Abstracts

GENERAL

M Blet-Lemarquand, S Nieto-Pelletier and B Gratuze. Depth profile LA-ICP-MS analysis of antique gold coins, in K A Sheedy and G Davis (eds), *Mines, metals, and money. Ancient world studies in science, archaeology and history. Metallurgy in Numismatics 6*. London: Royal Numismatic Society Special Publication 56, 2020, 195–206. ISBN 0–901405–37–X.

This paper presents use of the depth profile mode coupled with LA-ICP-MS for analysing ancient gold coins. It explains how this mode can improve the characterisation of coins for the following difficult analytical problems: surface gold enrichment, low fineness gold alloys, localised enrichments in platinum and palladium and inclusions of platinum group elements.

E Ferrari, F Mercier, E Foy and F Tereygeol. New insights on the interpretation of alum-based fake silver recipes from 3rd century CE by an experimental archaeology approach in the laboratory. *Journal of Archaeological Science: Reports* 36, 2021, 102742. DOI: 10.1016/j.jasrep.2020.102742.

Experimental archaeology represents an important research methodology for the study of ancient technologies and societies. Following this approach, two alchemical recipes from a 3rd century CE papyrus were reproduced in the laboratory. In this paper, a link between archaeometry and experimental archaeology is established, and a reinterpretation of the original recipes is proposed.

A Manas. 'All that glisters is not gold'. A colorimetric assessment of the touchstone for gold ternary alloys. *ArcheoSciences* 44(1), 2020, 51–62. DOI: 10.4000/archeosciences.7247.

The principles behind the touchstone have never been investigated scientifically, even though there are many technical and historical accounts of its effectiveness. In this article I investigate whether and to what extent the content of Au-Ag-Cu ternary alloys can be ascertained visually with a touchstone without acid. I show that it is very likely to be true as the touchstone solves several problems (illumination, surface state and curvature, etc) and makes it possible to carry out a luminance comparison. A colorimetric approach confirms the high level of accuracy attained.

O Oudbashi and R Wanhill. Long-term embrittlement of ancient copper and silver alloys. *Heritage* 4(3), 2021, 2287–2319. DOI: 10.3390/heritage4030130.

This paper presents a survey of fractographic analyses, in combination with the more widely used disciplines of microstructural studies, metallography, and chemical analyses for some Old-World copper alloy (bronzes) and high-silver alloy artifacts that have undergone long-term corrosion and embrittlement damage. The study and interpretation of fracture surfaces, fractography, is a minor or non-existent consideration for most archaeometallurgical investigations but we show that fractography, as an adjunct to metallography, can improve the interpretation of these types of damage and assist in selecting the best methods for restoration and conservation of the objects made from these alloys.

L Perucchetti, P Bray, A Felicetti, V Sainsbury, P Howarth and M K Saunders, P Hommel and M Pollard. Flame-D database: an integrated system for the study of archaeometallurgy. *Archaeometry* 63(3), 2021, 651–667. DOI: 10.1111/arcm.12616.

Much archaeometallurgical data are available but scattered across hundreds of publications, where they may be differently organised, based on the focus of the original papers. The FLAME-D database aims to collect widely scattered corpus of data on raw material or metal objects and include it in a versatile structure that also maintains the information about the organization and availability of original data. The database is complemented by a series of online tools that make data available to answer new questions.

BRITAIN AND IRELAND

P Bray 2020. Modelling Roman concepts of copper-alloy recycling and mutability. The chemical characterization hypothesis and Roman Britain, in C N Duckworth and A Wilson (eds), *Recycling and reuse in the Roman economy*. 237–264. ISBN 9780198860846, DOI: 10.1093/oso/9780198860846.001.0001.

The 'provenance hypothesis', which aims to establish a direct link between a chemical or isotopic signature of a copper-alloy artefact and its original ore source, is a notorious and significant challenge. An alternative approach to chemical data – a 'characterization hypothesis' is proposed. Rather than identifying a separate block of 'recycled metal' chemically, we can instead define a series of overlapping processes of metal melting, mixing, and manipulation. Instead of replacing the search for a provenance signal with one for a recycling signal, we should instead embrace the intricacies of the archaeological and chemical record. This complexity more accurately represents the multifaceted Roman relationship with copper and its alloys.

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

H Simon, G Cibin, I Freestone and E Schofield. Fe K-edge X-ray absorption spectroscopy of corrosion phases of archaeological iron: results, limitations, and the need for complementary techniques. *Journal Physics Condensed Matter* 33(3), 2021, 344002. DOI: 10.1088/1361-648X/ac08b6.

Data analysis methods for iron X-ray absorption spectroscopy (XAS) can provide extensive information about the oxidation state and co-ordination of an Fe-species. The application of the technique to complex, mixed-phase samples formed under real-world conditions is evaluated, using iron corrosion samples from cast iron cannon shot excavated from the Mary Rose shipwreck and compares the data with phase compositions determined by synchrotron X-ray powder diffraction (SXPD). While the pre-edge fitting methodology may be applied to a mixture of iron oxides or oxyhydroxides, the procedure was found to be inappropriate for a mixed metal-oxide sample without the application of a complimentary technique, such as SXPD.

U Veronesi, T Rehren, and M Martinon-Torres. The philosophers and the crucibles. New data on the 17th–18th century remains from the Old Ashmolean laboratory, Oxford. *Journal of Archaeological Science: Reports* 35, 2021, 102684. DOI: 10.1016/j.jasrep.2020.102684.

