to a broader rethinking of early technological development, underscoring the diversity and adaptability of ancient craft industries and their role in shaping Shang society.

Kwon, H. (2024), Characteristics of foundries and alloy composition of modern and contemporary Korean artistic bronze, *Heritage Science* 12(1), 385. https://doi.org/10.1186/s40494-024-01476-y

This study investigated the changes in foundries and production techniques of modern and contemporary Korean artistic bronze constructions from the 1910s to the 2000s. To determine the characteristics of foundries and changes in alloy composition based on era, interviews with key sculptors and foundry technicians, analysis of archival materials related to casting, and non-destructive X-ray fluorescence analysis of 92 bronze sculptures by Manlin Choi, were conducted. This study found that foundries for artistic bronze underwent technical and organizational changes from the 1910s to the 2000s. Modern casting techniques and foreign technologies have been introduced since the late 1960s. The portable X-ray fluorescence analysis of Manlin Choi's 92 bronze sculptures revealed distinct differences in alloy composition depending on the foundry, findings which are supported by records (contracts, receipts, payment confirmations). This study systematically outlines the changes in foundries and production techniques of modern and contemporary Korean artistic bronze, identifying correlations between alloy composition and foundries, and is expected to provide important data for the future conservation and scientific authentication of artistic bronze.

Wang, C., De Ceuster, S., Eremin, K., Laursen, S. & Degryse, P. (2025), A methodological case study of lead resource movements during the Warring States period and Western Han dynasty: applying kernel density estimation to four lead-barium glass *Bi* artifacts, *Journal of Cultural Heritage* 71, 71–80. https://doi.org/10.1016/j.culher.2024.11.007

Lead isotope analysis and Kernel Density Estimation (KDE) was used to explore the provenance of four lead-barium silicate glass artifacts in the Harvard Art Museums. The study demonstrates how KDE can be used to analyse lead resource distribution and movements. The lead from one artifact, attributed to the Warring States Period, is traced to southern Chinese regions such as Yunnan, Guizhou, Guangdong, or Guangxi. Two artifacts display distinctive lead isotope signatures potentially linked to materials used in the Shang Dynasty, highlighting unique methodological challenges. Another artifact exhibits anomalous lead isotopic and stylistic features, suggesting it might be from a different cultural context, possibly with lead sourced from Central China. By employing KDE in combination with lead isotope analysis, this case study not only demonstrates the effectiveness of this combination in archaeological provenance research but also offers insights into the use of lead in ancient Chinese glass production. The results reveal multiple lead sources for the glass-making industry during the Warring States Period and the Western Han Dynasty and further suggest that some artifacts contain highly radiogenic lead, probably sourced from South China.

Upadhyay, P., Sivarajan, R., Tripathi, V. & Upadhyay, C. (2024), Metallurgical study of copper objects from the Varanasi region, India (1200 BCE to 400 CE), *Archaeometry*. https://doi.org/10.1111/arcm.13054

This study investigates ancient Indian copper metallurgy based on selected copper artifacts recovered from India. The collected objects belong to the period *c.* 1200 BCE to 400 CE. The paper discusses the analysis of seven artifacts from two archaeological sites (Agiabir and Raipura) around the Varanasi region in Northern India. It explores the alloying practices and manufacturing techniques applied to the artifacts using optical microscopy, scanning electron microscopy, energy-dispersive X-ray spectroscopy, and X-ray fluorescence spectroscopy. The microstructure of the artifacts revealed the practices of casting, forging and annealing. Elemental analysis of these objects shows that most of the artifacts are copper–tin alloys, with varying amounts of tin. The tin content was varied according to the object's functionality.

Luo, Z., Jin, Z., Chen, Q., Huang, F. & Fan, A. (2025), New scientific analysis reveals the independent bronze production system of the indigenous Yue group in southern China during early western Zhou period, *Archaeological and Anthropological Sciences* 17(2), 37. https://doi.org/10.1007/s12520-024-02157-4

The bronze production system of local indigenous groups in Southern China is the focus of Chinese Bronze Age research. The chemical composition, metallographic microstructure and lead isotope ratios of eighteen Yue-type bronzes unearthed from the Shishijiang site in Xiangxiang County, Hunan Province were investigated. The results showed that the Shishijiang bronzes were mainly made of Cu-Sn-Pb alloys, with a small proportion made of Cu-Pb, Cu-Sn and Cu-Sn-As-Sb alloy combinations. The manufacturing techniques of Shishijiang bronzes were mainly casting although a small number of bronzes were heated after casting. The lead isotope data of Shishijiang bronzes showed a common lead source. The distribution range was very concentrated. The Cu, Sn, and Pb materials used in Shishijiang bronzes were probably all from the Southern Hunan region. The metal minerals of Southern Hunan were widely used in Yue-type bronzes, Chu-style mirrors, and the Tang-period coins unearthed from Hunan. Although the Shishijiang bronzes were influenced by the Central Plain culture of the late Shang and early Zhou Dynasties, the pattern of metal mineral use was significantly different from that of bronzes unearthed from the Western Zhou royal region and feudal vassal states. This suggested that the Hunan Yue Group had a relatively independent bronze production system in the early Western Zhou period, which provides a new insight into bronze technology development and extensive cultural interactions in Southern China.

