5th International Conference

Archaeometallurgy in Europe 2019

University of Miskolc, Hungary

19th - 21st June, 2019

Abstracts

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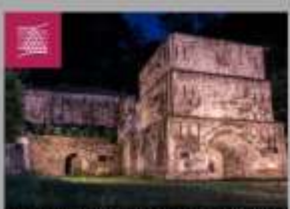

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FOREWORD

The 5th International Conference on Archaeometallurgy in Europe intends to promote an active dialogue among archaeometallurgy researchers with different specialisations and backgrounds, to create an opportunity to discuss the study of ancient metallurgical processes, and conservation science, and to discuss the application of modern metallurgical experimental methods and techniques to investigate, identify and date ancient artefacts. A further purpose is also that of creating an interaction between institutions and researchers, to facilitate the integration of different approaches and finally to promote contacts and collaborations between scholars from European and non-European countries and from different research areas.

In order to achieve the main goal of the conference, (i.e. emphasising and strengthening the interdisciplinary character and activities of archaeometallurgy), we bring together specialists interested in this topic, to exchange data, and update the knowledge on metallurgical activity in Europe from a global archaeometallurgical perspective. This e-book includes all the abstracts, submitted for the conference and accepted by the scientific committee, are those informing on recently excavated sites, results of analyses of related finds, new analytical methods, results of the latest comparative studies, as well as new trends and results in experimental archaeometallurgy.

I hope, by this event, that the good professional standards developed in the AiE-conferences up to now will be continued.

Dr. Béla Török

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PATINATED ALLOYS: HISTORY OF RESEARCH AND MOST RECENT DATA

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The earliest scientifically documented artificially patinated alloys, consisting of copper containing small amounts of gold, silver and often arsenic, are Egyptian, are dated to the 19th century BCE and called hmty km (black copper). The technique appears in the Aegean around the 16th century BCE under the name kuwano. In Roman times the black patinated alloy is called Corinthium aes. In this period different nuances and new artificial patinations of different colors appear. In Late Antiquity or Early Middle Ages this material disappears from the West, but is found in various Asian countries. This paper summarizes the researches on ancient artificially patinated alloys from earliest to modern times and discusses the still open problems.

CHALCOLITHIC COPPER SMELTING AT AKLADI CHEIRI, BULGARIA

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The invention of metallurgy is one of the defining steps in the emergence of complex societies. Recent research is increasingly shifting attention from the traditional debate of a single origin of this technology somewhere in the Middle East to a more nuanced picture with multiple origins, and a stronger emphasis on the Balkans as a major region to drive these developments.

The talk will present evidence for 5th millennium BC copper smelting from the site of Akladi cheiri, Chernomoretz at the Bulgarian Black Sea coast. Discovered during rescue excavations ahead of tourist development, Akladi cheiri has produced remains of a Late Neolithic / Early Chalcolithic settlement with unparalleled evidence for the smelting of ore procured from the copper rich mountains ('Medni rid') in the immediate hinterland. Several kilograms of ores, countless partly-slagged sherds of domestic pottery, and lumps of slag with metal trapped in it enable us to reconstruct the process in great detail, using optical and electron microscopy as well as trace element and lead isotope analyses as the main approaches. The emerging picture enables us to better understand the sparse evidence from other very early metallurgical sites elsewhere, leading to a much more colourful model of the origins of metallurgy in SE Europe, and beyond.

ARCHAEOMETALLURGICAL PRODUCTION AND SOURCES FROM THE VERA BASIN (SE IBERIA)

MERCEDES MURILLO-BARROSO[1,a], IGNACIO MONTERO-RUIZ[2,b], M. DOLORES CAMALICH MASSIEU[3,c], DIMAS MARTÍN-SOCAS[3,d], JOSÉ MIGUEL NIETO[4,e], MARCOS MARTINÓN-TORRES[5,f]

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The role of metallurgy in the Copper Age communities of the Iberian Southeast is a recurrent question in the archaeological research on Western Europe. In this work we address the territorial organization of metallurgical production in the Vera Basin (Almería, Spain) based on the lead isotopes and trace elements analyses of archaeometallurgical remains and Cu ores.

The material under study comes from the three main settlements with metallurgical activity in the area (Las Pilas, Santa Bárbara and Almizaraque), as well as ore samples collected on a geological survey. This study includes trace element compositions and lead isotope analyses by MC-ICP-MS of 44 ore samples, slag fragments and objects recovered in the three metallurgical sites as well as 34 ore samples from copper deposits from the Eastern part of the Internal Zone of the Betic Cordillera, some of them with evidences of prehistoric mining, recovered during the field work.

Data from the literature analysed by TIMS have been also considered for comparison although a larger analytical error is highlighted, especially for isotope 204. The lead isotopic signature of the analysed geological samples shows three separate isotopic fields. These fields are also consistent with differences in trace element compositions evidenced by principal component analyses.

When archaeological data is projected on the isotopic fields defined, we observe that each settlement exploits the resources of its immediate sourroundings (at a maximum distance of 20 km in straight line), prioritizing those mineralizations richer in arsenic and other impurities: Pinar de Bédar instead of Sierra Cabrera for the case of Las Pilas, and Cerro Minado for the case of Santa Bárbara and Almizaraque. This is also consistent with the Principal Component Analysis of trace elements compositions. The possibility that Almizaraque also exploited the minerals of Herrerías, although to a lesser extent, remains open. The organization of metallurgical production that we observe in the Vera Basin is therefore a small-scale regional production in which the exchange networks are observed in relation to the finished objects, for which a greater mobility can be inferred.

THE "OBERHALBSTEIN-PROCESS": THE CHAÎNE OPÉRATOIRE OF THE PREHISTORIC COPPER PRODUCTION IN THE OBERHALBSTEIN VALLEY (CH)

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In recent decades the precise mode of operation of Bronze Age copper smelting process in the Alps has been subject to ongoing scientific debate, dominated mainly by natural scientists. A new, transdisciplinary study in the Oberhalbstein Valley aims to shed a new light on these old questions from a new perspective: besides the common mineralogical and geochemical investigations, also a detailed typological and morphological examination of the main information carrier, the smelting slag, has been carried out. A joint interpretation of the results of these natural scientific and archaeological approaches lead to a less one-sided reconstruction of the smelting process. The proposed model shows parallels as well as significant differences compared to the east alpine "Mitterberg-process". According to geochemical analyses, Oberhalbstein copper can also be distinguished relatively clearly from other alpine copper.

Furthermore, intensive field survey resulted in a good knowledge of the mining area and its organisational structure with a total of approximately 100 sites, consisting of a couple of (pre)historic mines, dozens of smelting sites and a few prehistoric settlements connected to copper production by the finds of smelting slags and beneficiation tools. Furthermore, a significant improvement of the previously limited dating of these sites clearly shows the peripheral location of the copper production area under investigation – both from a geographical and a chronological point of view. While most of the (south)eastern and western Alpine mining districts flourished during different periods of the Bronze Age, the Oberhalbstein Valley in the central Alps did not reach its production peak until the Early Iron Age.

THE DARK SIDE OF ANCIENT COPPER PRODUCTION: MAPPING METALLURGICAL POLLUTION IN THE TIMNA VALLEY (ISRAEL)

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As part of Tel Aviv University's Central Timna Valley Project (http://archaeology.tau.ac.il/ben-yosef/CTV/) we conducted chemical analysis (pXRF) of the soil in one of the largest copper smelting camps in the region – Site 34 ("Slaves' Hill"). Based on a dense grid of more than a hundred samples we were able to map the distribution of various elements, which in turn enabled detection of activity areas and an assessment of the extent of metallurgical pollution in relation to its sources (ore processing and smelting workshops). Contra to previous claims our results show a discrete and contained Cu/Pb pollution, indicating limited effects on the population that lived in the area during and after the site's activity period (early Iron Age, late 11th – 10th centuries BCE).

REVISITING IRON IN ANCIENT COPPER: REGIONAL AND CHRONOLOGICAL TRENDS IN THE LEGACY DATASET

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In the Anglophone world the work of Paul Craddock and his colleagues at the British Museum did most to raise the importance of iron for understanding copper technology (Craddock and Meeks 1987). Building upon Percy, Tylecote, Charles and others, Craddock noted a stepwise increase of copper's iron content over time, which he linked to developments in the smelting process. He argued that early copper metallurgy was often centred on small-scale, crucible techniques of reducing hand-picked, enriched ores, which produced little slag and therefore no opportunity for iron to enter the system. In contrast, people in later periods produced far larger volumes of metal, but by smelting lower grade ores in true-furnaces. It was an important technological advance to be able to consistently produce iron silicate slags to draw away the unwanted gangue and keep the furnace productive. The molten copper would absorb low levels of iron in this process, and retain an appreciable amount even after deliberate refining.

Thanks to the efforts of generations of analysts, the archaeometallurgical community has access to a huge legacy dataset. FLAME and its predecessor projects have digitised, collated, and curated a significant portion of this history (http://flame.arch.ox.ac.uk/). This allows us to test Craddock's 'slag bath' model on regions and time periods that he was not able to consider. Extending from its other models, FLAME can characterise individual flows of copper to try to understand more precisely how trade, use, and other processes created iron patterns in specific regions. This paper will also highlight other ways for iron to enter copper that have come to light since Craddock's pioneering papers, such as the use of speiss (iron arsenide) in Bronze Age Iran (Rehren et al. 2012), and the effects of the cementation process in Roman brass making.

Overall, Craddock's argument for an increase of iron in copper over antiquity has strengthened significantly during the last 40 years. Through considering chemical data from Europe, Russia, the Near East, and China, over several time periods, we may in fact say that it is one of the most ubiquitous chemical patterns we have encountered. But below that broader consistency are a number of local patterns that deviate from the model of smelting improvements and the promotion of slagging. Alongside 'slag baths', we must also consider new mining regions, complex alloying procedures, and recycling as important factors. Currently iron is a blunt tool to bring to bear on copper and more work is required, but it is a pleasing thought that the metal that has stolen so much of copper's limelight in recent millennia can broaden our understanding of its venerable ancestor.

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INVESTIGATIONS OF GOLD METALLURGY OF COPPER AND BRONZE AGE IN THE CARPATHIAN BASIN

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Prehistoric gold finds suggest intensive trade contacts between Central European communities (Kovács, Raczky 1999; Csedreki, Dani 2011; Meller 2014). Due to most recent research of gold raw material exact provenance can be determined by invasive (LA-ICP-MS) methods only (Leutsch et al. 2015; Lockhoof, Pernicka 2014; Szathmári et al. in print). Identification of manufacturing techniques and the characterisation of the raw material by non-destructive methods, however, can provide a huge amount of information regarding the Copper Age and Bronze Age gold artefacts found in the Carpathian Basin. This paper focuses on studies of the gold artefacts of either the Early Copper Age Tiszapolgár culture (4350–4200 BC), and the Middle Bronze Age period from eastern and western Hungary (2000–1500 BC). In collaboration with the Department of Archaeology, Hungarian National Museum, the Déri Museum in Debrecen, the Laczkó Dezső Museum in Veszprém, the Ferenczi Museum Center and the Laboratory for Heritage Science at MTA Atomki, the Momentum Mobility Research Group of the Hungarian Academy of Sciences analyzes golden artefacts by non-destructive PIXE test series in order to determine their material composition (major, minor and trace element concentrations), to investigate various production techniques and to link them to possible ore sources and workshops. Our presentation collects new data to answer the question of how the metalworkers of the mentioned era could obtain the raw materials of golden objects discovered in present-day Hungary.

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PURE AND FINE, BUT REFINED? SOME EXAMPLES FROM THE CELTIC GOLD PROJECT

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During the first year of research within the French-German ANR-DFG CELTIC GOLD Project "Fine metal work in the Western La Tène culture" some partly rather inconspicuous objects became noticeable due to their particularly high gold contents. Usually, natural gold contains several percent of silver, mainly 10-35% Ag. In contrast, gold with less than 5% Ag is very rare. Therefore, such a pure gold, as it was used for the production of some of the Celtic objects, already indicate the use of refined metal, i.e. gold desilvered by cementation with salt. For some objects this interpretation seems obvious, while for others it remains questionable based on their dating and/or chemical composition.

Even though several experiments have been carried out during the last decades (review in Craddock 2000, Wunderlich et al. 2014), mainly focussing on the efficiency of the process, the behaviour of trace and platinum-group elements has received little attention so far (Blet-Lemarquand et al. 2015, Craddock 2000, Pernicka 2014). Further, there is still no general agreement about absolute minimum and maximum silver concentration thresholds for the identification of gold purified by the cementation process.

We want to pick out the Celtic gold finds analysed so far that may have been produced from purified gold and present them in their archaeological and chronological context and discuss the above mentioned question about threshold values and trace element patterns in the context of Celtic gold metallurgy. This discussion will provide some hints to indirectly tackle the difficult question of the potential gold refinement by the Celts in view of the scarce archaeological evidence.

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CELTIC GOLD TORCS – AN INTERDISCIPLINARY AND DIACHRONIC PERSPECTIVE

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During the Iron Age, gold torcs are particularly well represented in the archaeological record. They are mainly discovered in hoards, sanctuaries or funeral contexts, often mentioned by Greek and Roman texts and represented on anthropomorphic figures. This large variety of discovery contexts and the diversity of sources available extends our understanding of how they were worn and allows a glimpse on their social, ritual and symbolic value.

This paper deals with Celtic gold neck ornaments from an interdisciplinary and diachronic view. It scrutinizes the evolution of torcs in style, material composition and gold working technology, as well in the depositional practice in time and space during the Iron Age, from the sixth to the first centuries BC. The case studies presented will concern torcs from continental Europe, in particular from Belgium, France, Germany and Switzerland. At the beginning of the third century BC coinage arises. Accordingly, the specific relation between gold torcs and coins will also be discussed. The approaches applied in this study include various methods from archaeological science (SEM, XRF, LA-ICP-MS), typo-chronology, tool-mark analyses, manufacturing techniques, experimental archaeology and iconography. Particular emphasis will be laid in the results dealing with the analytical and technological aspects of this group of gold ornaments.

EXPERIMENTAL AND ANALYTICAL STUDY ON GOLD PARTING PROCESSES USED IN ANCIENT TIMES

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This research is based on the use of experimental archaeology, chemistry and thermodynamics for the interpretation of ancient gold purification methods, under the guide of ancient textual sources (from Dioscorides, Pliny and Leyden Papyrus as examples) and goldsmith's appraisal. The aim is to understand the processes and their outcomes, to give new interpretations on archaeological evidence related to gold metallurgy (i.e. in Craddock & Ramage, 2000), supporting, with this comparative experimental dataset, the archaeological interpretations concerning cementation in ancient times.

Several trials have been carried on by using different compounds, temperature ramps, environments, allowing a base interpretation of the processes and of the classes of cements. The main groups of compounds such as the sulphates-salt group (i.e. misy or ios scolekos) and the iron phyllosilicate-salt group (i.e. powdered brick) have been tested, characterized in the reagent-product chains and thermodynamically interpreted.

Experiments had also the intent to understand multi-purpose combination of processes such as the collection-cupellation-cementation method, for the parting of gangue, accessory minerals, copper, and silver from gold by the combination of different procedures conducted together in the same crucible (Celauro et al. 2017, Loepp et al. forthcoming).

In the last year new results have been attained and here proposed:

An analytical appraisal of special mineral compounds collected from the ancient Voukasa, in cooperation with the Hellenic Copper Mines LTD and the Geological Survey Department – Cyprus, allowed to verify their role for cementation.

The use of stibnite as parting agent has also been tested and interpreted, thus adding the sulphur process to the possible procedures used.

New trials on the multi-purpose methods of collection-cupellation-cementation have been improved by using different timing and temperature ramps, allowing a better interpretation of the process described in Agatharchides' On the Erythraean Sea.

Preliminary analytical results on trace elements quantification after cementation and cupellation are proposed as possible fingerprints of transient processes used in the fabrication of archaeological artefacts.

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FROM THERE, BUT ALSO FROM HERE: GOLD TECHNOLOGICAL TRADITIONS IN SAN PEDRO DE ATACAMA (CHILE, SOUTH AMERICA), DURING THE MIDDLE PERIOD (AD 400-1000)

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This paper investigates gold technology in San Pedro de Atacama (northern Chile, South America), a strategic node in the South Central Andes during the Middle Period (AD 400-1000). Nearly 200 gold and silver personal ornaments and ritual objects have been recovered as grave goods from cemeteries at San Pedro ("SPA") dated to this period (Barón, 2004; Stovel, 2001; Téllez and Murphy, 2007). The aim of this research is to reconstruct the biographies of 140 gold objects made of hammered sheets, considering their production, use and particular contexts to understand their technology and role within the SPA society.

This research is driven by the conceptual frameworks of chaîne opératoire and artefact life-histories, and supported by the materials science analyses of finished objects. The analytical methods employed include pXRF, SEM-EDS, PIXE, optical microscopy and macroscopic observations to determine the alloy compositions, manufacturing techniques and technical sequences.

The results identify a heterogeneous assemblage where compositions, techniques and designs are varied, suggesting that the objects were most likely imported from different areas of the South Central Andes, such as Tiwanaku and northwest Argentina. Most importantly, evidence of two unexpected local technological traditions is documented: 1) a small-scale goldwork production, implying the unprecedented presence of specialised metalworkers making gold items; and 2) a tradition of modifying and reusing imported objects, indicating that artisans in SPA were also adapting gold ornaments to local needs. These findings reveal different patterns in the material selection, transformation and further modification of the artefacts during their lives, challenging traditional assumptions that gold in San Pedro came exclusively from Tiwanaku.

Lastly, the use of the gold items to cover the face and upper body of the dead points to a local mortuary tradition where gold, silver and copper were highly significant.

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DEVELOPMENT AND CO-EXISTENCE OF BRONZE-MAKING TECHNIQUES IN PREHISTORY: THE CASE OF EMPORION'S NEAPOLIS IN NORTHEASTERN IBERIA (LATE 6TH CENTURY BC)

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Tin-bronzes can be produced by natural alloying, co-smelting, cementation, fresh metals alloying or recycling. Through micro-structural analyses of slag and technical ceramics using a combination of p-XRF, OM and SEM-EDS, it is possible to relate specific microstructures/compositions to each technique. Although traditional overviews indicate a technological evolution over time, recent research shows that the oldest techniques were not abandoned once the newest ones were mastered. They co-existed in the same contexts (Rovira, 2006; Rademakers et al., 2016; Renzi, 2013; Farci et al., 2017). The decision of which technique would be used must be related to broader socio-economic dynamics (ore/metal availability, cultural transmission, demand, social stratification/organisation, etc.) that limited/favoured their appearance, development, acceptance, spread and co-existence.
Our ongoing project aims to clarify this through a comparative study of selected case studies from North-Eastern Iberia. Through the characterisation of slags and crucibles from several sites dated between EBA and IA, we seek to create an explanatory model linking micro-structural patterns to specific dynamics that influenced the selection of a technique in a given time and context.
We present results from analyses of copper and tin-bronze by-products from Emporion's Neapolis (L'Escala, late 6thc.BC.). Apart from copper smelting and melting, bronze co-smelting, cementation, recycling and fresh metals alloying were in use contemporaneously. The identification of the later within the first Greek colony in Iberia supports a Mediterranean origin for this innovation. At the same time, we discuss the cost-efficiency parameters related to raw materials availability (ores, tin, charcoal) and demand pressures (time, quality) behind each of the bronze-making pathways, which are ultimately linked to regional and Mediterranean socio-economical trends.