This paper presents the analytical study of early modern chemical vessels used in the laboratory of the Old Ashmolean Museum in Oxford, the first university institution in Britain where chemistry was taught. The assemblage comprises crucibles of different types, ceramic distillation equipment and other containers. The analyses of residues found within them indicate that the laboratory's experimental programme engaged some of the most relevant technological as well as philosophical quests of the time, including the production/working of new types of glass and the distillation of zinc.

EUROPE

D Berger, M Brauns, G Brügmann, E Pernicka and N Lockhoff. Revealing ancient gold parting with silver and copper isotopes: implications from cementation experiments and for the analysis of gold artefacts. *Archaeological and Anthropological Sciences* 13(9), 2021, 143. DOI: 10.1007/s12520-021-01369-2.

Gold parting enabled the production of very pure gold for various purposes from the 6th century BC onwards. A new analytical approach for the identification of purified gold combines silver and copper isotopic with trace element analyses. Parting experiments were performed with gold-silver-copper alloys using the classical salt cementation process to investigate potential silver and copper isotope fractionation and changes in trace element concentrations. The first comprehensive dataset of silver isotope ratios of archaeological gold objects from the Mediterranean and Central Europe is provided to test whether or not gold refining can be identified on the basis of isotope systematics. Very heavy silver and copper isotopic compositions are clear evidence for parted gold, but the application of copper isotopes might be limited.

D Bursák, A Danielisová, T Magna, J Trubač. Shining like gold and new: The emergence of brass north of the Alps around the turn of the era. Preprint July 2021. DOI: 10.21203/rs.3.rs-715158/v1.

Archaeometric and advanced statistical multivariate analysis was applied to late Iron Age and Early Roman period (1st century BC – 1st century AD) brass and other copper-alloy objects from Bohemia to ascertain their provenance. The results for brass objects from the early phase of the extensive occurrence of Roman aurichalcum in the Barbarian territories, point to the ore deposits in the western Mediterranean or the Massif Central area in Gaul. Because of its gold-like appearance, it is believed that brass played an important role in diplomatic and economic contacts with indigenous communities, notably Celtic and Germanic tribes north of Danube and west of Rhine. Results for this early phase suggest the use of the western Mediterranean ore deposits or the Massif Central area in Transalpine Gaul, which became available as a result of Caesar's military campaigns in Gaul.

S Y Chazhengina, I Summanen and S A Svetov. Rare crucible from Medieval Karelian hillfort: Mineralogical fingerprints of functional use. *Minerals* 11(6), 2021, 648. DOI: 10.3390/min11060648.

A rare crucible with an unusually large volume and a pot-shaped bottom was excavated at the Tiversk hillfort (late 13th-14th century) in the north-western Ladoga region (Russia). ICP-MS data showed that it could be attributed to local technical ceramics. Because of its specific volume and shape, untypical of crucibles used in non-ferrous metallurgy in medieval Karelia, it had been attributed to the technical ceramics used for the cementation of iron. The present research has revealed traces of tin-bronze metal along with copper sulphide minerals on the crucible walls, suggesting non-ferrous metal working. Thermal treatment of the crucible at temperatures above 1050°C is evidenced by the heterogeneous composition of quartz and the thermal breakdown of biotite, recorded in the temper of the ceramic fabric, and the Raman spectra characteristic of haematite.

L Chiarantinia, I M Villa, V Volpic, G Bianchi, M Benvenuti, C Cicali, A Donati, R Manca and R Hodges. **Economic rebound versus imperial monopoly: Metal provenance of early medieval coins (9th–11th centuries) from some Italian and French mint**s. *Journal of Archaeological Science: Reports* 39, 2021, 103139. DOI: 10.1016/j.jasrep.2021.103139.

In this Pb isotope investigation of Italian Medieval coins, 44 specimens, minted between 9th-11th centuries AD, mainly from archaeological sites in Tuscany, were analysed by handheld X-ray fluorescence (pXRF) and the lead isotope composition (PbIC) by MC-ICP-MS. The compositions of the vast majority of coins from Italian mints were compatible with Melle and Harz Mountains ores and did not show isotope compositions that match with silver (lead-copper) mines from the Colline Metallifere district of southern Tuscany, despite their contemporary exploitation, evidenced by many local settlements.

H Gandois, L Rousseau, B Gehres, C Le Carlier, G Querré, B Poissonnier and J-M Gilbert. New hints of metallurgical activity on the Atlantic coast of France in the mid third millennium BC: overview and perspectives on beaker metal-

lurgy in western Europe. *Antiquaries Journal* 100, 2020, 1–32. DOI:10.1017/S0003581520000153.

Recent investigations of artefacts (copper residue, slags, smelting-crucible sherds) excavated at the Beaker culture site of L'anse de la République, Talmont-Saint-Hilaire, Vendée using XRF, petrographic analysis, metallographic microscopy, SEM and EDS microprobe analysis confirm that copper ore was smelted on the site. Radiocarbon dating of organic residue preserved on a ceramic sherd confirms the dating of the site to the earliest phase of the Beaker culture (2500 BC). The metallic copper produced here is characterised by two main impurities: arsenic and nickel. This article also considers the use of domestic smelting vessels for smelting ore; this technique may have been more widespread than previously thought in the Beaker culture on the Atlantic coast of Europe.

C Gardner, N S Müller, G Vekinis, I C Freestone, V Kilikoglou. High-temperature performance of two-layered ceramics and the implications for Roman crucibles. *Archaeometry* 62(5), 2020, 935–951. DOI: 10.1111/arcm.12569.