Wang, X., Liu, R., Wang, N., Yang, Y., Jiang, T., Wang, R. & Luo, W. (2025), State intervention in post-Qin bronze production in Sichuan: scientific insights from *mou* vessels, *Antiquity*. https://doi.org/10.15184/aqy.2025.15

Bronze *mou* vessels appear in Shu tombs in south-west China during the Eastern Zhou period (*c.* 771–256 BC). Examination of these vessels reveals major changes in the supply of metal and alloying technology in the Shu State, throwing new light on the social impact of the Qin conquest and later unification of China.

Park, J.-S. & Shinde, V. (2025), The key role of bangles in the evolution of standardised bronze technology in Indian antiquity, *Archaeological and Anthropological Sciences* 17(3), 54. https://doi.org/10.1007/s12520-025-02174-x

Bangles represent one of the few Bronze Age metal objects that survived the bronze-to-iron transition in Indian antiquity. Thirty-six bangles excavated from the megalithic burials at Raipur, India, were examined for their role in the evolution of Indian bronze technology. They were all made of binary copper-tin alloys (average: 9.3 wt% Sn). No lead was added to any of them. They were consistently treated by forging after casting. Laboratory experiments revealed that plastic deformation with proper thermal treatments could be effective in removing unwanted tin-rich, brittle δ particles from the alloys, greatly improving their forgeability. Such high-quality bangles, if used as intermediaries, would inevitably lead to a standardised and optimised bronze tradition dedicated to the manufacture of thin-walled prestige items in a simplified process of forging. As a symbol of wealth and status, therefore, bangles likely stimulated the dissemination of standardised portable bronze technology in keeping with the socioeconomic inequality emerging throughout India during the Indus-to-Megalithic transition period.

AFRICA

Thomas, E. & Gethin, P. (2024), An adapted method for researching ancient Egyptian mirrors, *Journal of Archaeological Science: Reports* 59, 104743. https://doi.org/10.1016/j.jasrep.2024.104743

Metallurgical analyses have been conducted on Ancient Egyptian mirrors. Both compositional and microstructural data are necessary to fully reconstruct the manufacturing sequences of these objects. To avoid unacceptable damage resulting from normal sampling practice, the method of deep-filed edge abrasion sampling with SEM-EDX analyses, based on coin studies, was adapted for examining Egyptian mirrors. This paper will establish how the methodology gathers reliable compositional and microstructural data while remaining visually discreet. It was carried out on four mirrors varying in condition, shape, and size and could be favourably compared with the traditional mounted 'V' cross-section taken in the 1990s from the same specimens.

Abdelbar, M. & Roshdy Elsakhry, A. (2024), Archaeometallurgical characterisation of Greco-Roman copper-based and iron nails from Tel Abu Seify, North Sinai, Egypt, J*ournal of Archaeological Science: Reports* 59, 104815. https://doi.org/10.1016/j.jasrep.2024.104815

A collection of copper alloy and iron nails discovered amid numerous metal artifacts in the archaeological excavations of Tel Abu Seify, North Sinai, Egypt was investigated. This site, identified as a shipbuilding and repair facility, dates to the Greco-Roman era (*c.* 332 BCE–AD 641). The composition of the alloys, the manufacturing techniques, and the characteristics of the corrosion products in the nails were investigated using optical and metallographic microscopy, X-ray radiography, portable X-ray fluorescence, SEM-EDS, μ-Raman spectroscopy, and X-ray diffraction. The results showed that 19 of the nails were copper alloys, and two were made of iron. The tin bronze nails contained 4.3 wt% tin, 4.7 wt% lead with traces of iron and arsenic. The iron nails were low-carbon iron alloys. Microscopy showed that the nails were made by cold hammering. The patina on the copper alloy nails consisted of cuprite, atacamite, clinoatacamite, antlerite, and cerussite with soil residues. Corrosion on the iron nails consisted of hematite, magnetite, goethite, akageneite, and lepidocrocite. Most copper-based nails remained in relatively good condition, generally retaining their metallic cores, although, a few exhibited partial or total mineralisation like the iron nails.

Odler, M., Kmošek, J., Verešová, V., Hulková, L., Jarmużek, Ł., Ryś-Jarmużek, A., Wodzińska, A., Hudec, J. & Rzepka, S. (2025), Unearthing fresh copper at Tell el-Retaba: From the Second to the Third Intermediate period, *Ägypten und Levante* 34, 419–553. https://doi.org/10.1553/aeundl34s419

Since 2007, thirty-one metalworking and artefact samples were excavated by a joint Polish-Slovak mission at the site of the Egyptian site Tell el-Retaba in Wadi Tumilat. Samples have been investigated archaeometallurgically. They date to the Second Intermediate Period and the New Kingdom. Published research on contemporary metalwork includes not only copper but also a unique silver toggle pin from the early New Kingdom. This article provides the first dataset on settlement metallurgy from Egypt for the Early Iron Age (Third Intermediate Period) ever investigated. The material also includes a copper ingot fragment found on site's surface, which probably dates to the Second Intermediate Period. The most unexpected finding is the identification of freshly processed copper, presumably sourced from mining sites in either the Eastern Desert or Sinai.