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RESIDUES IN ESTONIAN TECHNICAL CERAMICS AND MOULDS FROM THE BRONZE AGE TO THE EARLY MODERN PERIOD

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More than 300 crucibles and moulds were analysed with pXRF to characterize the alloys used during 2500 years of Estonian metal casting. The finds originate from sites covering long time periods: Late Bronze Age fortified settlements, Iron Age hill forts and settlements, and Medieval and Early Modern towns. During these times the crucible technology went through several stages, which is reflected in the crucible shape, heating method, and material . The mould making technology also went through changes. Several hundreds of clay moulds have been excavated from the Late Bronze Age, but in later periods they disappear from the archaeological record. Stone moulds were however widely used during all studied periods and are usually well preserved.

The results of our residue analysis show that over time, a larger variety of alloys and pure metals became available to the Estonian metalworkers, and their specialization increased. This development culminated in the Late Medieval period. The stone moulds form a separate casting branch and mainly display residues of alloys with a low melting point. We discuss the problems of using the pXRF for residue analysis, which is an issue that has been pointed at by several scholars (Dungworth, 2000; Kearns et al., 2010). Several case studies carried out with SEM-EDS complement the discussion and illustrate the different nature of residues that can be detected with pXRF and SEM-EDS analysis (Saage and Wärmländer 2018).

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FINE METALWORK BETWEEN TWO PERIODS: TRACING CHANGES IN GOLDSMITHING TRADITION AND CRAFT ORGANISATION IN THE MID-TO-LATE 5TH-CENTURY CARPATHIAN BASIN BY THE INVESTIGATION OF POLYCHROME GOLDSMITHS' WORKS

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In the Carpathian Basin, the centuries of stability ensured by the Roman Empire were followed by the dynamically changing Great Migration Period (4th–8th c. AD). The mid-to-late 5th-century artefacts of this area reflect the transformation of the late Roman institutions. Our research focuses on the fine metalwork and goldsmiths' activity of this transition period. Among the contemporary crafts, goldsmithing required the highest level of technical knowledge, and complexity of organisational background, i.e. long-distance trade links, expensive materials and complicated techniques. One of the crucial issues is how the traditions and practices of the workshops in the Late Roman Empire influenced the material culture of the neighbouring Barbarian tribes. How had the Roman heritage evolved or diminished? Since not a single goldsmith workshop or any archaeological remains related to some sort of goldsmiths' activity are known in the region, our results are attained indirectly, by the study of finished products. The examination of the pieces of fine metalwork from the territory of the 5th-century Germanic kingdoms promotes a deeper understanding of the political, economic and cultural changes of the area.

Our investigation applied a combination of archaeological and archaeometric methods. More than forty objects from the collections of the Hungarian museums were involved, including elements of jewellery and garment generally made of precious metals (gold or gilded silver) and characterised by polychromy. Applying gemstone, glass and niello inlays as well as chip-carving and punching were intended to improve their colouring and lighting effect. These splendid, outstanding works were investigated by non-destructive analytical methods: optical microscope observations were followed by handheld XRF, EPMA/SEM-EDS and µ-XRD measurements.

Our examination contributed to the reconstruction of the workflow of the manufacturing and decorative techniques, to the identification of the chemical composition of metals as well as decorating inlays and coatings, and also the phase composition of niello. By means of the results we were able to point out changes in the applied techniques and materials. We could trace differences in the general workmanship of the artefacts, in the practice of metal alloying, in the source of the garnet materials and even in the recipe of the niello inlays. The reasons and effects of the appearance or disappearance of certain raw materials or technical solutions were studied from chronological and spatial aspects.

SPATIO-TEMPORAL TRENDS ON THE CHEMISTRY OF PRE-COLUMBIAN GOLDWORK: PRELIMINARY RESULTS FROM COLOMBIA

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The archaeological record of pre-Columbian metallurgy is witness to a wide range of technologies such as lost-wax casting, mechanical working, depletion gilding, granulation, and sintering, identified on objects with diverse styles, iconographic motifs, functions and life-histories. Chemical analyses have revealed an extensive range of alloy compositions incorporating gold, copper, silver, platinum, arsenic, tin, nickel and lead. However, while local and regional metalworking traditions have been successfully identified on the basis of the aforementioned aspects of metallurgical practice, systematic comparative studies across time or different geographical regions have rarely been attempted. This is despite their potential in reconstructions of how metallurgical technology was adopted, transmitted and adapted throughout the continent.

This paper presents the initial results of a reconsideration of compositional legacy data in large-scale comparisons of alloying practices, as a means to aid the holistic reconstruction of pre-Columbian metallurgy. We first describe the design and implementation of a relational database used to promote data integrity and facilitate comparisons of chemical data with other data classes (such as object attribute, geospatial, or archaeological data). Preliminary results from the region of present-day Colombia are then discussed, drawing upon applications of Geographical Information Systems to seek and explain spatio-temporal structure in the dataset. Patterns of consistency and discrepancy in alloying practices are revealed, particularly between the northern and southern parts of the country. These compositional signatures are used to discuss the role of environmental, cultural or technological factors in the decision-making of pre-Hispanic metalsmiths throughout Colombia.

A COMPARATIVE STUDY OF THE FIRE ASSAY TECHNOLOGY IN LATE MEDIEVAL EUROPE: KUTNÁ HORA AND PORTO

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Understanding the assaying technologies employed to quantify the amount of silver in ores, ingots and coins is key to charting the development of silver exploitation, minting and alchemy in Europe in the late Middle Ages. This paper presents and contrasts two case studies, within a broader project focused on European assaying.

At the heart of one of the largest silver deposits in Europe, in the 14th century Kutná Hora produced about one third of the silver consumed in Europe, before the exhaustion of surface deposits and the war forced the mines to shut down in the 15th century (Spufford, 1988). During this period, the Royal Mint of the Czech kingdom was also established in Kutná Hora. As such, the region was not only an economic hub but a driver of technological knowledge in both mining and minting at that time. For example, Lazarus Ercker, author of Treatise on Ores and Assaying, was an assayer at the Kutná Hora Mint.

At the other end of Europe, the Porto Mint was one of the mints built in the second half of the 14th century by King Fernando of Portugal, primarily to pay troops and army movements during the war with Castille. Unlike most others, this mint remained in operation until the 17th century. By then, Porto was the second biggest town in the kingdom (Dordio, 2001).

This paper will present and discuss the analysis of relevant archaeological materials such as scorifiers and cupels recovered in both mining (Jesuit College in Kutná Hora) and minting contexts (Royal Mint in Kutná Hora, the Porto Mint). Their chemical and microstructural analysis, combined with historical information, allows new insight into the manufacture and use of assaying equipment, and the efficiency of the process. The ongoing project is facilitating unprecedented resolution in our understanding of evolution of the fire assay equipment and relevant technological knowledge.

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AN INSIGHT INTO IRON-MAKING PRODUCTION IN THE BASQUE COUNTRY (NORTHERN SPAIN), TECHNICAL TRADITIONS FROM I MILLENNIUM B.C. TO LATE MEDIEVAL TIMES

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Equipo de Arqueología del Museo de la Minería del País Vasco (‘Basque Country Mining Museum’) is an interdisciplinary research group –involving archaeologists, historians, geologists, material science specialists, etc.– aiming to investigate the ancient production of iron in the Basque Country, a region renowned by the superior quality of its iron products (Buchwald 2008, 168–69). Consolidated after seventeen years of experience working in the field, ongoing research has identified a dense network of more than 350 iron-making sites throughout the entire Basque Country that chronologically span from 5th cent. B.C to 14th cent. AD, registered in a detailed cartographic database (Franco et al. 2015). The majority of these sites corresponds to relatively small workshops (haizeolak, after its Basque name) typically located in the mountains equipped with a single furnace device, and identifiable on surface due to the presence of large slag heaps. While the bulk of haizeolak seem to operate continuously from 3rd to 14th century AD, recently obtained 14C radiocarbon dates point out that the technology could be rooted in the 5th century B.C. to decline when water-powered technology is introduced (Alberdi & Etxezarraga 2014; Franco & Gener 2016). This paper reconstructs the engineering parameters of this process by the application of laboratory techniques (OM, SEM-EDS, XRF-WDS) to an assemblage of technical materials such as slag, furnace walls and pieces of ore recovered from archaeological interventions in 6 diachronic sites from pre-Roman period to Late Medieval, and including a comparison with by-products from experimental archaeology (Franco, 2014; Franco et al. 2015). This paper investigates the types of technology being employed to smelt the ores in each of the sites and compares the results in order to identify technological traditions within them. Aspects investigated for each site include the types of ores and furnaces, operating conditions, temperatures and redox, inter-smelt standardisation and technical efficiency of the process. Traditional iron-making in the Basque Country is traditionally described in literature as a long-lasting tradition which would perpetuate along centuries. However, it is our opinion that ancient iron smelting is a complex phenomenon that was likely adapted to the geographic, economic and technologic conditions of each period, and, in principle, seems unlikely to remain unchanged for such a long-time span and operate in an identical way in each site. It is hoped that the analytical research in progress at the moment of writing this abstract will contribute to a better understanding of the technological procedure.

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IRONWORKING OF THE AVAR PERIOD IN THE CARPATHIAN BASIN - AN INTERDISCIPLINARY RESEARCH PROJECT

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A three-year research project has been carried out between 2015 and 2018 by our interdisciplinary research group. The research programme is based on the unique Avar archaeological sites of Zamárdi-Kútvölgy and Kaposvár-Fészerlak (Hungary), where iron metallurgical centres were found. The general aim of our research programme is to gain a better understanding of Late Avar Age (7th-9th cent.) iron production technology and the artisans' environmental knowledge. By analysing archaeological, technological and archaeometrical data, we tried to reconstruct the iron technologies of the Avars from the preparation of ores to the formation of iron artefacts. This paper presents a concise overview of the project.

The basic publication including the catalogues and illustrations for the iron bloomery centres of Zamárdi and Kaposvár as well as establishing the sites' internal chronology and spatial- and chronological correlations were carried out. The chronological examinations of the sites were supplemented radiocarbon (C14) dating and dendrochronology. Typology of the features and objects, related to iron metallurgical activities, was established. A comparative analysis on the sites of Zamárdi and Kaposvár, and also with close by Avar settlements and iron metallurgical sites, focusing on the structure of the workshops and settlements and the types of the bloomery furnaces, was also carried on.

A fundamentally archaeometrical objective of the project is to perform a complex materials testing of the archaeological finds that completely cover the fields of the professional activities of Avar Age ironworking, as well as ceramic production, plant and animal remains.

This study presents the materials testing of the slag finds and iron artefacts (chemical analysis (XRF, ICP), macro- and microstructural analysis (OM, SEM-EDS), mineralogical analysis (XRD)) as well as ceramic petrographic and archaeobotanical analyses. Different slag types and their metallurgical roles, as well as the fundamental manufacturing processes, applied by the Avars, were identified. The results of metallographic examinations on iron tools indicate that different kinds of manufacturing processes were applied. Layers of different amounts of carbon suggest that numerous iron artefacts from the Avar Period were manufactured through forging and the application of numerous reheating. Other artefacts were made from a piece of single iron bloom object by object. The metalloghraphic analysis of most of the iron tools denotes basically the technology of a free-form forging without purposeful heat treatment.

BLOOMERY WORKS – ORGANISATION OF AN EARLY MEDIEVAL IRON PRODUCTION PROCESS

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Selected areas of the lowland Drava River Basin in Podravina region (NE Croatia) were subjected to an extensive archaeological survey in order to define locations with possible iron production remains. This was done as part of the activities within the project TransFER: "Iron production along the Drava River in the Roman period and the Middle Ages: Creation and transfer of knowledge, technologies and goods"(IP-06-2016-5047) funded by the Croatian Science Foundation. Based on the results of the archaeological survey, several locations were subjected to geophysical prospection and subsequently excavated. At the Hlebine – Velike Hlebine site an iron smelting workshop with several slag – tapping bloomery furnaces as well as other structures was excavated. The scope of the workshop was assumed through geophysical prospection and confirmed during two excavation campaigns. The workshop is located on a slightly elevated ridge, while the nearest contemporary settlement, Hlebine – Dedanovice site, is situated several hundred meters to the northeast. Within the settlement grounds, two furnaces were unearthed. Preserved bases of these furnaces indicate somewhat different form of construction and spatial arrangement than the furnaces excavated within the smelting workshop. Iron slag preserved within furnaces at the Hlebine – Dedanovice site is relatively scarce as well as fractured and shows different surface morphology than the iron slag from furnaces excavated at Hlebine – Velike Hlebine site. Considering these preliminary results, several questions will be addressed; do these finds reflect different stages of iron production or different technological solutions for bloomery iron smelting and what can we conclude about the organisation of bloomery iron production process during Early Middle Ages (Early to Mid-7th. century) in the area of Podravina region.

SOME INSIGHT ABOUT THE IRON PRODUCTION DURING THE IRON AGE AND THE ROMAN PERIOD IN THE MAJOR REGION OF PRODUCTION OF PUISAYE (FRANCE)

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The natural region of Puisaye (France), situated in the north of the department of Yonne is, for France, one of the region which delivers the largest quantity of remains of iron production. During the beginning of the XXth century more than 500 000 t. of slag have been extracted to supply blast-furnace. Today, more than 2300 slag heap are known for a territory covering about 1500 km². If the localisation and the size of these heaps are known thanks to prospection realized for more than ten years (Pietak et al., 2012), little is known about the chronology and the smelting processes practiced. Since two years a new research program has started on this region in the objective to acquire dating and technical information. Two scale of study are considered. One is carried out at the scale of the natural region of Puisaye, on slag heap delivering remains of slag-pit furnaces. Around ten sites have been considered. Another scale of analyse concerned an area covering 2 km square situated in the north of the region, at Aillant-sur-Tholon, where around twenty slag heap are studied. On both scale, the topography of the heaps are registered. Punctual sampling of charcoal and slag are realised to acquire radiocarbon dating and technological information on the reduction processes. Surveys have been also conducted on six slag heap at Aillant-sur-Tholon, to acquire information in stratigraphy.

The aim of the communication is to present the first results of this research program, showing the long aging of the iron industry which begins during the iron age (around -600/-500) and covers the roman period. During this time span, it is also possible to propose, from the typology of the waste and their association, the existence of, at least, three or four types of reduction techniques. We will also discuss the importance of this district of production in its chronological context. The condition of its development in its cultural framework in comparison with other centres of iron production known in its vicinity will also be discussed.

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BLOOMERY SMELTING EXPERIMENTS: COMPARISON OF BOWL AND SHAFT FURNACES USING MATERIALS FROM SOUTHERN LEVANT

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Abstract: Series of iron smelting experiments using potential iron ores from Southern Levant were conducted in a cylindrical shaft furnace and various versions of smaller bowl furnaces. Given the archaeological evidence from the Iron Age Levant, exploring the possibility of iron smelting in a bowl furnace was one of the major goals. This furnace type, in which slag is kept at the bottom of the furnace during smelting, is less understood, in contrast to the well-known type of cylindrical shaft furnace, in which liquid slag is removed through tapping.

The results of experiments confirmed that the regional iron ores are suitable to produce bloomery iron in both shaft and bowl furnace. However, the choice of smelting installation affected the differences in the operation mode and the process parameters: temperature, reducing atmosphere, amount of supplied air and distribution of heat, amount and consumption rate of ore and charcoal, as well as the smelt outcome such as total yield, and the consolidation and homogeneity of the bloom. In contrast to the shaft furnace, in which ore undergoes gradual reduction upon its descend through the shaft, a bowl furnace dictates a different operational mode. Specifically, the most fruitful results of experiments in bowl furnaces revealed particular benefits of a two phase smelting operation: the initial phase carried at lower temperatures and less reducing atmosphere; the second phase held at higher temperatures and more reducing atmosphere. The collected experimental data and results of laboratory analyses support the feasibility of bowl furnaces for the production of small-sized blooms.

EVALUATION OF COPPER ISOTOPE FRACTIONATION DURING CHALCOPYRITE SMELTING

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Analysing different types of stable metal isotope systems can provide additional information about the artefacts being studied. Lead isotopes have long been used for provenience studies, but other isotopes can also be useful. For example, copper isotopes can be used to gather information about the type of ore that was exploited. In combination with lead isotopes, they can give information about the exploitation history of its ore deposit. However, linking the metal from the artefacts with the ores and mining districts requires identical chemical behaviour of the isotopes, i. e. no isotope fractionation occurring during the smelting process and during corrosion.

The behaviour of copper isotopes during smelting was investigated in several studies (Gale et al., 1999; Rose et al. 2017) for malachite ores but not for sulphidic ores like chalcopyrite, although they were much more widely exploited in many prehistorical and historical smelting districts. Smelting chalcopyrite requires multiple steps of oxidizing roasting and reducing smelting. The strong sensitivity of copper isotopes for redox processes makes it likely that these steps in the metallurgical chain will fractionate them, leading to different isotopic compositions of the metal and its ore.

This contribution presents the results of a series of chalcopyrite smelting experiments based on the metallurgical process reconstructed for the Eastern Alpine Bronze Age ("Mitterberg process") with the aim to quantify copper isotope fractionation during the smelting process. Samples from all materials used for and gained in each single step of the metallurgical process chain were analysed. Based on these experiments, a greater understanding of the fractionation of copper isotopes can be revealed.

To get a deeper understanding about the fractionation during each process, mass balance models were calculated for each single step and their results are compared to the analytical data from the experiments. As stable isotope fractionation follows fixed laws, such models allow one to draw conclusions about a broad range of isotopic compositions and copper concentrations in the ore and other materials used in the metallurgical process. This allows the evaluation of copper isotope fractionation during smelting of sulphidic ores, not only for the experiments but for all comparable processes. As a result, the combination of analytical data and mass balance models will allow for the first time a reliable evaluation of copper isotope behaviour during smelting of sulphidic ore, as well as allow the discussion of existing applications of copper isotopes and to identify potential new ones.

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BLACK BRONZES: TECHNOLOGICAL TRADITIONS, ARCHAEOLOGICAL QUESTIONS AND ARCHAEOMETRIC ANSWERS

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This paper presents the final results of an experimental and analytical project on “black bronzes”, a class of alloys used for high-status objects from ancient Egypt to modern Japan. These were copper alloys containing small amounts of gold that were treated with a variety of chemical solutions to develop a fine and durable black patina. For the first time, we compiled all the scientific and historical information concerning black bronzes into a single database which highlighted research gaps: What were the technologies used to patinate these alloys? Can different patination technologies be recognised through analysis of ancient objects, particularly using minimally invasive techniques? What is the role of gold in the final patina colour and durability?