Roman metalworking crucibles are frequently characterised by an extra outer layer of clay, applied to a pre-formed vessel. Three-point bending and standardised dead-weight loading tests were used to determine the advantages offered by the extra outer layer. Deformation and fracture behaviour, at temperatures up to 1100°C, of two-layer, monolithic and tempered-monolithic briquettes were compared. Measurements indicated that the two-layer briquettes were more resistant to fracture at high temperatures: > 850°C they showed more extensive plastically deformed regions than monolithic briquettes. The influence of temper was consistent with previous results: it caused quasi-stable fracture and reduced fracture strength. The results suggest extra outer layers assisted in preventing catastrophic failure.

M Géraud, J Flament, A Hunt, G Sarah, E Foy and F Téreygeol. Les céramiques métallurgiques de Castel-Minier (Ariège, France) (13th-15th cent.). [Metallurgical ceramics from Castel-Minier (Ariège, France)]. *ArcheoSciences* 43(1), 2019, 83–95. DOI: 10.4000/archeosciences.6317.

Castel-Minier is a mining and metallurgical site located in the central French Pyrenees. During the 13th-15th centuries CE, its workshops extracted copper, lead and silver from non-ferrous ores mined nearby. Recent excavations unearthed heating structures and an exceptional corpus of metallurgical artefacts highlighting the broad range of metallurgical activities at Castel-Minier. Among these artefacts were nine crucible fragments. This paper presents the study of their paste and the analysis of the vitrification and metallic remains on their surface. The results account for the polymetallurgical nature of the site by underlining the use of different metals (lead, silver or copper), and by identifying some of the metallurgical process for which ceramics were used, in particular silver refining. Different strategies in technical ceramics making were noted. Those used for the metallurgy of lead and silver recycle common pastes or pots, while for copper, specific pastes with physical qualities that seem more suited to metallurgy were used.

J Kershaw and S Merkel. Silver recycling in the Viking Age: Theoretical and analytical approaches. *Archaeometry* 64(S1), 2021, 116–133, DOI: 10.1111/arcm.12709.

The impact of precious metal recycling in a historical context in which silver remelting was the norm in Viking-Age Scandinavia (*c*800-1050 AD) is assessed. New large-scale lead isotope and trace element datasets show the potential for revealing the contribution of western European and Islamic silver sources to discrete archaeological assemblages and defined coin and artefact groups. Chemical markers of change in imported silver are used to assess the longevity of circulating silver stocks. Recycling allows evaluation of long-distance trade networks, the movement of silver and the frequency of recycling events.

W Knierzinger, J-J S Huang, M Strasser, K-H Knorr, R Drescher-Schneider and M Wagreicha. Late Holocene periods of copper mining in the Eisenerz Alps (Austria) deduced from calcareous lake deposits. *Anthropocene* 33, 2021, 100273. DOI: 10.1016/j.ancene.2020.100273.

Calcareous sediment cores from Lake Leopoldstein (Eisenerz) were used to reconstruct the evolution of prehistoric copper mining in the Eisenerz Alps (Styria, Austria) by analysing elemental variations, trace elemental enrichments of Cu, Ni, Zn, As, Cd, Sb and Pb as well as light stable isotopes of nitrogen (δ^{15}N) and sulphur (δ^{34}S). The Early Bronze Age to the mid-medieval period (2070 BCE–850 CE) was studied by isotopic analyses to a depth of 6.60m, corresponding to about 3100 BCE. Regional mining during the mid-Bronze Age (*c*15th–14th centuries BC), the Hallstatt period (*c*8th–6th centuries BC) and in the late La Tène period (3rd century BC) was indicated. Statistical evaluation of the data showed a good correlation of trace elements associated with local copper ores (fahlores, chalcopyrite). Enrichments of Pb, in contrast, are characterised by a more substantial deviation from the general trace element trend and are mainly linked to lithogenic input. The results show the necessity of a broad-based multi-proxy approach when using calcareous lake sediments. δ^{15}N and δ^{34}S revealed no particular potential for identifying past mining activity.

J R McConnell, N J Chellman, A I Wilson, A Stohl, M M Arienzo, S Eckhardt, D Fritzsche, S Kipfstuhl, T Opel, P F Place, and J P Steffensen. Pervasive Arctic lead pollution suggests substantial growth in medieval silver production modulated by plague, climate, and conflict. *Proceedings of the National Academy of Sciences* 116(30), 2019, 14910–15. DOI: 10.1073/pnas.1904515116.

Lead pollution in Arctic ice reflects large-scale historical changes in midlatitude industrial activities, eg ancient lead/silver production and recent fossil fuel burning. 13 accurately dated ice cores from Greenland and Severnaya Zemlya documented spatial and temporal changes in Arctic lead pollution from 200 BCE to 2010 CE, with interpretation focused on 500 to 2010 CE. Atmospheric transport modeling indicates that Arctic lead pollution was primarily from European emissions before the 19th-century Industrial Revolution. Temporal variability was surprisingly similar across the large swath of the Arctic represented by the array, with 250- to 300-fold increases in lead pollution observed from the Early Middle Ages to the 1970s industrial peak. Superimposed

on these exponential changes were pronounced, multiannual to multidecadal variations, marked by increases coincident with exploitation of new mining regions, improved technologies, and periods of economic prosperity; and decreases coincident with climate disruptions, famines, major wars, and plagues. Results suggest substantial overall growth in lead/silver mining and smelting emissions from the Early through High Middle Ages, particularly in northern Europe, with lower growth during the late Middle Ages into the early modern period. Near the end of the second plague pandemic (1348 to ~1700 CE), lead pollution increased sharply through the Industrial Revolution. North American and European pollution abatement policies have reduced Arctic lead pollution by >80% since the 1970s, but recent levels remain ~60-fold higher than at the start of the Middle Ages.