Mohamed, N. M. & Elmetwaly, M. S. (2025), Scientific investigation of the 20th century bronze bell in Asyut, Egypt: Insight into materials, chemical composition and preservation status, *Archaeological and Anthropological Sciences* 17(3), 63. https://doi.org/10.1007/s12520-025-02167-w

This research presents an historical background and an analytical study of a bell dating back to the early 20th century, currently located at Al Salam Modern School, formerly known as the American College in Asyut, Egypt, established between 1901 and 1909. The bell consists of metal parts (Bowl, Yoke, Standards, Clapper, Clevis Bolt, Toller, and Bearing) and wooden parts (Base or Frame and Wheel). These components were studied and analysed using microscopic examination, portable X-ray fluorescence (p-XRF), scanning electron microscopy (SEM) coupled with an energy dispersive X-ray spectroscopy (EDX), X-ray diffraction (XRD), and Fourier transform infrared spectroscopy (FTIR). Visual and microscopic examination revealed the presence of corrosion products on the surface of the bell and

its metal parts, embrittlement of the wood structure, fibre breakage, accumulations of dust and bird droppings. The wood was identified as oak, using a light microscope. The body of the bell itself was analysed using p-XRF and SEM-EDX and confirmed mainly as tin-bronze. The surface corrosion products on the bronze bell were identified as nantokite, paratacamite, atacamite, brochantite, antlerite, cassiterite and gypsum by XRD analysis while the corrosion products on the iron parts were magnetite, hematite, goethite, akageneite, lepidocrocite and gypsum. The wood showed embrittlement and decomposition of hemicellulose and lignin. Analysis also identified a local paint known as ARTEX (Pachin) was used in painting the wood.

AMERICAS

Crandall, J. M. & Risco Patiño, L. (2024), A deposit of silver *aquillas* from the site of Purun Llacta de Soloco, Amazonas, Peru, *Latin American Antiquity* 35(4), 1045–1051. https://doi.org/10.1017/laq.2024.3

This report examines the context and content of a 16th century cache of silver *aquillas* within a Chachapoya household at the site of Purun Llacta de Soloco. These findings have implications for a larger examination of social value in Andean societies and the specialized treatment and use of ritual objects during the tumultuous colonial period.

Vetter Parodi, L. & Barraza Lescano, S. (2024), ¿Las pinzas de metal fueron empleadas exclusivamente como depiladores en los Andes centrales? *Estudios Atacameños* 70, e5726. https://doi.org/10.22199/issn.0718-1043-2024-0001

In the central Andean territory, tweezers have been made from metals since the Early Horizon period (800–200 BC). In pre-Hispanic funerary contexts, they are usually associated with males and were long thought to be used mainly for hair removal, since that is how they appear in colonial written and iconographic sources and on pre-Hispanic ceramics. However, significant evidence allows us to verify multiple uses. This article reviews cases reported in the archaeological bibliography and museum records where tweezers are connected to several functions, including textiles, fishing, facial cleansing and, possibly, pre-Hispanic metallurgy. Ethnographic data and primary sources on tweezer use are presented, contributing to the understanding of their various functions and meanings.

Iucci, M. E., Becerra, M. F., Wynveldt, F., Fuertes, J. & Sallés Abal, J. M. (2024), Una pieza de oro en El Molino, Valle de Hualfin (Catamarca, Argentina) en tiempos del Inka, *Arqueología* 30(3), 13310. https://doi.org/10.34096/arqueologia.t30.n3.13310

A gold bar-shaped object was recovered within a funerary context in El Molino, a 15th century site in the Hualfin Valley (Catamarca Province, Argentina). The finding is significant not only because of the low occurrence of gold artefacts in Late/Inka times in Northwest Argentina, and even rarer in documented and dated contexts such as the one presented here, but also for its exceptional morphological and compositional characteristics, and its context of association. The bar was made by smelting and casting in a prismatic mould. It would have then been hammered and cut. The bar is made of native gold with low percentages of silver and copper, which is an uncommon composition compared to the known corpus of gold objects found in NW Argentina from this period. According to the characteristics of the object and of the gold metallurgy of NW Argentina's late periods, we interpret the bar as a metal reservoir, and its production is discussed in the context of negotiations between elites of the valley and the State during the expansion process.

The abstracts are edited by Janet Lang. The Honorary Editors would like to acknowledge her continuing help, and that of others who contribute abstracts. Where no source is given, the abstract has been adapted from that provided by the author(s) of the paper.

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