We addressed these and other unsolved questions through a systematic experimental project. We reproduced a series of alloys with controlled levels of Sn, Ag and Au. These were treated using four different procedures: chemical patination by means of solutions that mimic those used in traditional methods, Chinese patination using perspiration, thermal patination and simulation of natural corrosion. The resulting patinas were examined with a range of analytical techniques including UV-VIS and Raman spectroscopy, colorimetry, XRD, SEM-EDX, and pXRF.

The results provide information on composition, microstructure, colour, appearance and durability of the different patinas, and allow an understanding of the relationship between production technology, alloy composition and their physical-chemical characteristics.

The examination of the patinas demonstrated that it is possible to distinguish the use of copper acetate and copper sulphate, the two main ingredients described in ancient and modern texts, through analysis of the superficial microstructure of the objects. Thermal patination was successful only if both tin and silver were present in the alloy, excluding the use of this technology alone on copper-gold alloys to create black patinas. Patinas obtained in a simulation of a natural burial environment showed differences from artificially produced patinas.

The experimental data serve as a reference for the interpretation of archaeological black bronzes. Egyptian, Roman, Greek, Anglo-Saxon, Chinese and Japanese artefacts from a range of museums were analysed and compared with the experimental results providing insights into the procedures and ingredients used by the different cultures. The comparison of the experimental data and the results of legacy and new analysis on archaeological artefact explained the alloy selection in Chinese and Japanese cultures and gave interesting suggestions about the technological choices used by the other cultures in which black bronzes are present.

MULTIVARIATE STATISTICAL STUDY OF LEAD ISOTOPIC DATA: APPLICATION TO COPPER SLAG

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The relationships between copper ores and objects are at the heart of protohistory's problematics in view of the economic importance of this resource. Lead isotopy is one of the most commonly used methods to establish the origin of copper in artefacts.
This study proposes to compare copper slags lead isotopic signatures to a database of copper ores (the data used are from the literature). Copper's mineralizations are grouped by large geological entities in which multivariate statistics permit to determine homogeneous subpopulations. The signatures of the pyrometallurgical workshops are compared to the subpopulations thus defined. The method developed makes it possible to link slags to specific deposits (subpopulations) or to refute a possible regional origin of the ores (signature not corresponding to any population).
The results obtained by this statistical study were compared with those from the literature, obtained by graphic readout. We observe similar results between our method and the bibliography, the assignments being comparable. This new approach could therefore make it possible to test rapidly the origin of a large amount of artefacts (whereas binary projections are sometimes difficult to interpret with a comparable amount of data).
Slags were chosen because they are archaeological artefacts often related to a local exploitation of the ore deposits. The results of this study could pave the way for further work aimed at defining the origin of finished products (which can be exchanged over long distances) using correspondence tests with each geological entity.

DETERMINATION OF GENETICAL TYPES OF IRON WORKING SLAGS THROUGH COMBINED MINERALOGICAL (XRD-RIETVELD) AND MICROCHEMICAL (SEM-EDS) INVESTIGATIONS

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In the past few decades a growth of orders of magnitude happened in the number of sporadic findings, not necessarily related to industrial archaeology, which are defined as iron working slags on a morphological basis, but often without a technological context. On these findings the definition of fundamental characteristics is a frequent problem. Besides, if the material has been identified to be iron working slag, other questions are raised, such as determining the genetical types of different slag samples and the processes (smelting, purification of the bloom or forging) which can lead to the production of the examined slags.

Crystalline phases contain all the information of a slag from its solidification temperature, cooling rate, alterations and composition of ore +/- technological additives. XRD with Rietveld refinement allows calculation of exact amounts for crystalline and amorphous (glassy) phases, as well as crystallite sizes, an indicator of cooling rate. Cations from ore, flux and slagforming additives will be distributed among oxides, silicates and glassy phase. By SEM-EDS analysis all phases observed with XRD can be characterized with detailed chemical composition, allowing to observe cation partitioning according to temperature. As an example, >1200 °C Mn will be preferentially fixed in olivine type silicate structure, while Mg will form spinel type structure with Fe, Al and other metals. On the textural images and element distributions obtained with SEM the phase relations can be deduced to establish sequence of solidification and phase transitions.

IRON IN THE ARCHAIC IONIA. CASE STUDY: APOLLO SANCTUARY IN DIDYMA

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This paper deals with the archaeometric examination of iron objects and metallurgical waste from the supra-regional sanctuary of Apollo in ancient Didyma, and is set out as preliminary results of the research project Síderos. This project aims to explore the iron technology in the archaic period (8th – 6th ct. BC) in the Western Anatolian Littoral – known in historical times as Ionia – which played a vital role in sociocultural and economic connectivity between Anatolia, the Aegean, and the Greek mainland. The excavation at the "Taxiarchis-mound" near the central temple of Apollo yielded a complex debris comprising ordinary dedications and cultic utensils, and besides these a quantity of iron tools and anvils. The latter are under-represented in archaeometric studies from the Aegean region in favour of pottery or luxury and exotic items made of bronze. The findings offered, thus, a unique opportunity not only for a micro-regional, but also macro-regional study of the iron technology. The metallographic, SEM-EDX and micro-hardness analysis of iron anvils revealed both pure iron as well as high carbon characteristics, indicating a temperature-controlled quenching. This shows that delicate smithing operations of various metal types were realized at the area. Furthermore, remnant metal and fossil structure observed on corroded objects of supposed locally origin (knives, tools and obeloi) points to a variety of microstructural phases, which in turn resulted from a distinctive iron-working. Findings of slags and furnace lining localised the processing site in an extensive industrial area within the temenos of the archaic sanctuary, and besides the copper-alloy and pottery production. The major role of the supra-regional sanctuary at Didyma as one of the sociocultural foci in Ionia (Bumke 2002), which attracted highly skilled craftsmen, seems to be confirmed by the pilot archaeometric studies. However, the question of contextualising iron technology of Ionia within the Aegean remains crucial to review the existing model implying a technological diffusion into the region via Cyprus, Crete, and Athens (Snodgrass 1980) in favour of a more local development (Sanidas et al. 2016).

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EARLY IRON TECHNOLOGY IN THE CIRCUMPOLAR NORTH

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The introduction of iron technology in the northern Circumpolar area has for long been a subordinate topic of archaeological research. The emergence of iron technology in this area has traditionally been viewed as peripheral to Old World ferrous metallurgical developments and regarded as a very late phenomenon. Here we present two recently excavated sites that substantially expand the knowledge of iron technology in the Circumpolar North seriously opposing the traditional view, showing iron technology was an integral part of the hunting-gathering subsistence already during Pre-Roman Iron
Age (250-50 cal BC). The sites were excavated in 2010 and 2017, located near the villages of Sangis and Vivungi close to the Arctic Circle in northernmost Sweden, representing two of the earliest known iron production sites in northernmost Europe also including contemporary remains of primary and secondary smithing. Archaeometallurgical analyses show an advanced technological know-how already during the initial phase of iron technology, with evidence of intentional bloomery steel production and advanced smithing techniques including various heat treatments, thus surrounded by a complex organization. In iron research, bloomery steel is traditionally considered an accidental product of early iron production. Furthermore, advanced smithing techniques are not considered common in north European contexts before Viking Age or Medieval times. Hence, our findings seriously challenge prevailing views of Old and New World ferrous metallurgical developments and call for a redefinition of the mechanisms of transmission of technological knowledge in terms of the hunting-gathering subsistence in the Circumpolar North.

THE CELTIC-EARLY ROMAN PERIOD METALWORKER'S DISTRICT OF MEDIOLANUM-MILAN (LOMBARDY, ITALY)

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This paper deals with the study of the remains of metallurgical activities from via Moneta in the city center of Milan. The development of the layout, of the chronology and of the technology used in the metalworker's district of Mediolanum-Milan are discussed here. Its development belongs to the 4th – 3rd century BC, it reached its largest extension in the 2nd – 1st century BC and it lasted until the end of the 1st century AD. For at least four centuries, there were continuous metallurgical activities in the area. The district was located in the center of the oppidum near the area where the Roman forum will be built at a later stage and along the future decumanus maximus, because of this in the Roman period the metallurgical workshops had to move to more suburban areas of the town.

The remains of twenty-three metallurgical workshops contemporary and previous to the Romanization period were partially reconstructed. They were built with perishable materials and according to the local building techniques. In these workshops, raw iron was worked in order to be transformed into finished objects and accessories for furniture. The iron forges' hearts are described and reconstructed. These workshops are similar to those discovered in the oppida and in the villages of Transalpine Europe.

The metal production was highly specialized: various iron items and iron sheets were made, fluxes were used for its soldering. In many workshops, both iron and copper alloys were worked in order to make pieces of furniture and objects made with different metals. These metallurgists of Celtic tradition were highly specialized and had a superior degree of knowhow.

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TECHNOLOGICAL CHARACTERIZATION OF PRE-ROMAN WEAPONS FROM THE IBERIAN PENINSULA

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Metallographical studies of Iron Age weapons from the Iberian Peninsula are being carried out in the framework of the IBERIRON ("The Rise of Iron Technology in pre-Roman Iberia: a Large-Scale and Multidisciplinary approach") project. The aim of the project is to approach an extensive study of iron objects form the archaeological record, especially weaponry, and determine the characteristics of this technological knowledge in the territory. The results are to be used to approach more broader issues regarding how technological knowledge is developed, exchanged and transmitted, as well as address questions about the origins of iron metallurgy in this geographical area.

Here we are presenting results from weapons studied from the sites of Mianes (Tarragona, Spain. Iberian culture, 6th- 5th c. b.c.e.) and La Osera (Ávila, Spain. Vettonian Culture, 4th - 3rd c. b.c.e). This work shows some examples of the use of the combinations of iron and steel in weapons for these cultures, as part of an ongoing systematization effort for the gathering of technological information for iron metallurgy in pre-Roman Iberia. Samples, in some cases from multiple points, have been obtained from various weapon specimens (spearheads, soliferrea, knives and swords) and studied by metallography (optical and SEM-EDS), showing complex procedures in both cases, including the use of multi-metallic decoration as well as uneven use of selective carburization and composite welding, leading to preliminary comparative analyses for both sites. As part of the Open Science effort, all the data obtained is treated so to fall under the FAIR (Findable, Accessible, Interoperable, Reusable) principles (Wilkinson et al., 2016). The results also highlight some of the systemic methodological problems encountered in this research, such is the effect of the prevalence of cremation rituals as part of funerary practices in the period and area under study.

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ARCHEOMETALLURGICAL APPLICATION OF SCANNING ELECTRON MICROSCOPES

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The study of ancient metals in their social and cultural contexts has been a topic of considerable interest in archaeology and ancient history for decades. Archaeometallurgical investigations can provide evidence for both the nature and scale of mining, smelting, refining and metalworking trades. They can be crucial in understanding the economy of a site, the nature of the occupation, the technological capabilities of its occupants and their cultural affinities. In order to understand the role of metals in societies of the past, these material remains are to be studied by applying techniques used in natural sciences, among which chemical analysis, measurements of physical caracteristics, mineralogical and petrographical investigations are the most popular technologies.

Here I would like to focus on the scanning electronmicroscopic techniques that can help us to analyze deeper details of the samples, remains. As a first step, light microscopic investigations are used for observation and photographic documentation of all technological features recognizable on the surface (e.g. tool marks, solder joints, granulation, filigree) and therefore represent an important prerequisite for all further metallurgical investigations. Scanning electron micrographs allow better detection and accurate measurement of tool marks due to the higher magnification and better resolution. Besides the morphological characteristics, the chemical composition of the remains can be analyzed with the SEM systems equipped EDX detectors or WDS detectors. EDX (Energy dispersive X-ray analysis) can be used for qualitative (the type of elements) as well as quantitative (the percentage of the concentration of each element of the sample) analysis. By using the dedicated software, auto-identification of the peaks and calculation of the atomic percentage of each element that is detected is possible. One more advantage of the EDX technique is that it is a non-destructive characterization technique, which requires little or no sample preparation. Another technology, the wavelength-dispersive spectrometer (WDS) uses the characteristic X-rays generated by individual elements to enable quantitative analyses (down to trace element levels) to be measured at spot sizes as small as a few micrometers. WDS can also be used to create element X-ray compositional maps over a broader area by means of rastering the beam. Together, these capabilities provide fundamental quantitative compositional information for a wide variety of solid materials.

The ability to correlate data obtained from multiple imaging modalities allows researchers to correlate data from light microscopy with SEM systems. TESCAN offers a dedicated CORAL module as a comprehensive software tool for performing correlative microscopy experiments. It allows users easily import data from any source, easily correlate and overlay on top of an SEM image. RISE Microscopy is a novel correlative microscopy technique which combines confocal Raman Imaging and Scanning Electron (RISE) Microscopy within one integrated microscope system. This unique combination provides clear advantages for the microscope user with regard to comprehensive sample characterization.

EARLY TIN BRONZES IN EL ARGAR CULTURE (SE IBERIA)

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Tin bronze alloys were first used in the South-east of the Iberian Peninsula during the Argaric Bronze Age Culture (c. 2250-1550 cal BC). The earliest investigations in this area were conducted by H. and L. Siret (1890) and the materials recovered from some of the most significant sites, such as El Argar and El Oficio, are now part of several European Museums' collections. This paper presents the examination of the Siret Collection of the British Museum. 62 objects including ornaments, tools and weapons were analysed by X-ray fluorescence for their elemental composition and 22 of them were selected for provenance investigation by lead isotope analysis using MC-ICP-MS. The resulting data are discussed together with previous elemental analyses (700 analyses in total) and isotopic compositions (55 analyses in total) already published. Contextual information is also considered in order to understand the frequency, first uses, social value and provenance of this alloy.

The available data show that some object types, such as halberds, were never made of tin bronze, while a significant amount of personal ornaments (earrings, arm rings or finger-rings) contain tin. The chromatic effect resulting from combining different metals and alloys (copper, bronze, silver) in the same object or in the same burial, or the relative social value given to the different metals could explain the choices in the alloys used instead of functional or technological advantages during this Early Bronze Age. The option of metal imports from other Iberian or European regions is also considered to explain the presence of these first tin bronzes.

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COPPER BASED ALLOYS WEAPONS FROM MIDDLE BRONZE AGE II SOUTHERN LEVANT

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Hundreds of copper-based weapons (axes, daggers and spearheads) from the Middle Bronze Age II (MB II; c. BCE- c. 1950-1500 B.C.E.) have been unearthed, mostly from burials, all over the Levant. In contrast to the usage of copper and arsenic copper for production of weapons in the Early Bronze Age, and the mass usage of tin bronze for Late Bronze Age weapons, during the MBII period weapons were produced using both bronze tin and arsenic copper. Until now no clear correspondence between the alloys used and the MBII types, chronological sequence or regional distribution was found (Shalev 2009: 69-70).

In the present research, by using "higher resolution" correlation between shape (typology) of weapons, and their metal composition (metallurgy) it was clear that in the beginning of the MBIIA period and during the transition to the MBIIB period, most of the decorated and enhanced weapons were made of tin bronze, while during the transition from the MBIIA - MBIIB period and in the MBIIB period most of the weapons were made of more common and contain alloys of copper with different amounts of tin and arsenic (Kan-Cipor – Meron 2017).

This metallurgical change may reflect the metalsmiths' reliance on the availability of the raw materials, which, when not in abundance, encouraged the creation of metal alloys from recycled metals from earlier periods (Kan-Cipor – Meron et al 2018). These results can be related to changes in trade systems of the MBII . These trade routes through land and sea that connected Mesopotamia with Anatolian and Syrian-Lebanon and the Southern Levant in the MBIIA (Lehner 2014) were not operational due to political and economic changes, during the establishment of the Hyksos control centers in the Southern Levant in the MBIIB period (Oren 1997).

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EUROPEAN METALS IN SCANDINAVIAN FORMS

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The question of metal supplies is one of the core issues of Bronze Age (BA) research in Scandinavia. Recently completed multidisciplinary projects (Ling et al. 2013; 2014, Melheim et al. 2018, Vandkilde 2017) established that the Scandinavian copper alloys could not have been made from Scandinavian copper. This paper will present the results of a project based on lead isotope and chemical analyses of 250 Scandinavian bronzes dated to 1600-1100 BC. About 50 BA copper alloys from Hungary, Germany, Iberia and Ireland have also been analysed to increase the database for comparisons. The full comparative database included lead isotope ratios for about 8000 ore samples and other 3000 BA metals. The analytical results show that the earliest metals dated to 1600–1500 BC, have much more varied lead isotope and trace element compositions indicating several sources for the metal, than the metals dated to later periods. In general, more homogenous compositions can be identified during the period 1500–1100 BC, both in terms of lead isotope and trace elemental data.

The interpretation of these data suggests a complex picture of possible connections between Scandinavia and Europe during the BA. Overall, the varied origins of copper in artefacts dated to 1600–1500 BC indicate a very dynamic diffusion of metal across Europe. Furthermore, metalworking styles and the metal, in most cases seem to have different origins.

Our current results indicate that the supply channels changed about 1500 BC, when the supply of copper from the Great Orme in Wales declined and supplies from ores in Austria and Slovakia increased in importance. The results of our research to date show that most of the Scandinavian bronzes are geochemically consistent with the copper originating from the Italian South-Eastern Alps. Copper from the important deposits in southern Spain, as well as from Sardinia, has been identified amongst a few of the Scandinavian bronzes from this phase. It has been observed that the chronological variation in the Scandinavian material seem to correlate with the extent and structure of copper production in Bronze Age Europe. The results of this research suggest that there were various trade routes and networks during this period. In contrast, the analysed copper-based artefacts from other regions of Europe seem to be mostly made of copper from local deposits.

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TECHNICAL INFORMATION AND DEGRADATION RATE ON BRONZES FROM AN IRON AGE HOARD (TINTIGNAC, CORRÈZE, FRANCE)

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Corrosion of archaeological Tin bronzes in soil is of difficult interpretation for the complexity and the number of parameters involved. The phenomenon is influenced by the composition of the alloy, its microstructural features and the interactions with the environmental factors (Shreir et al., 1963; Piccardo et al. 2013). Nobility, cathodic and anodic processes, passivity are dependent upon the nature and the composition of the alloy, the heterogeneity of the soil is, on the other hand, responsible for the occurrence of different micro-environments (Francis et al., 2010).

In this study, a statistical analysis was performed on the Celtic deposit discovered in the area of Tintignac (Naves, Department of Corrèze, southwest of central France). This specific find spot bears more than 400 fragments of roughly 60 objects in an area of one square meter and 30 cm depth:defensive armor (shields and helmets), seven war trumpets (carnykes), and a wide variety of other fragments (Maniquet et al., 2011). From this recently excavated site it was possible to obtain the necessary information for the interpretation of archaeological artifacts corrosion behavior. Assuming that in such a narrow area many corrosion phenomena come into play, this study was to understand the mechanisms in order to morphologically and chemically categorize them. To reveal their manufacturing technology, corrosion morphology and increase the gain of knowledge on these highly precious objects, micro-samples were taken and classical metallographic techniques as Light Optical Microscopy (LOM) and Scanning Electron Microscopy (SEM) were used. To characterize the corrosion products microRaman analyses were performed. Results revealed variations of the corrosion morphologies according to the presence of specific microstructural features. In particular, a specific corrosion morphology was connected to peculiar environmental conditions and to particular compositions (10-13% wt of Sn). This type of corrosion was supposed to be related to the potential contact with organic matter or biological agents (Microbiologically Induced Corrosion or MIC), which might have affected the surface reactivity of the object.