S G de Madinabeitia, J I G Ibarguchi, and J F S Zalduegui. IBERLID: A lead isotope database and tool for metal provenance and ore deposits research. *Ore Geology Reviews* 137, 2021, 104279. DOI: 10.1016/j.oregeorev.2021.104279.

The use of Pb isotope data in geological research of ore deposits and metal provenance studies in archaeology has proved useful for investigating relations between ore sources and raw materials. The IBERLID database has been designed to include available information for nearly 3000 samples from the Iberian Peninsula and Balearic Islands in a currently complete but upgradable dataset using standardised variables. The database is available through an online interactive public tool (www.ehu.eus/ibercron/iberlid).

M Mehofer, M Gavranović, A Kapuran, J Mitrović and A Putica. Copper production and supra-regional exchange networks – Cu-matte smelting in the Balkans between 2000 and 1500 BC. *Journal of Archaeological Science* 129, 2021, 105378. DOI: 10.1016/j.jas.2021.105378.

The first archaeometallurgical results of slags from the sites Ružana, Trnjane and Čoka Njica, eastern Serbia are complimented by XRF and lead isotope analyses carried out on 28 copper-based artefacts. Radiocarbon dating points to copper being produced at the end of the Early Bronze Age (19th–18th centuries BC), more than 500 years earlier than previously assumed. Slag analysis indicates a copper matte smelting process in small open pit furnaces, using local sulfidic copper ores. This parallels the early production hotspots in central Europe, *eg* on the Hochkönig (Mitterberg mining areas), shedding new light on the development of copper based metallurgy in Europe. The eastern Serbia evidence shows that this area was a source of raw material for copper and bronze alloys. Our analyses also revealed that by the start of the Middle Bronze Age (*c*1700 BC) copper from the northern Italian mining areas in the Trentino region also reached the western and central Balkans.

J Montes-Landa, I Montero-Ruiz, Pere C Masoliver, M S Retolaza, J T Trilla and M Martinón-Torres. Traditions and innovations: versatility of copper and tin bronze making recipes in Iron Age Emporion (L'Escala, Spain). *Archaeological and Anthropological Sciences* 12, 2020, 124. DOI: 10.1007/s12520-020-01081-7.

Established around 575 BC, Emporion was a Greek colonial enclave in NE Iberia. An archaeometallurgical assemblage from a workshop context, dated the second half of the 6th century BC, included slag and technical ceramics. We aimed at reverse engineering the copper and tin bronze metallurgical technologies at the site. This identified copper smelting and melting, and a variety of bronze alloying techniques, together with iron smelting and forging. The use of Fe-rich copper ores with BaO, ZnO and PbO impurities is consistent with the exploitation of local sources, preceding the diversification of raw materials documented for later phases. The co-occurrence of co-smelting, cementation and co-melting as bronze making technologies is discussed with reference to efficiency and cost-effectiveness and contextualised in the broader colonial interaction. The early use of metallic tin for bronze production at the site supports a Mediterranean origin for this innovation in Iberia.

J Montes-Landa, M Murillo-Barroso, I Montero-Ruiz, S Rovira-Llorens, M Martinon-Torres. Interwoven traditions in Bell Beaker metallurgy: Approaching the social value of copper at Bauma del Serrat del Pont (Northeast Iberia). PLoS ONE 16(8), 2021, e0255818. DOI: 10.1371/journal.pone.0255818.

The analytical study of seven Bell Beaker (decorated and undecorated) vessels reused as crucibles is presented. We employed pXRF, metallography, SEM-EDS and lead isotope analyses. The results show evidence for copper smelting employing a remarkable variety of ore sources, including Solana del Bepo, Turquesa and Les Ferreres mines, and another unknown area. The smelting vessels were manufactured using the same clay, which contained both mineral and organic inclusions. The results support the notion that copper metallurgy played a predominantly utilitarian role in Bell Beaker societies and highlight idiosyncratic aspects of the metallurgical trajectory in the northeast. Differences between territories challenge unilinear explanations of technological and social development after the introduction of metallurgy. Separate trajectories can only be explained in relation to area-specific socio-cultural and environmental factors.

V Orfanou, T Birch, S Sindbæk, C Feveile, G Hoffmann Barfod, C Lesher. On diverse arts: crucible metallurgy and the polymetallic cycle at Scandinavia's earliest Viking town, Ribe (8th–9th c. CE), Denmark. *Archaeological and Anthropological Sciences* 13(5), 2021, 81. DOI: 10.1007/s12520-021-01308-1.

Results from the analytical investigation of the polymetallic, non-ferrous metallurgical cycle at early Viking Age Ribe in the 8th and 9th centuries CE are presented. Surface analyses of crucibles and moulds (handheld XRF) is combined with micro-destructive examination (micro XRF, electron microprobe spectroscopy (EPMA)) of crucibles, moulds, ingots, blanks, and finished objects from different stages of the secondary metallurgical production. The working of a range of copper alloys with (leaded) brass was the most common, alongside small-scale working of silver and gold. Analytical evidence suggests a move towards technological standardisation at Ribe workshops from the pre- to early Viking Age as reflected in the tighter compositional groupings for the crucible fabrics, the alloy choices for specific artefact types, *eg* keys and brooches, and an overall move towards high Zn brass from the 8th century to the first half of the 9th century CE.

L Perucchetti, J P Northover and M David-Elbiali. What is a dagger? A metallurgical interpretation of three metal daggers from western Switzerland dated from the late neolithic to the early Bronze Age. *Journal of Archaeological Science: Reports* 30, 2020, 102251. DOI: 10.1016/j.jasrep.2020.102251.