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GAULISH AND GALLO-ROMAN METALWORKING ON THE TITELBERG

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The Titelberg is a flat-top hill situated in the south west corner of the Grand-Duchy of Luxembourg. It was since the first century BC the principal oppidum of the Treveri, a Celtic tribe. The flourishing period ended when the status of Treverian capital moved to the "new" roman city of Trier at the end of the first century BC. Hereafter a Roman vicus remained on the Titelberg which was abandoned at the end of the Roman Empire.

Archaeological excavations started some 50 years ago. Later on, a small excavation was undertaken by an USA team. Since the beginning of the 1980s, much more extended excavations of the ca. fifty ha large plateau are conducted by a Luxembourg team.

The excavations revealed that an important metalworking activity took place on the Titelberg. Many small copper and copper alloy items, like sheet snippets, fibulae, coins etc were found all over the oppidum. It can be hypothesized that many vessels and certainly also richly decorated scabbards that belongs to the aristocratic grave goods buried in the neighborhood, were fabricated there. Brass snippets suggest that the oppidum was one of the first Celtic places where this "new" copper alloy was processed. The concentration of bronze fingerplates in form of dovetails indicates that apparently their production was a specialty of the Titelberg. These fingerplates are thought to belong to strainers or, most probably, to drinking vessels. Somewhat mysterious are coins with strange color patterns, which still could not be explained until now.

A workshop had been identified in the public space of the Celtic town. It was active between 20 BC and 20 AD. Traces of a second workshop, active during the Gallo-Roman period, were found by the American team in the residential area.

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IRON ORE MINING IN VOLGA-SVIYAGA INTERFLUVE IN THE EARLY MIDDLE AGES: IMPACTS ON SETTLEMENT PATTERN AND LANDSCAPE CHANGE

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The role of iron as one of the most important resources for the economy since the Early Iron Age cannot be doubted. The invention and spread of the iron making highly influenced different spheres of ancient society as well as human-nature interaction. We studied these aspects in the Volga-Sviyaga interfluve (Middle Volga region, Russia), a region comparatively rich with siderite iron ore. We used both archaeometric studies and paleo-landscape analysis methods as well as archaeological surveys and excavations. We examined the chemical and mineralogical composition using emission spectroscopy, petrography, and X-ray structure analysis of iron ore and slags to understand the possible provenance of raw materials for metallurgical production.

Our investigations reveal that the earliest specialized iron mining sites appeared between Volga and Sviyaga as early as in the 3rd - 5th c. CE. The excavations and surveys reveal that the regional population of that period used to mine siderite ore in the wet areas on the plateau of Volga upland. Plenty open pits dug from the surface and associated with the metallurgical kilns reveal the picture of massive extensive seasonal iron ore mining.

Another mining technology was used in the 5th-7th c. A site complex at Komarovka which comprises several hillforts and occupation sites together with a burial ground is a well-investigated example of the land use and settlement pattern of that time. Massive deposits of iron slags on the banks of gullies over about 2 km around the sites mark the impressive metallurgical activity in this area. We suppose that digging the ore deposits in the sources of gullies resulted in stream incision, slope erosion and deposition of colluvial fans. Off-site excavations revealed dramatic landscape changes due to ore mining. Permanent smelting activity was also recorded in the section of gully banks while the agricultural influence on the territory seems to be not that significant.

After a period of depopulation in the 8th c., in the 9th-10th c. iron sources in the region were developed by small groups of semi-sedentary newcomers in the flat wetlands of floodplains and uplands once again. The localities of iron making seem to be the first occupation sites after repopulation and many of them subsequently become medieval cities. The ore mining continued by Volga Bulgaria craftsmen and the region became a resource base of local Bulgarian urban centers, exporting iron across the Volga River.

THE IRON BLOOMERY SMITH AND HIS EQUIPMENT

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During metal detecting in a crop field near Elverum in Souteastern Norway in 2014, a large number of iron objects were discovered together. A rescue excavation the year after, in 2015, showed that the objects were placed in an older cocking pit C14 dated to AD 410-550, and the find became interpreted as a hoard. Altogether, the find contains 31 iron objects and one whetstone. The iron objects are related to iron processing and consist among others of an axe, a forging hammer, a sledgehammer, an ore/charcoal shovel, several celts, six iron blooms, an ingot, a knife, drill and an anvil. The items are difficult to date but the axe has parallels in the Norwegian material in the late 6th century and early 7th century AD. During further excavations at the same site in 2018, traces after houses, cooking pits and remnants after two iron bloomery furnaces were detected. The house and cooking pits are C14-dated to an earlier period. However, the two furnaces are younger than the settlement and can be related directly to the iron hoard both in time and spatially within the site.

The find is unique in Norway. Similar items have not been found in the same context earlier or rarely in any secure context related to production. Particularly the collection of iron blooms and the large and rough tools indicates that this is not any ordinary smithy equipment. Rather, we assert that the tools must be related to iron bloomery activity, a type of context we never have found a toolset in Norway before.

This winter, analysis of several of the iron objects and the associated productions slags will be performed. The aim is to look at both quality and the relations between the finds, from the furnaces, through the iron blooms and the ingot to the smithy tools. The combination of this preserved toolset at a production site combined with the metallurgical analysis greatly increases the knowledge that can be gained about iron production in the late iron age and early medieval age. Both the unique find and the results of the analysis will be presented broadly in this presentation.

BEYOND THE BOWL FURNACE: EARLY IRISH IRON SMELTING

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The idea of the bowl furnace, with the 'furnace bottom' as its characteristic waste, was first conceived in Ireland in the 1930s and would strongly influence the interpretation of remains of early iron smelting in Europe and beyond for decades after. In Ireland, until very recently, the bowl furnace was still considered the main type of furnace used in early iron smelting. However, building upon observations by Young (2003) and others, it is now clear that there is no evidence for the use of bowl-furnaces in early Irish ironworking (Rondelez 2018). Instead, the archaeological record points to several varieties of slag-pit furnaces used during the Iron Age and Early medieval period. The use of shaft furnaces with lateral slag removal appears to coincide with the arrival of the Vikings in the 9th century AD and continues in late medieval times, together with other furnace types (Rondelez 2014). This talk lays out the evidence against the Irish bowl furnace and illustrates the various types of furnaces used during the first two millennia of iron smelting in Ireland.

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SAME PLACE, SAME TIME, SAME CULTURE, YET DIFFERENT: VARIATION WITHIN VIKING AGE IRONMAKING TRADITIONS IN NORWAY

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The Viking Age saw the spread of a seemingly uniform ironmaking tradition across Norway, with slag-tapping furnaces replacing the well-established regional traditions in what seems a rapid transition. This paper attempts to understand observed differences in Viking Age ironmaking practice during this transitional period, through a comparative study of slag remains from two contemporary ironmaking sites in the Trøndelag region of middle Norway.

Slag remains from two contemporary Viking Age ironmaking sites (AD 885-1025) were studied macroscopically and by SEM-EDS. Less than 40 km apart, the sites of Skistua/Vintervatn and Håen 2 show similar structural remains: a single, free-standing furnace with an inner diameter of c. 30 cm, with what was interpreted as a slag-tapping channel and no further structures in immediate vicinity. The slag remains however differ substantially. The remains from Håen 2 have the typical flow morphology and microstructure of tapped slag, with virtually purely fayalitic microstructures. Slag remains from Skistua/Vintervatn were equally clearly not tapped. An explanation for this variation was found in the slag chemistry, where the tapped type had a clearly lower viscosity than the non-tapped one, which in turn compositionally resembled earlier slag from the region.

Pre-Viking Age ironmaking traditions in the region relied on batteries of large slag-pit furnaces, which were replaced in the Viking Age by smaller, slag-tapping furnaces. Although both sites here are contemporary, it is plausible that Håen 2 is fully representative of the new tradition. Conversely, at Skistua/Vintervatn, the furnace was equipped with a Viking-style tapping trench but the more viscous slag did not reach the necessary fluidity for tapping. Hence, this may be representative of the incomplete adaptation of the old technology to the new furnace types.

Although the transition from one furnace type to another is easy to observe in the archaeological record, detailed technological evidence for this transition is rare. Only through detailed comparative analyses can we begin to assess how the transition took place and attempt to explain why and how changes occurred.

SWEDEN´S MEDIEVAL MINING DISTRICT. A LANDSCAPE PERSPECTIVE

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The documentation of medieval mining production in Sweden conducted jointly by Riksantikvarieäm¬betet (The Swedish National Heritage Board) and Jernkontoret (The Swedish Steel Producers' Association) was initiated in 1980 and have identified 765 smelting sites, 465 blast furnaces, 161 copper and 69 silver smelting sites and about 10 000 mines. These investigations have significantly increased our knowledge of the extent of the medieval metal production. The interdisciplinary approach in our project provides opportunities to get a deeper understanding of the ancient mining landscape and the dynamic role of iron and copper in the moder¬nization process in Sweden 1150–1350 AD. The inception of mining in the region was during the 10th century and excavations show a developed blast furnace in the 12th century and also developed a certain copper smelting process.

The mining area Bergslagen is situated north and west of the lake Mälaren. Stockholm, the capitol of Sweden, is located by the rapids, where the lake flows into the Baltic Sea. The introduction of industrialized mining has had a crucial bearing on our understanding of the urbanization of the Mälar areas, ancient monuments that provide possibilities to interpret the earliest industrialization and its organization of woodlands, rivers and lakes. Ore, wood and charcoal were moved to sites, from which metal was transported on land, water and ice to towns. Stockholm was founded where the traders were forced to transship metals from small boats to ships.

The aim of the project is:

- To present the investigations in maps.
- To present a conclusion of mining and metal production in landscape, economy and society
- To discuss how the industrial development in mines and smelting sites influenced the legal organization of the mining area, the organization of the landscape including transports, the relation between agriculture and mining and the dynamic power of the mining economy.

One site, Lapphyttan, contributes to understanding of land use and daily work at a blast furnace site. The excavations show an industrial facility in the 13th century. Ores of different qualities were used from different mines some 20 km away. Charcoal was produced within a radius of 20 km. Trading goods such as lump iron, osmund iron and iron bars, have been found. Based on the archaeological material the paper discusses tacit knowledge and technology involved to manage the logistic systems in different parts of the landscape.

NEW INFORMATION ON CELTIC-TYPE GETO-DACIAN SILVER COINAGE BASED ON XRF ANALYSIS OF COINS' ALLOY

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For coins, chemical differences that occur due to different metal sources and during preparation of alloys - found in their elemental composition - can be used for the identification of technologies and workshops and also to distinguish between originals and counterfeits. We illustrate with the case of 12 Dacian Radulesti-Hunedoara tetradrachms (Herakles head – averse, horseman – obverse, both strongly barbarized - see Constantin Preda, History of coins in pre-Roman Dacia, in Romanian, Editura Enciclopedica, Bucharest, 1998) found in the last years in the area of sanctuaries from Sarmizegetusa (ancient Dacian capital), coins having a high content in silver (73.2-90.2%) and an important presence of copper (3.1-19.3%), tin (3.8-7.3%) and lead (0.2-1.4%) – all constituents of ancient bronze alloys. These coins also have relevant traces of bismuth (0.2-0.8%), a fingerprint for Balkans silver minerals. A comparison with Radulesti-Hunedoara coins found in Dacian settlements relatively far from Sarmizegetusa, coins practically from bronze with a small quantity of silver (up to 10%), suggests Sarmizegetusa coins are produced to be votive depositions. Bismuth was detected in Thasos tetradrachms - mainly "barbarian" (Thracian) copies – also found in Sarmizegetusa, suggesting these were melted to be used to produce Radulesti-Hunedoara tetradrachms by alloying their silver with some quantities of bronze, a Celtic procedure we also found for Dacian silver adornments (including spiraled bracelets from Oradea and Herastrau). An interesting case is Toc-Cherelus coins (found near Arad area at the border with Hungary), issued in 2nd Century BC. Their composition consists in five metals: silver, copper, tin, lead and zinc, suggesting the use of silver-zinc minerals from Rhodopes Mountains (West of Bulgaria), so a Scordisci (Celtic population) provenance. The possible significance of the Geto-Dacian silver coins – real coins? signs of power? tribal symbols? – will be discussed.

THE SEUSO TREASURE – DETAILED ARCHAEOMETRIC STUDY ON COMPOSITION, RAW MATERIAL PROVENANCE AND TECHNOLOGY FOR UNDERSTANDING THE LATE ROMAN SILVER-SMITHING

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The Seuso Treasure, one of the most significant silver hoards of the late Roman period, comprises fourteen large silver vessels (platters, ewers, toilet casket, amphora, situlas) used for dining and washing. The objects can be dated to the 4th century AD and were most probably hidden during the last third of the 4th century AD in Pannonia close to the Lake Balaton, in the vicinity of Polgárdi-Kőszárhegy, Hungary (Mráv & Dági, 2014).

The treasure was analysed using various chemical methods in order to determine the elemental composition, provenance of raw material and production technology. Non-destructive handheld X-ray fluorescence analysis was first applied to analyse the objects systematically along a pre-designed grid at several points to check any inhomogeneity. In order to determine the bulk chemical and lead isotopic composition of the objects and to verify the handheld XRF results, tiny metal samples taken from the different structural parts of the objects were analysed by using LA-QICP-MS and MC-ICP-MS.

The analysed objects were manufactured from rather pure silver (88–98 wt%) intentionally alloyed with copper. The copper content is different in the various parts of the composite objects (ewers, amphora, situlas). Gold, lead and bismuth, the most important trace elements in silver objects, also show variations among the artefacts suggesting the use of different raw materials. The nearly constant gold and lead contents of the objects (typically below 1 wt%) indicate that not re-used or re-melted, but primary, cupelled silver was used for manufacturing the artefacts. Based on the lead isotopic composition, the raw material of the objects could come from the territory of the Balkans. The differences in the used raw materials and in the specific manufacturing techniques could indicate different workshops.

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SILVER GRAVE GOODS FROM THE EARLY MAGYAR BOLSHE-TIGANSKY CEMETERY

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This paper presents an entirely new results of technological study of silver items from the outstanding graves of the Early Magyar Bolshe-Tigansky cemetery found on the River Kama left bank (Rep. Tatarstan, RU) dated to the 9th - early 10th centuries (Chalikova-Chalikov, 1981). Manufacturing techniques of jewellery, amulets, belt and headgear fittings (approximately 120 samples from 20 graves) were investigated with the optical microscopy and SEM. Chemical composition of silver alloys was provided by the Micro-XRF at the archaeometry laboratory of the Department of Archaeology (Moscow State Lomonosov University). Many items were produced by the lost-wax casting technique or by the casting in a clay mould made by the impression of a model or a previously cast ornament. It is common to find traces of deepening the ornaments, filing and polishing of the surface and the casting seems as well as extensive use of fire-gilding. The most elaborate group of jewellery includes temple-rings decorated with filigree and granulation. Silver of the different purity (between 54 % and 93%) was diluted by brass, bronze, gunmetal and copper with a high arsenic content. Zinc-rich silver alloys containing between 1% and 15% of zinc are the largest group in the selection. A small group of belt and headgear decorations coming from relatively early graves (second half of the 9th century) shows arsenic between 1,3% and 5,5% and the absence of zinc. Elevated arsenic contents seem not to be related to an intentional alloying of silver or copper. Possibly, it has been associated with copper smelted of fahlerz ores. Most of the samples show gold impurity between 0,1% and 1%; the lack of bismuth (the detection limit of ca. 0,1%) indicates that Islamic coins were not used for the production of silver grave goods from Bolshe-Tigansky cemetery. Technological and stylistic analysis leads us to identify the dress and harness accessories produced over a long period by the craftsmen belong to Early Magyar and Saltovo cultures and to the Volga-South Ural region. A variety of the silver alloys reflects the different origin of the raw metals. Based on published data, the preferential use of zinc-rich silver alloys for cast items was detected on the remote territories of the Eastern and Central Europe comprising Hungary, Slovakia, Austria, Romania (Greiff, 2012), Middle-Volga region (Saprykina et al., 2010) and in the watershed zone between the Oka and Don Rivers (Murasheva, 2008).

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THE SOURCES OF VIKING WEALTH: ARCHAEOMETRIC ANALYSIS OF EARLY VIKING-AGE SILVER

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The Viking Age was a Silver Age. Across areas of Scandinavian settlement, hoards containing silver ingots, ornaments and foreign and domestic coin testify to the vast amounts of wealth accumulated in Viking hands. Contemporary written sources describe the Vikings acquiring loot through raids in western Europe, as well as Islamic silver via eastern (Russian) trade routes. Yet whilst the potential sources of Viking wealth are known, the relative quantities in which they were acquired is a key unsolved question of medieval archaeology.

Since much of the silver acquired by the Vikings was melted down and refashioned into Scandinavian artefact forms (e.g. ingots, rings), the only means of identifying the potential sources of Viking silver is through archaeometric methods. As part of a new five-year ERC-funded Starting Grant project, we are capturing lead isotope and trace element data from early Viking-Age silver across the Scandinavian world of the Viking Age. We are obtaining data for over 1000 individual objects, through both solution MC-ICP-MS and LA-MC-ICP-MS, across labs in five different European countries.

In this paper, we present the analytical results of 37 silver objects contained in the Bedale, hoard, deposited around c. 900 AD in North Yorkshire, England. The hoard contains cross-inscribed ingots, arm and neck-rings and an enormous torc. We compare the results with regional coin and ore data from both Western Europe and Western Asia. Initial interpretation of the lead isotope and trace element data suggests that, despite being buried in a western Viking context, the major contributor to the hoard was Islamic silver dirhams.

PROVENANCE STUDY OF THE VIKING AGE SILVER RINGS

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At the turn of the 9th century CE, objects made of silver became more present in south Scandinavia. Silver ornaments and coins found in hoards across the region reflect a long-distance trading connection between Northern and Eastern Europe with Asia. Besides trade, Vikings acquired silver through other means, such as plunder and levy, from Western Europe and other neighbouring regions. Hoard finds provide a valuable foundation for studying trade and interactions during this period. Among these finds, Perm'/Glazov and Duesminde type rings are especially interesting due to their unique distribution and standardise weight production. Whole or fragmented Perm'/Glazov rings can be found in all areas where Vikings deposited silver objects as hoards, but they are most common in south Scandinavia and in Russia — Perm Krai and Udmurtia regions. Similar rings named Duesminde type are also common in silver hoards from this period, but unlike Perm'/Glazov rings they are mainly found in south Scandinavia. Both rings highlight the economic and cultural interconnectivity between Scandinavia and Russia. In order to better understand the relation between rings, as well as the provenance of silver during the early Viking Age, rings of both types from across south Scandinavia were analysed in order to obtain chemical (µXRF, LA-ICP-MS) and lead isotope (MC-ICP-MS) compositions. The results obtained from archaeometallurgical analyses allowed for better understanding of long-distance communication and the development of 9th century silver network between Northern Europe and Eurasia during the early Viking Age. The presentation will present preliminary archaeometric results from PhD project that aims to understand the provenance of 9th century silver found in south Scandinavia.

THE BIRINGUCCIO LADLE -THE USE OF WRITTEN SOURCES IN ARCAHEOMETALLURGY

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The results of metallographic analysis are often interpreted from the viewpoint of a modern perception of materials and processes. However, this may often be misleading as the raw materials in the past were often different in composition and form. At the same time, the perception of which characteristics was of importance was often different from what it would be today.

One example is a casting technique, which seems to have been widely used from 14th to 16th century, but which has hitherto apparently avoided being noticed in archaeological excavations. Probably because it differs greatly from the methods you normally imagine from the period.

Glazed fragments of clay with copper traces were thought to originate from furnaces used for bronze casting. However, on the basis of Birringuccio's "De la pirotechnia" from 1540, they could be interpreted as fragments of a form of ladles. That is, large open crucibles made from plain clay in an open basket of iron. Heating took place as known from the Bronze Age, by burning charcoal on top of the crucible. Not, as otherwise known from the Middle Ages, by charcoal lying around the crucible. Interpretation might not have been possible without the written source.

The casting method seems to be associated with a special copper alloy containing antimony, arsenic, nickel and often large amounts of lead. This might be the copper produced in connection with the silver extraction from fahlertz in the central European saigerhütten. The products seems to have been mainly pots and mortars, but also church furniture as candlesticks and baptismal fonts.

GLOBAL METAL TRADE IN THE 16TH CENTURY AD – FROM EUROPE TO NAMIBIA: THE SHIPWRECK OF THE BOM JESUS

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In the 16th century AD tons of European metal fabricates reached the coast of West Africa via Portuguese traders. Those metals have been exchanged for gold, ivory and slaves.

However, despite numerous written accounts on the African metal trade, not much is known aboutthe purpose of those metal fabricates, let alone their physical appearance, their chemicalcomposition, where they have been produced and from which ore deposits. Written sources suggest that the so called „Manillas“ - a kind of brass bracelet - were highly sought after by African people and it is also indicated that Portuguese traders bought them millionfold at the international market of Antwerp. New combined historical and geochemical research reveals that their purpose was much more that of an ingot than currency or jewellery, and thus highlights their impact in African metalworks.

It is indicated, that the early Manillas have been highly chemically and physically standardised and were produced from the same Slovakian copper- and central European lead- and calamine ore deposits that supplied the world with metals since the post medieval era.

THE IMPACT OF EUROPEAN METALS IN AFRICAN METALWORK: COPPER FROM SLOVAKIA AND LEAD AND CALAMINE FROM CENTRAL EUROPE FOR AFRICA

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REVISITING HISTORIC SAMPLES: THE HMS SIRIUS ARCHIVE

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HMS Sirius was the escort to the First Fleet sailing with its complement of convicts to establish the colony at Botany Bay in Australia, in 1788. Her incomplete hull had been purchased by the British Admiralty and completed as an armed storeship in 1782. In 1786 she was then taken back into the dockyard for conversion to a 16- gun 6th rate for service with the first fleet. She was wrecked at Norfolk Island in 1790 while on a supply mission for the colony. A series of grants from the Australian Bicentenary Authority provided funds for the logistics and conservation operations along with full archaeological documentation of the finds from the wreck site.
From the early 1980s onward, various components were sampled for analysis and metallography. Compositions were published but not much metallography. Fortunately, though, the samples were preserved, and the results of the new study presented here.
The original studies faced a lack of comparative material as no systematic metallurgical study of Royal Navy sheathings and fastenings of the period. New metallurgical research in the University of Oxford, supported by documentary research in previously unused archives, has corrected this. Electron microprobe analysis (EPMA), optical metallography, and electron back scatter diffraction (EBSD) have een combined to explore both microstructures and compositions.
The career of, Berwick/Sirius spans an important stage in naval history when copper fastenings were replacing iron to prevent corrosive interactions with the copper sheathing. Ro assist in the exploration of this the samples from Sirius were made available. All have now been re-analysed by EPMA allowing the construction of a unified dataset which can be correlated with the earlier data and some systematic errors eliminated. Optical metallography and microhardness testing is carried out on all the samples. Throughout the employment of copper sheathing by the Royal Navy there were disputes about its quality and this work will assist in demonstrating the variability of the sheathing. The results will also be compared with the contractor's workshop archive to shed much light on the supply chain. Also, to be considered are brass bolts from the wreck site because they were available in the yard when Berwick was completed and may not be anachronistic.
This project has demonstrated the value of archived sample collections for evaluating earlier results, applying new techniques, and avoiding new sampling – the finds are preserved on Norfolk Island.

IRON ORE SOURCES OF THE SOUTHERN LEVANT; EXPERIMENTAL IRON SMELTING

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The transition from bronze to iron use is one of the most intriguing technological developments in human evolution. This technological breakthrough started in the southern Levant at the end of the late Bronze Age (ca. 1300 BCE) and culminated during the Iron Age IIA (late 10th c. BCE), when iron production was practiced in major urban centres located throughout the entire region. Analysis of production debris from some of these sites indicated that the entire chain opèrtoire of iron production was performed; from smelting of the ores to secondary smithing and forging. This meant that (readily available?) iron ore was brought to the settlement sites, a situation that enabled complete control over the process, and must have had bearings on various aspects of Iron Age society, including socio-political and economic organization.

Despite that this subject was studied extensively over the past few decades, one major question remains unanswered – the question of provenance. Where is the iron ore coming from? Were there one or more communal sources or small deposits near the Iron IIA settlements?

In an attempt to answer some of these questions, and others related to the technological choices and decisions made by the Iron Age metal smiths we initiated an Experimental Archaeology program in which locally available iron ores were subjected to experimental iron smelting.

Ores rich in iron occur in several locations in the south of Israel (Negev and Arabah), none of which, show evidence of early exploitation These ores were tested for feasibility of use in the bloomery process using both shaft and bowl furnaces. Attempts were successful, and three iron blooms were produced. The blooms were further worked to complete the chain opèrtoire.

In my presentation I will demonstrate how experimental archaeology accompanied by chemical and isotopic analysis is implemented as an investigative tool for the reconstruction of ancient technologies; to identify potentially expolited ores from the avialable ancient resources, to better understad the diversity in iron production debris and to isolate and identify human choices controlling the process.

BARRA FERRI ROTONDA IN CASTEL-MINIER IN THE XVTH CENTURY: FROM THE SEMI-PRODUCT TO FINAL OBJECT, A MORPHOLOGICAL AND METALLOGRAPHIC STUDY

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Abstract: not less than 200 words and not more than 400 (references included). It should contain: some introductory information on sites, objects or materials examined, aims of the work, techniques used and results obtained so far, including a short interpretation. The above information is necessary in order to help convenors to understand the work involved and to select the papers for oral or poster presentation.
References in the text as Surname et al. (2006) or (Surname et al., 2006).
Castel-Minier is located on the today’s Aulus-les-Bains (Ariège, French Pyrenees). Known as one of the most important silver-bearing site in the French kingdom, it presented also a significant iron production activity from the XIIIth century to 1580. It is established that the iron is produced in Castel-Minier under various shapes : flat bars, rods … (Téreygeol, 2016). In this framework, we will focus more particularly on the production, under hydraulic hammer, of a specific type of semi-product on the site, more complicated to produce, the round bar also called barra ferri rotonda (Verna, 2001).
Around twenty offcuts of these bars were discovered in the channel dating to the XVth century. They all present the same morphology: a circular-shaped body hot sliced with a crushed circular or oval head. A morphological study distinguishes four classes of circular bars according to the diameter of their body. In the mining area, two chain fragments were found. Their diameter is similar to the largest category corresponding to the offcuts. This supposes a direct relation between these final objects and the barra ferri rotonda. Metallographic analyses permit to evaluate that, more than a simple morphological similarity, a correlation in the nature of the metal exists between these two products coming from successive steps of the “chaîne operatoire”. Coupled with these analyses, microhardness measurements estimate the metal quality.
All these analyses permit to understand how the round shape was obtained from a square shape under hydraulic hammer, the nature of the iron they are composed and their use from the need in tools in the site. This research is part of a largest comparative study whose aim is to qualify the quality of various ferrous alloys produced in different contexts and different periods in occidental Europe. Measurements of criteria linked to chemicophysical nature of materials such as microstructure or mechanical behaviour enable to discriminate groups of qualities. These groups will be related in a second phase to descriptive criteria such as the origin or the dating of the semi-product. This corpus allows, in this context of study, to comprehend the link between quality and morphology. It enables to connect, its quality with its dedicated use as a final object and if there is a notable evolution between these two steps of production.

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METALLIC TIE-RODS IN HISTORICAL MASONRY BUILDINGS: CORRELATION OF MECHANICAL CHARACTERISTICS AND METALLOGRAPHIC FEATURES

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Historical metal tie-rods are relevant structural elements in heritage masonry buildings, contributing to guarantee an efficient connection between walls and playing a decisive role in the control of horizontal thrusts (both permanent, as in the case of arches and vaults, and environmental, as in the case of seismic actions, CALDERINI ET AL. 2014). However, few studies were carried on the mechanical behaviour of metal tie-rods in the last years and most of them are devoted to the identification of the axial stress. This results in rather unreliable models of these reinforcing elements, based on simplified constitutive laws (usually disregarding deformability issues, that play a fundamental role in modern seismic engineering) and on conventional material properties (usually extrapolated from those of modern ferrous alloys, or from some literature tests on XIX century steel bridges). At a bigger scale, this results in rather unreliable models of heritage buildings, leading to unreliable safety assessment procedures and unaware consolidation interventions (mostly replacements). The paper presents the first results of an on-going study on the mechanical characterization of historical iron tie-rods directly issued from their "operating" position in the masonry. Their function and age are thus precisely defined making them a statistically representative and valuable sample to acquire mechanical properties and to combine them with the metallurgical features resulting from the manufacturing process (VECCHIATTINI 2019). This should represent a paradigm of reference for further and systematic collection of tie-rods from restoration works or building demolitions. Dealing with a structural ferrous material originated by bloomery smelting (an iron making process based on iron ores in use since the European Iron age) an high volume fraction of slags (e.g. glassy silicon base non metallic phases directly related to the ores) and inclusions (e.g. iron oxides) are expected (DILLMAN, 2007, DILLMAN ET AL. 2019, CALDERINI ET AL. 2019). The smelted iron is poor in alloying elements (e.g. Mn, Ni, P, C) diffused from the ores or from the fuel (i.e. charcoal) during the smelting process or, for the C only, during the forging process too. Both elements, the potentially high concentration of slags and the roughly uneven distribution of carbon resulting in microstructural differences, are the main reasons for the unpredictability of the mechanical behavior of the the tie rods (DILLMAN 2019, CALDERINI ET AL. 2019). The set of tie rods available for this study where thus mechanically characterized (by a stress strain test) and investigated by classical metallography.

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ATTRIBUTION OF OBJECTS ON IRON MAKING SITES OF THE KUZNETSK TATARS OF THE 18TH CENTURY*

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Abstract: In the North-West of the Sayan-Altai region, a tradition of the iron making had been maintaining until the 18-19th centuries. The local turkic peoples, who were added in Russia in the 17th century, received the name the Kuznetsk Tatars for this. The Russian archival documents of 17-18th centuries allows us to get for the volume of iron making, as well as the diversity of products of the local blacksmiths. The mapping of that data gave the areas of the most intense metallurgical crafts. More than 50 archaeological sites with presumably remains of the iron smelting furnaces of different times were identified in that same areas. Their study has been just beginning (Martyushov, Shirin, 2018).

The only one detailed description of the iron making process of the Kuznetsk Tatars was made according to personal observations in 1734 by Gmelin (Gmelin, 1751). The sketches of that process were made by Lursenius at the same time (Vodyasov, 2016). Now, that text by Gmelin is raising the reasonable doubts, both for the indicated time of the metallurgical process and its productivity.

The analysis of material remains left by smithing activities on the settlements of the XVIII centuries Tesh-5 and Sharton-1 allowed to distinguish several types of the forges. Some of remains of the iron smelting furnaces and the blasting pipes of these sites were reconstructed. That are similar in appearance to were described by Gmelin and Lursenius. However, the practical purpose of these furnaces is not always clear.

The chemical analysis of the metallurgical slag of all morphological types of Tesh-5 and Sharton-1 was carried out taking into account the experience of similar studies (Serneels, Perret, 2003). The obtained data has been supplementing the database on chemical, petrographic and mineralogical analyses of residues from the iron-producing objects of various sites of the Sayan-Altai region.

* The research was supported by RSF (project №18-78-10076).

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LEAD CORES IN LATE BRONZE AGE BRONZE PALSTAVES REVEALED USING NEUTRON TECHNIQUES AT THE ISIS PULSED NEUTRON AND MUON SOURCE

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Bronze artefacts were buried in large quantities in isolated hoards in the Atlantic façade of Europe, between the Bronze Age and the beginning of Iron Age. This practice was particularly intense, and despite many years of research, even today we do not understand what motivated such disparate and widespread communities to express themselves in this way (Armada and Martinón-Torres, 2016; Montero Ruiz et al, 2015). This presentation is focused on the totally non-invasive characterisation of leaded bronze unused (as-cast) axes from NW Iberia using neutron probe. Our main focus is the presence and distribution of high quantities of lead in the axes, which raises interesting questions about their manufacture as well as challenges for conventional analytical techniques (Harrison et al. 1981; Gutierrez Neira et al, 2011). The sample includes a variety of compositions and states of preservation, as well as an enigmatic palstave that has a thick lead core as well as a large lead ball inside the casting sprue. Our specific objectives are (1) study the manufacturing processes of these axes; (2) study the inner morphology; (3) quantify their bulk chemical composition without analytical biases derived from sampling uncertainty. The experiments were performed at ISIS pulsed neutron and muon source in Oxfordshire UK exploiting complementary techniques such as neutron tomography and radiography, prompt gamma activation analysis and neutron diffraction. Neutrons are a unique probe for the investigation of metal objects because of their weak interaction with matter and high penetration power allowing the study of the features of the objects in their bulk in a non-destructive and non-invasive way (Festa et al, 2018). Results from the neutron tomography study provide new insight into the inner morphology of the axes, including 3D rendering and segmentation of their various inner parts, and leading to new hypotheses about their manufacturing techniques. The presence of a sphere of pure lead in the core of one of the axes opens multiple scenarios on the manufacturing processes of this object, suggesting the presence of a double casting or the occurrence of a massive lead segregation. Through neutron diffraction and prompt gamma activation analysis, it is possible to perform a thorough chemical characterisation in the bulk of the objects as well as the multiphase analysis thus allowing to study the corrosion patinas present on the surface of the axes. We discuss the implications of our study for the analysis of leaded bronze objects using conventional techniques.

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NONINVASIVE ANISOTROPY EXAMINATION BY X-RAY DIFFRACTION ON THE SEUSO TREASURE

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The manuscript presents the utilization of a unique, non-invasive X-ray diffraction (XRD) based texture examination method on the Perfume Box of the precious and famous treasure of Hungary, the Seuso Treasure from the late Roman era. The method was developed by the authors (Sepsi et al., 2019) for portable centreless X-ray diffractometers which are originally intended to measure residual stress rapidly on large-scale objects without the need for sample cutting even as on-site measurements. Thus, with these benefits over conventional, fixed laboratory X-ray diffractometers, it was possible to carry out texture measurements on such precious archaeological finds as the Seuso Treasure held at the Hungarian National Museum in Budapest. Since there is no other practically available method to obtain such information about the texture of these artefacts, the obtained result package is one of a kind. Pole figures obtained from the different parts - bottom, circumference and edge of the Perfume Box had notable differences: pole figures revealed quasi-isotropic structure on the bottom, a notable texture on the circumference and strong, characteristic texture on the edge. It was deduced that the near-surface regions of the examined sections suffered different type and/or degree of deformation during the production steps. The results are presented and discussed with respect to the actual penetration depth of the applied X-ray source.

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BRONZE RELIQUARY CROSSES WITH NIELLO DECORATION FROM NORTH-EASTERN RUS': THE FIRST STUDIES OF THE NIELLO COMPOSITION AND THE TECHNIQUE OF ITS APPLICATION

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Pectoral crosses should be regarded as a meaningful phenomena of Medieval Rus' culture. Resent investigations revealed that the small smooth pectoral crosses with niello with Crucifixion and the Virgin Orans were introduced in Rus' at the end of the XI cent. Their manufacture developed on the basis of the Byzantine and Balkan traditions, following the shape and size of the objects and the iconography of the images.

The paper presents the results of studies of the niello composition and the technique of its application on the 12 reliquary crosses from Suzdal region (Russia). Previously, the niello on bronze has not been studied in Russia. All the leaves of crosses were cast from a multi-component zinc-containing copper-based alloys. The complex of different analytical methods was employed to study the niello composition. It is the first time, when niello is examined with 6 different analytical techniques, including the combination of X-ray synchrotron methods (X-ray fluorescence mapping, X-ray diffraction, X-ray energy- dispersive), synchronous thermal analysis, scanning electron and optical microscopy.

Analysis revealed the use of multi-component copper-based alloys which included Sn, Pb and almost in all cases some amount of Zn for production of the niello. Sulfur content in the decoration of the reliquary crosses was found to be in range 11.5- 21 weight %. It was found that the niello consisted mainly of the copper sulfides (chalcosite, djurleite, anilite, yarrovite, digenite, covellite), and in small amounts of lead sulfides (galena), tin sulfides (berndtite). In small concentrations, metallic copper and lead were presented in some samples. For the one type of artefacts niello was used as inlays whereas for the second one may receive decoration from rubbing of heated material.

70 comparable items are known on all territory of Medieval Rus'. Strong similarity of artefacts indicates that they could have been the products of several workshops. The appearance of the niello technique in bronze objects in Rus' is related to the beginning of manufacturing the reliquary crosses. The technology of the non-silver sulfides involvement for the manufacture of the niello decoration on bronze items seems to be innovative.

The study is performed with support by the Russian Foundation for Basic Research, № 17-29-04129.

NON-DESTRUCTIVE COMPOSITIONAL, STRUCTURAL AND MORPHOLOGICAL ANALYSIS OF JAPANESE SWORDS BY NEUTRON METHODS: A NOVEL INSIGHT IN THE MANUFACTURING TECHNIQUES

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The study of the forging and assembling techniques represents one of the most interesting topics in the investigation of ancient Japanese metallurgical manufacturing methods [1-2]. In this work, we present novel results from a non-invasive approach to the study of Japanese swords based on Neutron Tomography and Neutron Diffraction[3-6] .
Several swords, both from Museums (Stibbert Museum, Florence, Italy and Wallace Collection, London, UK) and private collections, were analyzed using these two methods. We obtained volumetric details concerning the steel quality (carbon content and slag inclusion amount and distribution), the distribution of welding lines, the presence of defects and flaws, and the amount, shape and distribution of quenched areas. The obtained data can clearly show the relevant details of the manufacturing methods employed for the production of each of the analyzed Japanese swords.
A total of 20 swords and 8 broken sections, pertaining to different periods ranging from 14th until 19th century, have been analyzed. Neutron experiments were performed at the ISIS (UK), J-PARC (Japan), PSI (Switzerland) neutron sources. Tomography analysis was performed on the whole volume to identify the whole range of morphological details while diffraction measurements were focused on specific parts of the swords as the tip, the core of the blade (differentiating among the cutting edge, the centre and the back) and the tang, to determine the quantitative distribution of the metal and non metal phases. The comparative analysis of the phase distribution in the different samples permitted to identify peculiar characteristics related to the forging traditions and periods of the Japanese history and to determine the inner metal phase distribution thus confirming the differentiate specialization of the single parts of this kind of swords.
Due to the high quality level of the results in terms of spatial resolution and quantification of phases and microstructures, this multi-methodological non-destructive approach presents an incomparable potential in the field of historical metallurgy.