The role of daggers in prehistoric European society has been long debated. Within this discussion, we may add some hints to understand the human choices behind daggers' production, in a study which combines their shape, the metal used for them, the working production techniques. In this paper, we are applying this approach in the study of three daggers (owned by the museum of Neuchatel) from western Switzerland, dated to the end of the neolithic and Early Bronze Age.

M J Ponting. Recycling and Roman silver coinage, in C N Duckworth and A Wilson (eds), *Recycling and reuse in the Roman economy*. 2020, 265–284, ISBN: 9780198860846. DOI: 10.1093/oso/9780198860846.001.0001.

One of the great advantages of non-ferrous metals over most other materials, with the exception of glass, is the fact that artefacts that are broken or otherwise no longer of use can be melted down and remade into something else. For Roman coinage, this characteristic would have been particularly useful, enabling frequent changes of both emperor and coin type without the need for large amounts of freshly mined metal and incurring the associated costs of smelting. Furthermore, it also means that objects already made of metals of the correct composition can be converted into coin relatively easily. Evidence of both trace elements and lead isotopes is reported, presenting a complex picture of mixing, recycling, refining, and episodic use of stored resources that are occasionally supported by references in historical documents and stylistic features of the coins themselves.

W Powell, M Johnson, C Pulak, K Aslihan Yener, R Mathur, H Arthur Bankoff, L Godfrey, M Price and E Galili. From peaks to ports: Insights into tin provenance, production, and distribution from adapted applications of lead isotopic analysis of the Uluburun tin ingots. *Journal of Archaeological Science* 134, 2021, 105455. DOI: 10.1016/j.jas.2021.105455.

At least 117 ingots (roughly one tonne) of tin were raised from the Late Bronze Age Uluburun shipwreck (*c*1320 BC). Over half of the analysed ingots have high Pb concentrations (>100 ppm). LIA indicates that the Pb originated from the Pb-Ag-rich Bolkardağ region of the south-central Taurus Mountains. A second group of *c*28 tin ingots with Pb <100 ppm contain additional uranogenic Pb but retain $^{208}Pb/^{204}Pb$ compositions that overlap with the *c*300Ma tin regions of Western Europe and Central Asia, with the most likely source being the Tienshan Mountains in Kyrgyzstan, Tajikistan, and Uzbekistan. It is now possible to contextualize the Uluburun tin ingots more securely within the metallurgical systems of the Central Taurus-Cilicia-Amanus axis. Tin production in the South-Central Taurus region appears to have served elite and common consumption networks via markedly different technologies. The south-central Taurus and Cilician cities served as important components of maritime and terrestrial metal distribution around the E Mediterranean, providing a range of metals from a single geographical region.

T Skowronek, A Hauptmann, M Segschneider, J Auer, S von Arbine, A Maass, A Pappot, Th Maarleveldh, and N Brinck. Reißscheiben from shipwrecks as an indicator for copper qualities produced in the major middle and North European mining districts during the late medieval and early modern period 15th–17th Century AD. *Journal of Archaeological Science: Reports* 39, 2021, 103155. DOI: 10.1016/j.jasrep.2021.103155.

Major advances in maritime archaeology in the last 20 years resulted in the discovery of several shipwrecks carrying copper slab ingots (Reißscheiben). We present ICP-MS trace elemental and lead isotope data for 52 Reißscheiben ingots salvaged at three different findspots in northern European waters dating to the 15th and 16th century which show the Reißscheiben originated from two different mining centres, Slovakia and the southern Harz foreland. The results reveal the difficulties that early modern copper smelters may have had to deal with when processing sulfidic copper ores, as it seems that refining processes were not understood sufficiently. The written historical sources, however, suggest that early modern brass makers already understood which regions produced copper with the most suitable qualities.

J G Tarbay, B Maróti, Z Kis, G Káli and L Szentmiklósi. Non-destructive analysis of a Late Bronze Age hoard from the Velem-Szent Vid hillfort. *Journal of Archaeological Science* 127, 2021, 105320. DOI: 10.1016/j.jas.2020.105320.

The small Ha B1 bronze assemblage from Velem-Szent Vid (Transdanubia, Vas County, W Hungary) of a spearhead with remains of the wooden shaft, a sickle, and three different types of ingots was examined using XRF, PGAA, TOF-ND, neutron and X-ray imaging. The spearhead was a good quality casting with a relatively high Sn and extremely low porosity, with minimal post-casting treatment. Wear traces suggested it may have been used in parrying situations. It was intentionally destroyed by plastic deformation prior to deposition. The ingots were cast in open one-piece moulds and were untreated before deposition. The ratio of Pb in the miniature plano-convex ingot (89±0.3m%) and the rod ingot (94±0.3m%) was high, identifying them as lead ingots, a rare raw material type during the Late Bronze Age. The cuboid ingot contained high Pb (13-37m%) and Sb (0.6-6.2m%) based on PGAA. Chalcocite (Cu_2S) was identified by TOF-ND, which points to the possible origin of the raw material or production method (smelting).

F Téreygeol, G Sarah, and B Gratuze. D'argent, de verre et de plomb: maximisation de la production et économie de pénurie dans les mines de Melle au haut Moyen Âge. in D Boisseuil, C Rico and S Gelichi (eds), *Le marché des matières premières dans l'Antiquité et au Moyen Âge* [on line]. Rome: Publications de l'École française de Rome, 2021. ISBN: 9782728314072. DOI: 10.4000/books.efr.7882.