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FIRST TO THE FINISH LINE? METALLURGY OF LEAD MAKING IN THE 6TH AND 5TH MILLENNIUM BC BALKANS

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The recent advancements in the studies of early metallurgy of copper have provided support for its multiple origins across the Old World in the early 5th millennium BC (Radivojević et al., 2010). The role of aesthetics and colour preferences for particular types of copper ores used in the early copper metal making have been argued as one of the driving forces for early experimentation (Radivojević, 2015), including not only copper but also tin bronze and gold (Radivojević et al., 2013; Leusch et al., 2015). However, the so-called polymetallic horizon of early Balkan metallurgy also includes lead, the production of which has remained poorly studied and understood.

Here I present a new evidence for lead production from the Vinča culture site of Belovode in eastern Serbia, which in absolute dates predates now well published record for the world's earliest copper metallurgy. A combination of contextual, microstructural, compositional and provenance analysis of a lead slag cake from this site provides insight into the early technology of lead extraction, while a systematic revision of lead artefacts in the Balkans, and across the Old World during the 6th and 5th millennium BC illuminates on the knowledge of lead making at the very beginnings of extractive metallurgy.

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USE OF GALENA IN THE NEOLITHIC OF NORTH-WESTERN IBERIA

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Neolithic is a period characterized by the development of new technologies and a broader use of organic and inorganic materials. Some of the metallic minerals were used for making ornaments and pigments before their use as metals (copper or iron ores are a clear example of this exploitation). Galena (lead sulfide) is not usually mentioned in this period, but a new research find a frequent presence of blocks of galena since the Early Neolithic in several Catalan sites. Just in one case was found as a grave-good (female grave in Masdervenger, Tarragona), but most of them come from domestic context. Galena is not a good material to be worked using knapping methods due to its cubic crystals and fracture properties: one of the striking features is a fine cleavage. However its metallic luster and weight could attract the attention of the people.

This early contact with galena however did not drive to a metallic use of lead. It is intriguing the fact that lead beads were common (hundreds) in southern France Chalcolithic, where a later and less clear pattern of galena use during the Neolithic (since Early Chasséen) is known; on the contrary just only one lead bead was found in Catalonia (Cova de L´Heura, Tarragona) and its lead isotope signature matches the local lead mines.

This paper includes a provenance study by Lead Isotope Analysis (using MC-ICP-MS) to understand the local pattern of exploitation of galena, with the Molar-Belmunt-Falset mines in Tarragona and The Martorell/Begues mines in Barcelona as the main and only areas supplying the galena during the Neolithic. This research has been funded by the project “Producción, variabilidad técnica e innovación tecnológica en el Neolítico” (HAR2016-76534-C2-2-R) and "Inici i desenvolupament de les comunitats neolítiques a la plana occidental de Catalunya (c. 5.500-3.000 cal ANE)" (núm. exp. CLT009/18/00021)

INCISED LEAD INGOTS FROM THE SOUTHERN ANCHORAGE OF CAESAREA, ISRAEL

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During the 2nd millennium BCE in the Levant, objects made of lead were rare and this malleable and rather dull metal, which does not occur in local ore deposits, was used mainly for its heavy weight property, mainly for filling bronze weights, or for the production of fishnet sinkers. Occasionally, lead was added to bronze figurines in order to facilitate their casting, but chemical analysis of 90 objects from the southern Levant dating from the 13th to the 9th century BCE, including bronze figurines, generally did not detect the addition of lead. In light of this scarcity, a small group of lead ingots, comprising part of a ship's cargo found in the southern anchorage of Caesarea, off the Carmel coast is particularly intriguing. Three of these ingots are marked by signs used in the Cypro-Minoan syllabary, which based on comparisons may be dated to the end of the Late Bronze Age. Lead isotope analysis performed on the four ingots sheds light on the origin of the lead. Together with additional results of lead isotope analysis performed on other lead ingots and well-dated lead objects, it is possible to reconstruct far reaching maritime trade activity between the eastern and central Mediterranean during the Late Bronze – Iron Age transition.

RECONSTRUCTION OF PRE-MODERN PB-AG METALLURGICAL PROCESSES BY ANALYTICAL AND EXPERIMENTAL CHARACTERISATION OF SMELTING SLAGS FROM KOSOVO

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We analysed a suite of pre-modern slags from Kosovo for their bulk chemistry and phase composition by X-ray diffraction, electron microprobe and inductively coupled plasma mass spectrometry (ICP-MS) to reconstruct Pb-Ag extraction processes. The samples were collected during systematic surveys from several smelting sites within the ancient mining districts of Janjevë/Janjevo and Novobërdë/Novo Brdo in which old workings date to Roman, medieval and early modern times, i.e. between the 1st and 17th centuries CE (Ćirković, 1981; Körlin & Gassmann, 2016; Rexha, 2012).

We established a classification scheme for slags based on their phase assemblages (i.e. main silicate phases, Fe oxides) which is also reflected by differences of the bulk chemistry of the subtypes. The identified slag types correlate with the redox conditions of the furnace atmosphere, which together with the composition of the liquid are demonstrated to control characteristic parameters of the slags. Most importantly the metal yield is negatively correlated with the bulk SiO2/FeO ratios of the samples, which in turn are larger for slags generated at a more oxidising furnace atmosphere. Coupled with experimental data on the solidification behaviour and viscosity of the slag liquids, we reconstruct the specific influence of different factors, including the smelted raw material, potentially added fluxes, charcoal ash and furnace lining on the efficiency of the metallurgical process and subsequently discuss an intentional or coincidental generation of the different slag types.

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A GEOCHEMICAL CHARACTERIZATION OF LEAD ORES IN CHINA: AN ISOTOPE DATABASE FOR PROVENANCING ARCHAEOLOGICAL MATERIALS

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A well reasoned lead (Pb) isotope-driven provenance study lies in concert with a comprehensive and evaluated database of geological ore sources. In this study we compile around 6,000 Pb isotope data of galena and K-feldspar from China and provide geological interpretations of how ore-forming substance evolved in various tectonic terrains with distinguishable isotopic features. We pay particular attention to the geological settings of host ore deposits that were likely exploited in ancient and historic China, demonstrating both heterogeneity and homogeneity of ore formation across different metallogenic provinces and belts. It turns out that ore bodies in North China has the least radiogenic Pb isotope signature, serving as a promising region to trace Pb sources in metal. This background information and ore data are used in three case studies to reevaluate Pb isotope provenancing of Chinese cultural materials, including Warring-States bronze coinage, Qin state bronze ritual vessels, and Tang Dynasty leaded glaze. The data are presented in ternary diagrams that allow for the rapid and accurate comparison of ores and objects.

PERSIAN IRON SMITHY IN TEL AKKO

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This paper presents the results of the excavation and analysis of an extensive iron industrial area (smithy) of unprecedented size dating to the 6th–4th centuries BCE (Persian period) at Phoenician Tel Akko, Israel. This 22-hectare commercial and industrial harbor town connecting the Mediterranean Sea with the Levant has dominated the Plain of Akko's ancient landscape for four millennia (see e.g. Artzy and Beeri, 2010). Current excavations of the Tel Akko Total Archaeology Project, directed by A.E. Killebrew and M. Artzy under the auspices of the University of Haifa and the Pennsylvania State University, focus on the late Iron Age and Persian period (ca. 8th–early 4th centuries BCE) Phoenician city in Area A at the summit of the tell. Here huge quantities of iron slag, hearths, tuyeres, hammer scales, and cultic installations have been uncovered. This mid-first millennium smithy, the only known iron working facility in the Levant dating to the Persian period, provides an unparalleled opportunity to explore iron production at a Phoenician maritime center (see e.g. Killebrew and Quartermaine, 2016 regarding the current excavations).

The focus of this presentation is the preliminary results of analyses conducted by Ü. Güder of this largescale iron industrial area. These include sources of iron ore, modes of production and remains of possible ritual practices. The significance of iron production at Tel Akko is contextualized in its Phoenician cultural milieu and its role within the Neo-Assyrian and Persian empires. In addition, as part of the Tel Akko Total archaeology project, smithing experiments were performed with students in order to understand the effectiveness of smithing hearths excavated at the site, source of air, the impact of the smithy's location etc. The archaeometric analyses (metallography, petrography, ICP-MS, XRD, SEM-EDX and micro hardness) and experimental studies reveal that the slags were smithing slags, distributions of trace elements in slag compositions are compatible with each other (possibly due to usage of iron ore from one source), suggesting production of iron artifacts on an industrial (imperial) scale.

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THE PHENOMENON OF KOSH-AGACH TYPE OF IRON-SMELTING FURNACES IN THE ALTAI MOUNTAINS

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Discovered in the region of Gornyy Altai, iron-smelting furnaces of the so-called Kosh-Agach type, dating back to the first millennium A.D., are the largest ones in Central Asia (Ziniakov 1988).

The above-ground part of the furnaces was rectangular, up to 2 m long and 1 m wide, and was made of clay. The height of the preserved clay walls equated to 0.5 to 0.7 m. The underground part consisted of a rectangular iron-smelting chamber around 1 m deep, lined with vertical stone slabs. The average volume of one such furnace was 1 m3.

A large number of holes for bellows – 8 to 11 on each of the longitudinal walls – are a distinctive feature of the furnaces. The chamber of the furnace was built at an angle in order to allow for the release of liquid slag through a special underground channel which connected it with an additional pit. The remaining slag at the bottom of the furnace weighted over 400 kg.

Overall, 15 furnaces of this type, located exclusively in the Kosh-Agach area of the Republic of Altai (Russia), were studied in the 1970s to the 1980s – all of them dating back to the period from the sixth to the tenth centuries A.D. (Ziniakov 1988). The emergence of these is associated with the first Turkic Khaganate.

The excavations we carried out in 2018 of the Kuyakhtanar iron smelting site allowed reassessing the previously suggested date for the furnaces. Based on a series of radiocarbon dates, it was established that the furnaces of the Kosh-Agach type emerged in the third to the fourth centuries A.D. Their origins remain unknown as we are not aware of the existence of their analogues in neighbouring territories.

Acknowledgements

The research was supported by RSF (project No. 18-78-10076).

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PRODUCTION AND TRADE OF IRON IN THE KHMER EMPIRE (9TH-15TH CE): A COMBINATION OF TECHNOLOGICAL, CHRONOLOGICAL AND SOURCING ANALYSES

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Investigation into material production and distribution is an important way of understanding the political and socioeconomic organization of premodern states. Reconstructing how iron was managed in the Khmer Empire is therefore a critical perspective for documenting the interrelationship between its multiple sociotechnical systems and greater historic trajectory. In this paper, we propose to combine archaeological, archaeometallurgical, technological, chronological and sourcing investigations of iron to reconstruct the spatial, diachronic and synchronic organization of the iron exchange system within the Khmer empire between the 9th to the 15th centuries.

To reach these objectives, we have investigated three classes of iron objects—architectural crampons, armatures for statuary and objects, and tools and weapons—that have played minor roles in past research but in combination may significantly alter our understanding of the Angkorian past. Since 2015, we have examined a statistically significant number of architectural supports (250 crampons) recovered from 7 from the Angkorian masonry complexes (9th to 15th c. CE) and tools and weapons from consumption sites (9th to 12th c. CE). The methodology was recently implemented on the iron armatures from the religious statuary and objects made of bronze that were also produced in massive quantities during the Khmer state.

The combination of the analyses have generated evidences of form, process of secondary manufacture, association with reduction systems, and date of production. This investigation was paired with extensive analyses of the vast iron production landscape of central Cambodia and evidence from northeast Thailand. Gathering all evidences permits to identify changes in the production and consumption strategies of the Khmer state that seem to be linked to key historical developments of the empire. Moreover, the resulting large datasets offer new methodological perspectives to apprehend the combination of data. Overall, it is possible to move towards reconstructing premodern iron economies and the interrelationship between the sociotechnical system and historic trajectory of the Khmer Empire.

IRON METALLURGY ON THE NORTHEAST COAST OF MADAGASCAR (11TH-15TH CENTURIES CE): PRODUCTION AND ORIGIN OF THE TECHNOLOGY

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In 2017 and 2018 two excavation and survey campaigns were carried out in northeastern Madagascar. These campaigns confirmed the presence of iron production workshops along the coast between Vohémar and Antalaha and defined a metallurgical district. The detailed study of the archaeological remains and the analysis of the waste (slag, tuyeres, etc.) allow us to reconstruct the furnaces. These were probably bowl furnaces with a single cylindrical tuyere and walls built from sand: a simple technology but still allowing the reduction of lateritic ore, present near the sites. Indeed, contrary to what has been mentioned in the literature, lateritic ores were used during the reduction process and not iron rich black sands found along the coast.

From one workshop to another, variations can be observed. However, these variations are small and could correspond to local variability. This tends to demonstrate the use of a same technology throughout the period of metallurgical production, between the 11th and 15th centuries AD. During this period, an Islamized population called Rasikajy occupied this region of Madagascar. This population, still very poorly known, participated in the large medieval trade of the Indian Ocean. The comparison of the technologies studied in the Northeast of Madagascar with the technologies known in the Indian Ocean region (from East Africa to China via India and Arabia) would help to understand the questions of geographical origin and the modalities of the transfer of this technology.

THE SOURCE OF SILVER IN THE EARLY IRON AGE SOUTHERN LEVANT: THE PROBLEM OF PROVENANCING CU-AG ALLOYS

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The Source of Silver in the Early Iron Age Southern Levant: The Problem of Provenancing Cu-Ag Alloys

Silver in the Bronze and Iron Ages in the southern Levant served as currency, was valued by weight and was often hoarded. Out of 30 hoards which were unearthed in different excavations, ten hoards date to the LB III/Iron I transitional period in the southern Levant (~1200-950 BCE). Over 80 silver items from eight hoards were subjected to chemical and isotopic analysis. The results indicate that silver in this period was extensively alloyed with copper, in contrast to hoarded silver from earlier and later periods. This suggests an instable period, when many hoards were not claimed, yet rather abandoned, and possibly a shortage of silver in the region.

Lead Isotope Analysis (LIA) of the alloys suggests that some of the Ag-Cu alloys originated from Anatolia/the Aegean and some of the items originated from Sardinia or from overlapping Pb-rich copper ores from the Araba in the southern Levant (Timna and Faynan). The overlap between ores, and the mixed state of the silver-copper alloys limit the possibility to provenance the alloys using LIA alone. Detailed chemical analysis was used to further investigate this question. The results show that much of the added copper contributed As, Sb and Ni to the alloys. The abundance of these trace elements in the added copper suggests that in addition to the use of copper from the Araba valley, Pb-poor As-rich copper from Anatolia was added to silver. It is likely that the silver originated from Anatolia as well.

METALWORKING AT THE ANGLO-SAXON PALACE AT RENDLESHAM IN EAST ANGLIA

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Around 6km North-East of the world famous Anglo-Saxon burial ground of Sutton Hoo lies the site of Rendlesham. Fieldwork at Rendlesham in Suffolk has identified a major central place complex of the early–middle Anglo-Saxon periods, hinting to the location of the 'royal settlement' mentioned by Bede in the 8th century. The assemblage was recovered during a systematic metal-detecting survey, with only limited excavation carried out. There is however a high proportion of precious metal objects and coins, along with brooch types rare in England, which all point to an elite site. Also discovered was a range of non-ferrous (gold, silver and copper alloy) metalworking waste including, scrap metal, globules of spilt metal, casting sprues. Unusually for a single site the full process of manufacture is present, allowing a unique study of metalworking waste in the form of sprues, unfinished objects in a variety of states and their compete counterparts.

A variety of analysis techniques is being used to investigate this large assemblage which included gold, silver and copper alloy objects, and related metalworking waste. This presentation will provide the first look at the metalworking assemblage from the site, which may have been the workshop for the elite burial ground at Sutton Hoo, as represented by the gold and silver metalworking waste and objects found.

The primary focus of this presentation however will be on the copper alloys, the analysis of which is providing more information about the manufacturing methods by the Anglo-Saxon craftworkers, as well as thoughts and choices made. The compositions may ultimately assist in the examination of trade and distribution of unique object types from this site.

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EARLY MEDIEVAL GOMBIKY (SPHERICAL HOLLOW BUTTONS) FROM MIKULČICE, GREAT MORAVIA

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Mikulčice is one of the most important Great Moravian political, ecclesiastical and economical centre in the ninth century and possibly the seat of the Moravian ruler (newly e.g. Poláček 2017). A high concentration of prestigious grave goods belonging to the Moravian ruling elite was discovered there in particular in the churches 2 and 3 and their graveyards in the acropolis as well as in the graveyard of Kostelisko in the extramural settlement. Among them, are numerous exquisite jewels in massive gold, silver or gilded copper alloys decorated either by filigree and granulation or chasing and repoussé work. One specific type of these jewels is represented by gombiky which are spherical hollow buttons, used as prestigious clothing fasteners or pendants, as well as luxurious amulet usually found in pairs in the wealthiest graves (Krupičková in print). In order to characterize metal composition, construction, and manufacturing processes of these type of jewels, thirty specimens were investigated by observation under optical stereomicroscope (Olympus SZ60), X-ray radiography, scanning electron microscopy (SEM), supplemented by electron microanalysis (EDS). Replicas of each main type of gombiky were manufactured by a professional goldsmith to understand the different stages of manufacture and soldering techniques. Results have evidenced the use of almost pure gold, silver alloys, gilded copper, different type of soldering techniques (fusion welding, hard solder), gilding by fire-gilding, specific tool marks and high skills in chasing, filigree and granulation work. The research provided a better understanding of the construction, manufacturing techniques, soldering technique and stages of fabrication of this type of jewels. Comparison with the recently investigated gombiky from the contemporary Lumbe´s Garden cemetery in Prague (Ottenwelter et al. 2014, 163–288) will be presented, and importance of past restoration treatment will be stressed upon.

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MANUFACTURE OF REPLICA OF EARLY MEDIEVAL GOMBIKY (SPHERICAL HOLLOW BUTTONS) FROM MIKULČICE, GREAT MORAVIA

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The aim of this contribution is to present the different steps of manufacture of the main types of gombiky (globular hollow buttons) recovered in Mikulčice, one of the most important Great Moravian political, ecclesiastical and economical centre in the ninth century (newly e.g. Poláček 2017). Gombiky are hollow spherical pendants found in the graves of the wealthiest individuals in Great Moravia. They are found in the graves of both men and women as well as children. They may have been prestigious clothing fasteners, symbolizing affiliation to the upper classes or a luxurious amulet (Krupičková in print). They are made of gold, silver and gilded copper alloys and are decorated by chasing, repoussé work or filigree and granulation work. The manufacture of replica of the main types of gombiky from Mikulčice has enriched the archeological and material science study of these jewels. It provided a better understanding of the construction, manufacturing techniques and stages of fabrication of this type of jewels. It confirmed several types of construction and use of soldering techniques evidenced by analysis. It further allowed comparison on approximate time of manufacture, level of difficulty and weight of precious metal used for each type of gombiky giving additional parameters of comparison to those provided by the archaeological context and material science approaches (see also Ottenwelter et al. 2014, 163–288; Barčáková 2014, 311–418).

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ARCHAEOMETALLURGY OF PRECIOUS METALS OF VILNIUS IN THE 13TH-17TH CENTURIES

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I will introduce the research database of archaeological artefacts (gold and silver artefacts, crucibles) of Vilnius in the 13th-17th centuries.

In Vilnius there were found more than 22 archaeological artefacts of gold and more than 70 artefacts of silver from 13th to 17th centuries. Now there have been 70 research database from the three laboratories. The results were received about metal alloys, solders alloys and identification of mercury. It was possible to analyze the artefacts using only non-destructive methods (X-ray spectroscopy and the stone – lyddite).

In Vilnius of the 13th-17th centuries gold-silver-copper and silver-copper alloys were used. The alloys of silver and gold varied and had not changed from the goldsmiths' privilege in 1495. Then there was established the standard of silver – 958 (the standart of gold was not established).

Golden artefacts (rings, decorative details, chain) were found in Vilnius Lower Castle - the main residence of the Grand Dukes of Lithuania (Dukes jurisdiction), from Palace of Bishops (Bishops jurisdiction) and artefacts from Vilnius city and churches (from the Cathedral - Catholic and from Evangelic-reformat cemetery).

More silver artefacts (rings, earrings, mounds, buttons, etc.) were found in various places of Vilnius. The alloy of silver varied and the standard was not always followed. This metal has a long history of usage and has been popular in Lithuania from the first millennium.

Crucibles with gold were found in three places of Vilnius Oldtown – Vilnius Lower Castle, Pilies Street and Pranciskonu Street. The crucible with silver was found in Vilnius Lower Castle. In other places of Vilnius were found crucibles with copper alloys. The analysis of crucibles was performed using the X-rays and SEM-EDX methods.

From the 13th to 15th centuries we can rely only on archaeological research database and artefacts. From the 16th century the goldsmiths' documents appeared.

A LATE PREHISTORIC COPPER PRODUCTION IN CENTRAL LAOS: THE VILABOULY COMPLEX – TECHNOLOGICAL RECONSTRUCTION AND EXCHANGES

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Evolving from purely 'origins'-based research, significant advances have been made in our understanding of early Southeast Asian metallurgy in the last decade, partly through new excavations of metal production sites, and partly through the application of established provenance methodologies to assemblages covering almost two millennia. On the fieldwork front, ancient copper mining and smelting sites at the Vilabouly Complex (VC, formerly known as Sepon) in Savannakhet Province, Central Laos, have been excavated by a Lao-Australian team led by Dr. Nigel Chang and Viengkeo Souksavatdy since 2008, in conjunction with the owners of the LXML concession. The VC, with a radiocarbon sequence from the early Bronze Age (c. 1000 BC) to the late Iron Age (c. 500 AD), is one of only three prehistoric copper production sites physically known in Southeast Asia, the other two being in Thailand. The VC lead isotope signature has been identified in the copper exchange networks across Southeast Asia, involving metal consumers from Myanmar, Thailand, Cambodia, and potentially as far as Indonesia.

The Vilabouly Complex displayed evidence of a copper production with artefacts linked to the smelting of copper (ores, slags, crucibles, molds, and scorched clay) along with copper and copper-alloyed artefacts (ingots, drums, axes etc.). In conjunction with ongoing studies of production materials, analyses of the different types of metal artefacts (OM, SEM-EDS, Raman Spectroscopy, pXRF) permit the reconstitution of the copper production techniques involved at the VC. One of the main questions to resolve is the type of ore used during smelting. According to local geological evidence, oxidic ores are to be mainly expected but recent results have shown the presence of matte in some types of artefacts. Ergo, based upon the metal artefacts, do we have real matte smelting or an intentional/unintentional co-smelting? These observations can then be compared to those previously proposed for early Thai copper production to see if any correspondences can be deduced. A second main objective is to understand VC copper production at the scale of regional and inter-regional metal exchange networks, with the lead isotope analysis of 59 VC metal artefacts within the scope of the Southeast Asian Lead Isotope Project. This is the first ever study of prehistoric Lao copper-alloy artefacts, and will play a significant role in developing our understanding of material and technological transmissions around Southeast Asia, and beyond.

GEOCHEMICAL ANALYSIS OF EXPERIMENTAL EGYPTIAN COPPER SMELTING: THE AYN SOUKHNA PROCESS AND BROADER IMPLICATIONS FOR ARCHAEOMETALLURGY

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Copper smelting technology in Egypt is poorly understood for the entire period of Pharaonic history. The site of Ayn Soukhna has provided the first detailed documentation of primary smelting workshops, dating to the Middle Kingdom (2nd millennium BCE) (Abd el-Raziq et al. 2011, Verly 2017). Our understanding of this smelting process, taking place in highly standardised furnaces, has grown over the past decade through the iterative development of excavation, experimentation and archaeometric research, each of which plays an essential role in informing the other. This integrated approach to metallurgy is essential not only towards understanding the archaeological remains as such, but furthermore in obtaining a detailed understanding of what happens within these furnaces. In this paper, we discuss the experimental and archaeometric aspects of this research. Over 60 smelting experimental smelts have provided a detailed understanding of the functioning of these furnaces under different conditions. The varied experimental production remains are validated through comparison to their archaeological counterparts. Furthermore, they have been characterised by elemental and lead isotope analysis to reconstruct different geochemical pathways from ore to metal for this Middle Kingdom smelting technology. These results are then compared to the field analysis (portable XRF) conducted at the site of Ayn Soukhna, were sampling is not possible.

These results have important ramifications towards our interpretation of Egyptian archaeological metals and production remains (e.g., Rademakers et al. 2018), as they refine our understanding of potential geochemical changes and contaminations that may occur during this primary production step. Importantly, these reflections are equally relevant to the interpretation of chemical and lead isotope data in archaeometallurgy more broadly.

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RECYCLING IN NEW KINGDOM EGYPT: A CASE OF COPPER ALLOY ARTEFACTS FROM ANIBA, NUBIA

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The New Kingdom of Egypt is known as an "imperial" phase of ancient Egyptian history, with an unprecedented abundance of written and iconographic sources. Yet, the studies of Egyptian bronze objects of this period have uncovered a complex picture of recycled and remelted material with unclear signs of lead isotopic ratios and trace elements. We have had the opportunity to sample an assemblage of 40 well-dated objects coming from archaeological contexts at the Nubian site Aniba excavated by Georg Steindorff and currently deposited in the Ägyptischen Museum – Georg Steindorff – der Universität Leipzig. They are datable to the C-Group and the New Kingdom, i.e. to the Second Millennium BC in Egypt (preliminary results published in Kmošek et al. 2016). New dating of the pottery assemblage from Aniba has enabled us to reassess the archaeological context and distinguish between reliable and less reliable contexts. We have applied a wide range of archaeometallurgical methods to the samples obtained. Selected artefacts have been studied by metallographic methods in combination with microhardness tests and XRD. Chemical composition analyses were carried out by means of the ED-XRF, SEM/EDS and neutron activation analysis. Lead isotope analyses were carried out using a MC-ICP-MS spectrometer in order to better understand the geographic provenance of the copper ores used.

In this paper, we would like to discuss the results and preliminary interpretation of the data, testifying to widespread recycling and the use of several sources of ore. On the background of previously published studies (e.g. Rademakers et al. 2017; Shortland 2006), we would like to address anew the question of the reuse of copper on the "imperial" scale in New Kingdom Egypt through data from its southern "province". This case study might bring new insights to the wider issues of the identification and interpretation of recycled material in ancient metallurgy.

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THE APPLICATION OF COMPUTER SIMULATION ON REVERSE ENGINEERING OF ARTEFACTS

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As for other processes, the need for modelling of casting normally originates from a technical problem. The first step in the solution process consists of describing this problem by the proper physical terms. The mould filling is recognised as a fluid flow problem, the solidification basically as a heat transfer problem and the distortion as a solid mechanical problem. Secondly, these physical problems should be described by a proper mathematical model. In all cases, a choice has to be made whether the mathematical model should be so simple than an analytical solution could be obtained or a more accurate analysis is needed meaning that a numerical solution be obtained. It should be emphasized that a mathematical model of a physical/technological problem always is an approximation of the original problem no matter the solution method. [1]

Once the mathematical problem has been solved, the results should be interpreted. Especially in manufacturing process the misinterpretation of otherwise correct mathematical results could lead to totally wrong conclusions. Solution of the technological problem can be obtained as follows: Technological problem ⍰ Physical phenomena ⍰ Mathematical model ⍰ Mathematical solution ⍰ Physical interpretation ⍰ Technological solution.

The basic flow of numerical simulation can be divided as: pre-processing, main-processing and post-processing, see Fig.1.

Fig.1. Basic flow of simulation

In this paper an axe geometry from the bronze age is examined to demonstrate the possibilities of computer simulation methods on reverse engineering of artefacts. Approximately 120 input parameters are considered to describe the original casting process, such as casting-mould-environment geometry, chemical composition, physical parameters, casting technology, etc. The examined geometry of the artefact and the shrinkage calculation results can be seen if Fig.2. [2-3]

Fig.2. Examined geometry and calculated shrinkage results

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COPPER OF THE FAHLORE TYPE IN LATE GEOMETRIC GREEK BRONZE CAULDRONS: A MULTIPLE APPROACH ON A SUDDEN INDUSTRIAL BOOM

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During Early Iron Age, the custom of dedicating bronze tripod cauldrons in Greek sanctuaries comprised a typical practice. Greek sanctuaries served as central meeting places for the elite, hence these tripods may be used as a means of assessing contemporary economic structures. On the other hand, the investigation of tripods' technological/materials aspects can contribute towards a better understanding of the manufacturing technologies along with the raw materials' circulation and consumption (Kiderlen et al. 2016). In this perspective, about 260 relevant micro-samples are investigated through chemical (HR-ICP-MS), lead isotope (MC-ICP-MS), and partly also metallographic (OM), and micro-phase elemental analysis (SEM-EDX).

Preliminary results point to the mines of Wadi Araba as the source of the majority of the samples, indicating the existence of a Levantine-Aegean copper trail (op. cit.). However, nine samples that are dated to the second half of the 8th century BCE, show a particular geochemical pattern, which suggests the presence of fahlores in the copper mines as well as zinc, lead and iron mineralizations. Lead isotope data favour the Aegean region and especially NE-Greece (Melfos & Voudouris 2012). This paper presents the geochemical data of these ‚fahlore'-copper tripod fragments with respect to the NE Greece ore mineralizations additionally to metallographic studies that clarify how this particular metallurgy is reflected in the metal.

Results hint to a major change in copper economy around 750 BCE, with a then diminishing role of the Wadi Araba and its related long-distance trade systems, and the rise of other mining districts. Although the detected ‚fahlore'-copper may stem from one single source in NE Greece, it is well known that, at the beginning of the 8th century BC, several mining centres in the Aegean emerged and developed (Economopoulos 1996). In any way, our data show that mining activity in NE Greece had a market within the elites of SW Greece.

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BETWEEN EAST AND WEST: A BRASS PRODUCTION RECIPE FROM THE BYZANTINE TREATISE 'ON THE HIGHLY APPRECIATED AND FAMOUS ART OF THE GOLDSMITH'

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The Treatise "About the Highly Esteemed and Famous Art of the Goldsmith" is an anonymous Byzantine-Greek treatise with 57 recipes pertaining to gold and silversmithing. The text of the treatise, which originally dated to the 11th century A.D., has survived in the form of two different copies (one in the Codex Parisinus graecus 2327, another in the Meteora Convent Hagios Stephanos (Martelli 2018)).

The text was first published as a French translation at the end of the 19th century (Berthelot & Ruelle 1888), which was then re-translated in 2004 from French into German with the addition of a goldsmith's commentary (Wolters 2004). This ‘recipe book’ is of great interest for the study of Byzantine crafts and trades, however many details were literally "lost in translation", leaving several of the recipes incoherent and unreproducible.

As a part of the Leibniz-WissenschaftsCampus Mainz (a cooperation between the Johannes Gutenberg-Universität Mainz and the Römisch-Germanisches Zentralmuseum Mainz), the treatise is being translated from the Greek original into German and evaluated by an interdisciplinary group of philologists, historians, art historians, material scientists and gold- and silversmiths. A unique feature of this project is the involvement of experimental archaeology in order to carry out practical trials of selected goldsmithing recipes.

Ones of these recipes titled “How to make copper like gold” deals with the production of brass through cementation. After a brief introduction of the project as a whole, this presentation will then deal with the recreation of the recipe, its results and comparison of the recipe to evidence of brass production from both Western and Eastern sources.

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CONSIDERATION ABOUT THE METALLURGY OF CU-AS BRONZES

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In the Alps the copper production began at the end of the 3rd millennium BC, especially at the ore deposits in Salzburg and Graubünden. For copper smelting the main ores were sulfides like chalcopyrite $CuFeS_2$ and fahlores, e.g. tetraedrite $(Cu,Fe)_{12}Sb_4S_{13}$ or tennantite $(Cu,Fe)_{12}As_4S_{13}$. The copper smelting metallurgy was extensively described by Tylecote (Tylecote 1976).
Arsenical bronzes, produced from fahlores, were widely used in the Alps. However, in ancient bronze objects a wide range of arsenic content was observed. One question is: how many arsenic is transferred into the bronze alloy during smelting? We got the possibility to investigate a cross section of a bronze ingot containing As and Sb, beside S and Ni (Haubner et al. 2017). Thermodynamic equilibrium calculations, which simulate the roasting processes, showed that As react to gaseous As compounds already before Cu_2S is attacked and metallic Cu is formed. In case of Sb, during roasting liquid Sb_2O_3 is formed quickly, and is finally enriched in the slag.
Another interesting question is: takes an As loss of arsenical bronzes during remelting place? Several artificial arsenical bronzes (Cu-As alloys) were study by thermogravimetry (DTA/TGA) (Mödlinger et al.). No relevant evaporation of As, respectively As loss, was measured. Thermodynamic equilibrium calculations revealed that Cu_3As is very stable and during remelting no evaporation of As was observed. Moreover, during oxidation of metallic Cu-As the formation of Cu_2O is favoured, before a reaction of Cu_3As takes place. If oxidative conditions are present, the result should be an As enrichment in the melt. At the end these effects are superimposed and if recycled Cu alloys are used the starting concentration of As is unknown.

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REVEALING THE MATERIALS AND PRODUCTION TECHNIQUES OF EUROPEAN HISTORICAL COPPER-BASED SEAL MATRICES

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Seal matrices have been used in many civilizations across the globe since several millenniums. In Europe, during late medieval and early modern periods, they were made of a resistant material such as metal, most of the time copper-based alloys, and were an essential item of official documents, acting as personal signatures. The matrices accompanied the sigillants throughout his life, as they carried it often on their belt, visible for everyone (Vilain 2015). Those objects remained totally undocumented until very recently. Our work contributes to lift the fog on the technical landscape of seal matrices production by looking at materials and techniques in presence. Our study brings his attention to the collections kept at the French National Archives institution and at the Fine Arts Museum of Lyon which constitute a unique corpus of objects from the 13th c. to the 17th c., mostly French, but also Italian.

More than four hundred objects have been analysed using a recently developed portable XRF protocol for copper-based alloys analysis (Heginbotham and Solé 2017). In addition, more than one hundred of them have been carefully documented at a micro scale in order to determine the engraving techniques. Finally, cross sections have been obtained from six broken seal matrices; allowing to reveal the manufacturing process of the objects.

Thus, this study provides and discuss new data on an exceptional ensemble of European Medieval and Early Modern copper-based seal matrices. First, although a wide range of alloys are documented, two groups of objects are identified based on the lead content, questioning the alloys quality and the production costs. Second, a clear evolution of engraving techniques is highlighted with three different successive know-how involved between the 13th c. and the 17th c. Finally, identical patterns could be drawn between French and Italian productions, questioning a potential transborder practice. Not only these results provide insights into historical seal matrices production, but they also contribute to document medieval and early modern copper-based workshops.

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MORE ON THE DAWN OF METALLURGY IN THE SOUTHERN LEVANT: THE NEWLY DISCOVERED GHASSULIAN WORKSHOP OF HORVAT BETER (BEER SHEVA, ISRAEL)

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Copper metallurgy is one of the Ghassulian Chalcolithic (6,000-6,500 Cal. BP) main features. This first occurrence of metalworking technology in the Southern Levant appears as two distinctive technological paths; prestigious items made mostly of arsenic-antimony copper using the 'Lost Wax' technique, and "utilitarian" objects made from pure copper using open casts. The latter were made based on locally-smelted copper ore, as evidenced by metallurgical remains found in the Nahal Beer-Sheva area (Shiqmim and Abu Matar, e.g., Golden 2010). However, the fragmentary quality of the archaeological record left the reconstruction of the technology debated and incomplete.

In the same area, at Horvat Beter, also a Ghassulian Chalcolithic site, metalworking clay-vessels were found recently during a salvage excavation excavated by Y. Abadi-Reiss, T. Abulafia, and D. Yegorov (Abadi-Reiss, 2017). The assemblage consists of a broken installation(s), several broken crucibles, and slags from at least three locations in the site, but most in the same context- a refuse pile. Quantitative chemical analysis was conducted by pXRF to determine the used technological path as well as the melting and smelting procedures and to shed light on possible connections with other metalworking workshops in the area.

The Horvat Beter site's metallurgical vessels and slags assemblage enrich the knowledge of the Ghassulian Chalcolithic metallurgy. As no arsenic and antimony were detected in any of the samples, it became evident that the workshop was dedicated to the production of pure copper (used for manufacturing the Ghassulian "utilitarian" objects). This separation of metallurgical activities reveals a high degree of specialization within the Ghassulian metallurgical industry. Measurements performed on the slags of the Horvat Beter assemblage demonstrate that the Nahal Beer-Shava copper industry shared some technological knowledge and maintained traditions. The samples from the installation contain copper mostly in inner locations (avg. wt%= 5.9, SD.=7.0) suggesting it was used for smelting of the copper ore. Samples from crucibles indicated that the presence of copper is more prevalent on inner locations and along the rims, suggesting they were used to further purify the metal by melting it, and as pouring vessels. Thus, revealing a two-stage production process (furnace and crucibles) as suggested by Shugar (2003).