The lead-silver deposit at Melle was opened during the 6th century AD, expanded in the second half of the 7th century, to decline and die out in the 10th century. However, it is no longer possible to reduce Melle's mining production to silver alone. The lead, an obvious by-product of the smelting of argentiferous galena, must be taken into account. More unexpectedly, glass is also included in this technical and economic scheme. The work undertaken on the dissemination of the mine's products across Europe associ-

ated with the archaeological excavations at Melle highlights the productive logic of this major silver mining exploitation whose first victim was the neighbouring forest.

J van Bennekom, E van Bork and F Tereygeol. Explorative studies in 16th century silver refining recipes. *Journal of Archaeological Science: Reports* 36, 2021, 102775. DOI: 10.1016/j.jasrep.2020.102775.

XRF analysis showed that several works of Adam Van Vianen, one of the founders of the Dutch *Kwabstijl*, had a more elevated silver and lower bismuth percentage in the silver alloy than was commonly found in works of his contemporaries. We hypothesize that Van Vianen used an alloy with a high percentage of silver as it is more malleable, allowing him to achieve extreme deformation of the silver without the formation of cracks. Recipes that would have been widely used at the time and which describe silver production and refining in the silversmith workshop were chosen to serve as a basis for making reconstructions in silver. Those in *Probierbüchlein* (The little book on assaying) by Calbus of Freiberg and *Beschreibung allerfürnemisten mineralischen Ertzt und Berckwercksarten* (Description of leading ore processing and mining methods) by Lazarus Ercker were selected. Reconstructions of the recipes on assaying were made and are discussed.

J R Wood, Y-T Hsu and C Bell. Sending Laurion back to the future: Bronze Age silver and the source of confusion. *Internet Archaeology* 56, 2021. DOI: 10.11141/ia.56.9.

We suggest ancient metallurgists recognised that silver minerals (*eg* horn silver) could be concentrated in molten lead and that the lead isotope analysis (LIA) signatures of Bronze Age silver artefacts reflect the use of exogenous lead to extract silver. We suggest that the Laurion lead used for silver extraction resulted in the inadvertent transfer of its LIA signature to silver objects and metallurgical debris recovered around the Aegean. Recent analyses of Mycenaean shaft-grave silver (*c*1600 BCE) support these conclusions. A mid-1st millennium BCE date for the first exploitation of silver from argentiferous lead ores is consistent with the absence of archaeological evidence for centralised control over Laurion until the Archaic period, the paucity of lead slag associated with silver-processing debris at Bronze Age sites, the scarcity of silver artefacts recovered in post-shaft grave contexts at Mycenae and throughout the Early Iron Age Aegean, the few Attic silver coins with LIA signatures consistent with Laurion until after 500 BCE and a single unambiguous mention of silver in the Linear B texts.

NEAR EAST

C J Davey, B Santarelli, T Rehren. Egyptian Middle Kingdom copper: Analysis of a crucible from Buhen in the Petrie Museum. *Journal of Archaeological Science*: *Reports* 36, 2021, 102859. DOI: 10.1016/j.jasrep.2021.102859.

The study of a well-preserved crucible fragment from the Middle Kingdom Egyptian fortress in Buhen in lower Nubia revealed the unexpected presence of numerous prills of an arsenic- and nickel-rich copper alloy, apparently in a smelting slag. The possible metallurgical processes producing strongly reducing conditions preserved in the sample, taken from near the low-sitting spout of the vessel, indicate its use for smelting a very rich secondary copper-arsenic ore, rather than for the more oxidising refining of raw copper, or simple casting of a copper-arsenic alloy. These alternative interpretations are also discussed, considering the chronology and location of the fortress near a known copper deposit in the then southern border of Egypt.

P Holakooei, O Oudbashi, M Mortazavi, M Ferretti. On, under and beneath the patina: Evaluation of micro energy dispersive X-ray fluorescence quantitative data on the classification of archaeological copper alloys. *Spectrochimica Acta Part B: Atomic Spectroscopy* 178, 2021, 106128. DOI: 10.1016/j.sab.2021.106128.

The viability of quantitative XRF data for the classification of ancient copper alloys was checked by quantitative micro XRF (μ-XRF) analysis of a corroded surface, a stripped-patina area and polished cross sections of 25 archaeological copper alloys from Iran. Detection limits and quantification, precision and accuracy were measured using 12 certified reference materials (CRM). The data obtained by these three methods were statistically evaluated and compared with the compositional data on the same samples obtained by ICP-OES. The corroded surfaces were depleted in Ni and Zn and enriched in Pb, Sn and As. We suggest that although μ-XRF data from the corroded surfaces may result in misleading information, the areas with the lowest Sn concentration may represent the closest compositional data to the absolute quantity of Cu, Zn, As and Pb in ancient copper alloys. The quantitative μ-XRF data from the stripped-patina surface and from the polished cross sections are comparable with the ICP-OES data and can be confidently used for determining the diversity and technology of ancient copper alloys.

S Merkel. Evidence for the widespread use of dry silver ore in the Early Islamic period and its implications for the history of silver metallurgy. *Journal of Archaeological Science* 135(3), 2021(3), 105478. DOI: 10.1016/j.jas.2021.105478.

This study has found evidence that extremely rich silver ores must have played a key role in one of the major silver-using polities in the 8th and 9th centuries AD: the Early Islamic Caliphate. Metallography of 26 coins revealed that matte inclusions (silver-copper sulphides) are widely found in Umayyad and Abbasid dirhams, renowned for their exceptionally pure silver. Since matte preserved in the coins could not survive the strongly oxidising refining process required to separate lead from silver, this silver cannot have been produced solely from lead ore or through the use of lead. This suggests that 'dry' silver ore consisting of nearly pure silver minerals were processed without lead and made a vital contribution to the Early Islamic silver supply. The results have major technological and economic implications and overturn long-standing views on the history of silver metallurgy. They also have important consequences for provenance studies and the interpretation of elemental and lead isotope data.

O Oudbashi and M Mishmastnehi. Archaeometallurgy of copper in the Middle Elamite period of southwestern Iran: Analytical investigation of various parts of the copper produc-

tion in Haft Tappeh. *Journal of Archaeological Science: Reports* 30, 2020, 102216. DOI: 10.1016/j.jasrep.2020.102216.

The analytical results from metallurgical materials from the important Middle Elamite site of Haft Tappeh (*c*1400 BC) include slags, metallic ingots/prills and objects. They suggest a partially incomplete primary copper smelting process which may be interpreted as a two-step procedure, with partial smelting of copper from sulphidic ores leading to matte production and then refining the copper ingots/prills to obtain metallic copper. The cementation of copper and cassiterite was the main process used to make tin bronze ingots/prills. To produce bronze, the Elamite metalworkers might have smelted mixed copper-tin ores directly as well. A third technique used at Haft Tappeh was the manufacturing of small objects made of impure copper and/or tin bronze. The copper-base metallurgy in Haft Tappeh can be seen as three main stages including copper smelting from sulphidic ores, the refining of copper ingots/prills, and producing tin bronze in different ways.

O Karagiorgou, S Merkel and M Wołoszyn. A contribution to the technology and sources of lead in Byzantium: lead isotope analysis of ten Byzantine seals. *Byzantinische Zeitschrift* 114(3), 2021, 1161–1203. DOI: 10.1515/bz-2021-0058.

This article presents the results of lead isotope analysis of ten Byzantine seals from the sigillographic collection of Robert Feind (Cologne). Four seals are datable to the Early Byzantine period, five to the Middle Byzantine and one to the Late Byzantine period. Three seals are of imperial issue. The results of the analysis of lead are compared with results of isotope analyses of other silver and lead artefacts from Late Antiquity and the Late Byzantine period. This leads to the following conclusions: many of the seals have isotope ratios consistent with Aegean-Bulgaria-Western Turkey sources; reused lead was also employed in the manufacture of seals; there appear to be significant chronological and regional differences in the lead used for casting blanks in the eastern Mediterranean.

C D Standish, S Merkel, Y-T Hsieh and J Kershaw. Simultaneous lead isotope ratio and gold-lead-bismuth concentration analysis of silver by laser ablation MC-ICP-MS. *Journal of Archaeological Science* 125(1), 2021, 105299. DOI: 10.1016/j.jas.2020.105299.

A new approach is presented for the simultaneous analysis of lead isotope ratios and gold, lead, and bismuth concentrations in metallic silver using nanosecond laser ablation multi-collector inductively-coupled plasma mass spectrometry (LA-MC-ICP-MS). Corrections for both isotope and concentration analyses are performed using an in-house matrix matched silver reference material RM3834. Accuracy and external reproducibility are demonstrated by repeat analyses of a further seven silver reference materials all characterised by solution (MC)-ICP-MS approaches. Internal precisions and external reproducibilities of gold, lead and bismuth concentration analyses are typically <25%. Data are consistent with solution-based approaches. Methods are further demonstrated through analyses of a set of Islamic silver dirhams from the mint of al-Muhammadiyya, highlighting their applicability to geochemical studies of archaeological artefacts.

C Wouter, C J Davey and S Hendrickx. An Early Dynastic crucible from the settlement of Elkab (Upper Egypt). *Journal of Egyptian Archaeology*, 105(1), 2020, 29–42. DOI: 10.1177/0307513319885098.

During excavations in the spring of 2015 in the settlement of Elkab, a complete and almost intact crucible was discovered on the floor level of a Second Dynasty building. The crucible has the shape depicted in Old Kingdom tomb metal-working scenes. Its profile became the hieroglyphic ideogram denoting metal-workers implying it was an iconic implement, although this is currently the only example of this kind of crucible from Egypt. Indeed, this is the earliest complete crucible for melting copper yet found anywhere.

ASIA

M Cadet, F Tereygeol, T Sayavongkhamdy, V Souksavatdy, T Luangkhoth, N Chang, P Dillmann and T O Pryce. Late prehistoric copper smelting in the Lao PDR: Experimental reconstruction based on the Vilabouly Complex evidence. *Journal of Archaeological Science: Reports* 37, 2021, 102932. DOI: 10.1016/j.jasrep.2021.102932.

Field experiments in copper smelting were carried out elucidate the copper production processes at the Vilabouly Complex (VC), an Iron Age extraction and production site in central Laos, one of only three such sites known in southeast Asia. Analysis of the ores, crucibles, slag fragments and copper alloy objects and the geology suggested the introduction of sulphidic ores during the smelting process, probably co-smelting with carbonate ores (*eg* malachite) and a secondary copper sulphide, chalcocite (Cu_2S). Experimental reconstructions co-smelting malachite with chalcocite in a one step-process, using crucibles based on the archaeological examples, produced matte of different compositions, depending on the charge used, with metallic copper and slag. The ratio (1:1) of malachite:chalcocite resulted in products comparable to the Vilabouly Complex material and thus strengthens the hypothesis.

S Liu, T Rehren, D Qin, J Chen, W Zhou, M Martinón-Torres, X Huang and W Qian. Coal-fuelled crucible lead-silver smelting in 12th-13th century China: A technological innovation in the age of deforestation. *Journal of Archaeological Scienc*e 104, 2019, 75-84. DOI: 10.1016/j.jas.2019.01.004.

The unique silver-lead production site in Hebei province, north China, (12th and 13th centuries AD) yielded many slag-filled tubular crucibles and coal-ash slag chunks. The refractory clay crucibles contain slag with lead silver particles, un-reacted ore and numerous fragments of metallic iron, suggesting the reduction of argentiferous sulphidic lead ores to metal by desulphurisation using metallic iron. Coal fuelled this process from outside the crucibles. This was an important technological innovation, probably associated with rampant deforestation and the fuel crisis historically documented for the early 2nd millennium in northern China. The early adoption of coal was not as widespread as typically assumed, as it required a range of technological innovations. Crucible smelting, as one of the solutions, was embraced by lead-silver smelters, while most

iron smelters in this period still persisted with the charcoal-fired furnace smelting tradition.

W Zhou, S Liu, Liu Haifeng J Chen and T Rehren. Traditional Chinese technology of crucible lead smelting: A comprehensive study based on historical records and archaeological findings. *Chinese Annals of History of Science and Technology* 5(1), 2021, 27-57. DOI: 10.3724/SP.J.1461.2021.01027.

In crucible lead smelting, a traditional technology unique to China, lead is produced by reducing lead sulphide with iron metal in crucibles. Recently, a number of crucible lead production sites of the Liao-Jin-Yuan periods (10th-14th centuries CE) have been found in northern China, providing opportunities for the study of the technology. This paper provides a comprehensive overview of this technology based on historical and archaeological evidence, with particular emphasis on the crucibles. Firstly, it reviews the historical records on crucible lead smelting, and introduces the technology used in Gansu during the Qing period (1644–1911) as well as indigenous methods used in the 20th century; secondly, it summarizes the discoveries of crucible lead smelting sites in recent years, and reconstructs the manufacturing of crucibles and the iron reduction method by analysis of the crucible and slag; finally, it expounds the technical characteristics of crucible lead smelting, and explores the origin and development of the technology.

AFRICA

F Bandama, S Chirikure, S Hall and I Shuro. Iron fabrication during the "Age" of tin and bronze in the Southern Waterberg of Limpopo Province, South Africa. *Studies in the African Past* 13/14, 2018, 1–19.

Since the 1908 re-discovery of the pre-colonial tin mines at Rooiberg in the Southern Waterberg of Limpopo Province of South Africa, the focus has been on tin and bronze production, to the exclusion of iron and copper which were exploited even before the 2nd millennium CE inception of tin and bronze production in this area. Iron production and consumption patterns at the 2nd millennium CE sites of Rhenosterkloof 1 and Tembi 1 in the Sand River Valley of the Southern Waterberg are explored. Analysis of blooms and metallic objects showed that they were products of an indigenous bloomery iron technology, widespread in southern Africa in the pre-colonial period. Careful hot and cold working achieved optimal qualities of these pre-dominantly non-utilitarian iron objects.

AMERICAS

M C Lucchetta, G Gutiérrez and H De Rosa. Studies on wrought iron pieces from the Villarino ship, 1880 (Argentina). *Journal of Archaeological Science: Reports* 39, 2021, 103179. DOI: 10.1016/j.jasrep.2021.103179.

The *Villarino* steamer was a transport vessel of the Argentine navy launched in 1880. It sank in 1899 off the town of Camarones, Province of Chubut, Argentina. The main goal of this work is to present a metallurgical characterisation of the parts used in the construction of the *Villarino* hull, in order to extend the knowledge of the technology used in this ship. In addition, the authors attempt to put the results into a historical context, relating it to technological changes that occurred in the naval industry in the second half of the 19th century.

F Téreygeol and P Cruz. La mine d'argent de Potosi: la technique au centre d'une lutte de pouvoir entre les Incas et les Espagnols (XVIe-XVIIe siècles) [The Potosi silver mine: technique at the centre of a power struggle between the Incas and the Spaniards (16th-17th centuries)], *Patrimoines du Sud* [on line], 13, 2021. DOI: 10.4000/pds.6164.

In recent years, numerous works have begun to examine Potosi's past and the colonisation of the region. These studies re-envision the connections between regional political relationships and the two historical invaders of the area, the Inca and the Spanish. Archaeological studies of sites of production have expanded our understanding of the processes. Technical topics covered include mining, preparation of ores, extractive metallurgy, muffle and reverberatory furnaces for reduction and cupellation. The reconstruction of indigenous know-how and production techniques highlights the power struggles over control of silver production.

U Veronesi, T Rehren, B Straube, and M Martinón-Torres. Testing the New World: early modern chemistry and mineral prospection at colonial Jamestown, 1607–1610. *Archaeological and Anthropological Sciences* 11, 2019, 6851-6864. DOI: 10.1007/s12520-019-00945-x.

Research on an assemblage of metallurgical crucibles used in the assay of minerals at colonial Jamestown to explore the range of chemical operations carried out at the site of the first permanent British settlement in America is reported. The results show that the colonists used high-quality Hessian crucibles to perform tests on different types of complex polymetallic sulphides. This was done to prospect for potential silver and copper ores and to find suitable sources of zinc and tin to be alloyed into brass and bronze through cementation with imported copper offcuts.

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. Other abstracts relating to archaeometallurgy can be found in the British and Irish Archaeological Bibliography, available at http://www.biab.ac.uk, and in Art and Archaeology Technical Abstracts, available at http://aata.getty.edu/Home.