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A MAJOR SITE OF NEOLITHIC METALLURGY : "LE PLANET" (FRANCE)

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The Planet site (France, Fayet, Aveyron) was identified in 2015 thanks to the discovery of a menhir statue (Tauriac group). A thick stratigraphy, over more than 3 m of sediment, thus delivered a series of about twenty occupations chanting the final Neolithic (2880-2500 BCE). These horizons include many outdoor habitat structures that contrast with a relative "poverty" in archaeological artefacts. The greatest interest of the site lies in a set of metallurgical treatment facilities, in an exceptional state of conservation, particularly of the fireplaces. Pits have also delivered many wastes or discharges: ore, crushing residues, emptying of fireplaces (slag, walls of fireplaces), shards of vases, furnaces or crucibles, percussion tools… These facilities are located between 2 and 6 km from major copper mines, some of which have been in operation since prehistoric times.

First metallurgical analyses demonstrate utilization of copper ores which contain also lead, antimony and silver. Principal ores used are bournonite, tetrahedrite, malachite and bindheimite. Slags, sediments, fireplaces but also ceramic which show exposure to excessive heat or slag deposits contain lot of lead and copper. The lead metal drop discover permit us to imagine this copper metallurgy also could deliver lead metal in 2800 BCE. "Le Planet" site discovery permit us to learn unusual information's about Neolithic metallurgy. The important stratigraphy should give chronological elements and local evolution. It permit us to compare these data with the Cabrière-Peret mining and metallurgical district. "Le Planet" site ask us some questions about deposits mined, metal produced, its diffusion, its place and impact in first metallurgy evolution.

«...NUNC IN BERGOMATIUM AGRO...» THE ZINC MINING AREA IN THE DOSSENA-GORNO DISTRICT NEAR BERGAMO AS A POSSIBLE SOURCE FOR ROMAN BRASS

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Pliny writes in the first century AD that cadmea, interpreted to be calamine, was mined in the region of Bergamo at the extreme north of Italy (Pliny 34:2). The beginnings of the wide-scale use of brass by the Romans can be found in the middle third of the first century BC (Istenic and Smit, 2007) and this could be linked to exploitation of calamine in the southern Alps (Grant, 1946, pp.87-90). The Dossena-Gorno lead-zinc district was a major supplier of zinc in the 19th-early 20th centuries and is the only zinc deposit in the province of Bergamo (Assereto et al., 1979). Roman mining activity has been hinted by the finding of two denarii in an ancient mine (Bottani et al. 2008), but until recently, no archaeological investigations of the mining landscape have been undertaken. Since 2016, several small-scale surveys of the Dossena mining district have revealed numerous pre-modern mining traces ranging from open-cast mines, collapsed mine shafts (Pingen), and subterranean mines partially made with firesetting and/or pickwork. The exact dating of the mining remains is still difficult, and an investigation of C14 samples is currently underway. The main mineral was calamine of which samples were collected for mineralogical, chemical and lead isotope investigations carried out at the Deutsches Bergbau-Museum Bochum. The calamine is mainly composed by the minerals smithsonite and hydrozincite, which are ideal for the brass cementation process. The lead isotope ratios of calamine from Dossena are consistent with brass sestertii of the 2nd-3rd century AD minted in Rome, which means that it is possible that the calamine mines just to the north of Bergamo were a source of zinc ore for Roman brass production.

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BEYOND ROŞIA MONTANĂ – THE ANCIENT MINING DISTRICT OF VÂLCOI-CORABIA, BUCIUM, ROMANIA

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Transylvania and the encircling mountains of the Carpathians are among the most important mining regions in Europe. However, apart from a few prominent examples (Cauuet et al., 2003; Harding and Kavruk, 2010), research on ancient mining is still in its infancy (Thomas, 2014). Therefore, an international team in cooperation between the Muzeul National al Unirii Alba Iulia and the Deutsches Bergbau-Museum Bochum is researching since 2017 old mining in the Vâlcoi-Corabia mining district of Bucium in the Transylvanian Ore Mountains.

At an altitude of 1200 m and in a confined space, extensive traces of mining can be found here, which can above all be attributed to the period of Roman Dacia. Since modern mining in the vicinity of the site has only taken place to a modest extent, the archaeological findings are almost undisturbed. In addition to the actual mining, there are the remains of Roman settlements, processing installations, cemeteries and a Roman road connecting the district with Zlatna - the Roman Ampelum (Ciugudean, 2012).

The site is known since the 19th century at the latest, when the extensive features were first described and excavations took place in the area of the cemeteries (Téglás, 1890). Since then, however, field research has been sporadic.

In the course of the recent fieldwork, the visible structures were documented in detail using an airborne digital elevation model. Field surveys, geophysical measurements, drillings and test excavations provide complementary results, which are extended by a first series of radiocarbon data. Even now, the Vâlcoi-Corabia district appears to be a complex mining landscape that can be used to study the structure as well as the functioning and organisation of an ancient mining community in detail. The diversity and quality of the findings make the district one of the most important and perhaps best preserved ancient mining areas in the Transylvanian Ore Mountains.

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THE LATE BRONZE AGE MINING SITE AT PRIGGLITZ-GASTEIL, AUSTRIA: METALLOGRAPHIC ANALYSES

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Excavations from 2010-2014 at Prigglitz-Gasteil, Lower Austria, revealed evidence for the largest copper ore mining site at the eastern end of the Greywacke zone in Lower Austria. At the site, radiocarbon-dated to the late Urnfield period (c. 1012-907 BC; see Trebsche 2015), evidence for the complete chaîne opératoire was found: from the extraction of copper ore to the production of tin-bronze objects.
About 30 objects from Prigglitz-Gasteil, as well as from find spots from the closer surrounding (such as Pottschach (graves), Urschendorf (settlement), Mahrersdorf (deposit), Kammerwandgrotte (cave)), were characterized by metallographic analyses (SEM-EDXS, optical microscopy in LF/DF) and chemical analyses (XRF, SEM-EDXS). Moreover, their lead-isotope ratios will be determined.
The aim of the analyses is to achieve information about the production, usage, and distribution of the locally mined copper, as well as chemical composition and alloying practice of the objects. Moreover, manufacture and usage of objects, and the extend of recycling are evaluated, in order to reconstruct the complete chaîne opératoire of metal working. At the conference, preliminary results of these analyses will be presented. Part of this research was funded by the Austrian Science Fund (FWF): [P30289-G25].

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HIGH-LEADED BRONZE PALSTAVES FROM NORTHWESTERN IBERIA: NEW INSIGHTS INTO THEIR TECHNOLOGY AND METAL PROVENANCE

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Palstaves are the most abundant metal object in the northwestern Iberian Peninsula during the Late Bronze Age and the transition to the Earliest Iron Age. They usually occur in isolated hoards, while socketed axes are underrepresented in the area in comparison with other regions of the Atlantic Europe.

Many of the palstaves contain high quantities of lead and have morphological features (such as the presence of the casting jet) that are incompatible with their use as ‘functional’ tools or weapons. On the other hand, the phenomenon of large hoards composed of high-leaded and unused (as-cast) axes has parallels in other areas of western Europe (Huth 2000; Roberts et al. 2015). Despite the long research tradition, many questions persist around the functionality, production technology and metal provenance of these artefacts.

In this contribution we will present new data on the elemental and isotopic composition of c. 25 leaded palstaves preserved in museums of the Iberian northwest and in the British Museum. The new dataset is complemented by a reassessment of former analyses that are re-evaluated according to the typology of the palstaves.

The results show that most of the palstave types documented in northwest Iberia have high-leaded items. The production technology still poses several issues and, although the use of metallic lead is documented, it is also possible that some palstaves were produced using copper-lead ingots cemented with tin ores (cassiterite). Finally, lead isotope analyses suggest that many of these metal resources come from the mining areas of the south of Iberia (Linares, Gádor and Cartagena) and could have reached the northwest of Iberia within the framework of the exchange networks promoted by Phoenician communities. These hypotheses are being tested in an ongoing research project (ATLANTAXES: Mass production and deposition of leaded bronzes in Atlantic Europe during the Late Bronze Age - Iron Age transition. Funding body: Spanish Ministry of Science, Innovation and Universities, HAR2017-84142-R, 2018-2020).

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PRELEMINARY RESULTS OF THE ANLYSES OF FEATURES, SOILS AND SLAG FROM A NEWLY EXCAVATED LATE BRONZE AGE METAL WORKSHOP

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A number of Late Bronze Age settlements in south-eastern Europe are assumed to contain dedicated activity areas for metallurgical production, or they are even described as production centres of metal objects. However, actual finds of such production areas are very rare and even fewer of them have been investigated with modern archaeological and scientific methods, and not much is known about the structure and organization of production activities.

Our presentation concerns a recently excavated metal workshop at the Late Bronze and Early Iron Age Teleac hillfort in south-western Transylvania. The workshop was located in a building that was part of an area of the hillfort that was set aside for high-temperature production activities. The 9 x 6 m large building contained five fire installations of various sizes and types, as well as casting equipment and slag.

Teleac is situated in a region with several copper and gold sources that probably were exploited in prehistory and the aim is to investigate which materials were smelted or (re)melted in this workshop using X-ray fluorescence spectroscopy and light microscopy to analyse the fire installations and other related finds. The results of these attempts will be presented, as well as what can be deduced regarding local technical knowledge and production techniques.

THE EMERGENCE AND SPREAD OF TIN BRONZE ALLOYING IN PREHISTORIC IRAN – THE LBA METALLURGY IN SAGZABAD, NORTHERN IRAN

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Within an ongoing cooperation project between the Art University of Isfahan and the VIAS-Vienna Institute for Archaeological Science, University Vienna the occurrence and spread of the tin bronze technology in Iran during the Bronze Age (3rd – 2nd mill. BC) is under research. To date, there is limited systematic scientific data about the alloying process and the tin bronze technology applied by ancient Iranian metalworkers. This is especially true for the Middle and Late Bronze Age. In cuneiform texts from the Near East, some alloying recipes are presented which give certain ratios for copper and tin. On the other hand, the currently published analyses of some Iranian Bronze Age artefacts showed that there is no correlation between the object's type and the tin concentration suggesting an uncontrolled (or uncontrollable) alloying process for the production of binary copper - tin alloys. This observation stands in contrast to the fact that the Iranian region had close economical, artistic and technological relations with Mesopotamia during the Bronze Age, as e.g. observable at the important archaeological site of Susa. One could conclude that the technological traditions of Iranian metalworkers to produce bronze by alloying are to date not fully described or examined. In a first step chemical (EDXRF, ICP-OES) and metallographic analyses were applied on LBA artefacts from the Bronze Age and Iron Age site of Sagzabad, northern Iran (Tala'I, 2002; Tala'I, 1998; Tala'I, 1983, Ghodousiyan et al, 2017) in order to get an insight in the local metallurgical alloying traditions. In a next step the results of these analyses will be set in relation to already published analyses e.g. from Tappeh Yahya, Marlik, Godin Tappeh, Malyan, Luristan and other prehistoric sites (Frame, 2010; Oudbashi et al., 2017; Pigott, et al. 2003). Tin bronze has been a commonplace material at the end of the third millennium BC. It has been permanently used in the second millennium BC in northern and western Iran, although some evidences of application of Copper - arsenic alloy are also visible in the LBA period in northern and central Iran. The results of the LBA artefacts' analyses from Sagzabad, an important site in the Qazvin Plain, are very significant to understand and describe the technological traditions of bronze alloying and use in the region under study. We will further compare the results of this investigation with other available data from the Early to the Late Bronze Age, during which the shift from arsenical copper production to the introduction and spread of tin bronze alloying tradition in northern Iran can be observed.

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ISOTOPIC AND CHEMICAL COMPOSITION OF LATE BRONZE AGE TIN INGOTS FROM THE EASTERN MEDITERRANEAN SEA, AND THE QUESTION OF TIN PROVENANCE

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The origin of the tin used for the production of bronze in the Eurasian Bronze Age is still one of the mysteries in prehistoric archaeology. In the past, numerous studies were carried out on archaeological bronze and tin objects with the aim of determining the sources of tin, but all failed to find suitable fingerprints. In a recent study we investigated a set of 27 tin ingots from well-known sites in the eastern Mediterranean Sea (Mochlos, Uluburun, Hishuley Carmel, Kfar Samir south, Haifa) that had been the subject of previous archaeological and archaeometallurgical research. By using a combined approach of tin and lead isotopes together with trace elements it is possible to narrow down the potential sources of tin for the first time. The highly radiogenic composition of lead in the tin ingots from Israel allows the calculation of a geological age of the parental tin ores of 306 ± 24 Ma. This theoretical formation age excludes Anatolian, central Asian and Egyptian tin deposits as tin sources since they formed either much earlier or later. On the contrary, European tin deposits of the Variscan orogeny agree well with this time span so that an origin from European deposits is suggested. With the help of the tin isotope composition and the trace elements of the objects it is further possible to exclude many tin resources from the European continent, and considering the current state of knowledge and the available data, Cornish tin mines are the most likely suppliers for the 13th–12th centuries tin ingots from Israel. Even though a different provenance seems to be suggested for the tin from Mochlos and Uluburun by the actual data, these findings are of great importance for the archaeological interpretation of the trade routes and the circulation of tin during the Bronze Age. They demonstrate that the trade networks between the eastern Mediterranean and some place in the east in the first half of the 2nd millennium BCE (as indicated by textual evidence from Kültepe/Kaneš and Mari) did not exist in the same way towards the last quarter of the millennium. New tin sources required the establishment of trade routes to the north-western territories of Europe.

MINOR ELEMENTS AND IRON SMELTING SLAG

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The presence of minor elements in smelting slag can provide major information about the ore used and the other substances eventually involved in the process. Moreover, the enrichment of the minor elements in specific mineral phases in the smelting slag is informative about the reduction condition inside the furnace and the slag cooling process.

Several minor elements, like Titanium, Manganese, Chromium, Vanadium, Cobalt and Nickel are frequently abundant in iron ores. The relation is highly variable because it is depending on the specific metallogenic process. One key factor is the fugacity of oxygen during the ore-forming process as Fe2+ and Fe3+ behave is a significantly different way under different conditions.

During the smelting process, highly reducible minor elements (like Nickel and Copper) will partition massively in favour of the metallic mass. Mildly reducible minor elements (like Manganese, Chromium and Vanadium), the element will partition in a much more complex way depending on the reduction condition in the furnace. During the cooling of the slag, the minor elements will be trapped in different ways by the different minerals. The behavior of the minor elements is mainly related to the oxygen fugacity during the cooling process and the ratio between the main components of the slag melt (silica, Alumina and Iron Oxides).

Chemical data obtained from minerals in recently studied smelting slag will be presented.

THE PROBLEM OF LOCALIZATION OF RAW MATERIALS FOR MEDIEVAL CRAFT CENTERS

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The identification and characterization of raw materials sources is one of the complicated problems of ancient metallurgy and metalworking. We distinguish both natural resources (ore and wood), and artificially obtained materials: blooms and charcoal.

It is believed that the main raw material for ancient and medieval metallurgists were bog and field iron ores. However, not all ores, as the experience of the ancient metallurgists shows, are suitable for a bloomery process. For example, there are ores with a high content of silicon, which prevents the reduction of iron. Thus, the question arises: if the ore have been explored in ancient times.

Staraya Ryazan – the capital of Ryazan principality – located on the mean river flow of the Oka River. As a result of many years of archaeological research, numerous iron and steel artifacts have been found on the site. The question arises about the sources of metallurgical raw materials for the production of forge artifacts.

Our attention was attracted by the settlement Istye 2, located on the ore field. It is situated 24 km from the Old Ryazan the capital of the Ryazan principality. A lot of metallurgical scrap was found here (slags, nozzles, pieces of baked clay). There is every reason to believe that this is metallurgical production for the blacksmiths of the capital of the principality. To argue the validity of these assumptions, it is necessary to provide evidence of the suitability of local ores for the bloomery process, as well as the metal composition similarity and presence impurities in the metal of forging products from settlement Istye 2 and Staraya Ryazan.

In the first case, we applied an experimental research method — modeling of a bloomery process. Raw material from the Istya ore field has been enriched: washing, sorting and burn. Birch charcoal was used as fuel. As a result, a metallurgical conglomerate was obtained (a mechanical mixture of slag and reduced iron particles) and several pieces of spongy iron, a product characteristic of the bloomery process. A metallographic analysis of the obtained iron was detected as ferrite with traces of random carburization.

Thus, in the course of the experiment it was proved the possibility of occurrence of iron from the Istya ore using the bloomery process.

Using the fluorescent analysis allowed us to prove that the content and presence of trace contaminants is similar to the blacksmith's objects from Istye 2 and Staraya Ryazan.

Obtained objective analytical data make it possible to prematurely consider a settlement Istye 2 as a source of raw materials for such a large production center as Staraya Ryazan. This was facilitated by the convenience of transport communications: downstream of the Istya and Oka rivers.

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[1] The work was supported by the Russian Science Foundation (grant number - 19-18-00144).

THE ROLE OF METALLOGRAPHY VERSUS CURATORIAL EXPERTISE IN THE IDENTIFICATION OF BOTH MODERN AND HISTORIC ARMOUR FAKES

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The Wallace Collection contains one of the largest and finest Armoury collections on display in all of London, if not in the whole of Britain. Metallurgical analysis of its European armour first commenced nearly fifty years ago, and more recently has been followed by investigations into the nature of its Indo-Persian and Ottoman blades and armour, and these studies continue to this very day. However, the Collection is particularly useful to scholars and researchers not only because of the quality and extent of its historic art-works and armour, but also because it is completely static in nature, constrained by the original terms of the will bequeathing it to the British nation in 1897. No other art-object is allowed to be 'kept mixed' with the core collection assembled in the nineteenth century by Sir Richard Wallace, so It is therefore absolutely certain that not one modern-made twentieth-century 'fake' exists within the museum's walls. What does exist, of course, is nineteenth-century fakes… and because of the very high quality of the Collection generally, these fakes are usually of very high quality also. Because there is no possibility of 'contamination' by modern works, this means that the Wallace Collection exists as a powerful research tool for all those interested in learning how to distinguish genuine antique armour from antique forgeries (often extremely difficult to identify, bearing as they do the visible signs of age and wear that one would expect to find upon a genuine piece). It is the aim of this paper to reveal the part that optical microscopy and other scientific techniques can play in lifting the veil on such objects, but also to highlight the limitations of these techniques. Ultimately, in certain cases science cannot (at least, not yet) prove date and authenticity, and therefore the much-vaunted experience, observational skills, and 'gut instinct' of the curator or conservator may still have a role to play in identifying forgeries.

METALLOGRAPHY OF TWO EARLY MEDIEVAL SWORDS FROM ŠLAPANICE, CZECH REPUBLIC

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Archaeological rescue excavation conducted in Brno-Šlapanice in 2009 (under direction of M. Geisler) revealed several Great-Moravian graves generally dated to the 9th and early 10th centuries, including two graves with swords (Nos. 10 and 29). The swords were submitted to the Institute of Archaeology of the CAS in Prague for conservation treatment and conservation survey, which included, among others, metallographic examination of the blades. Both the blades appeared to be made entirely of steel, but they show different construction schemes. While blade of the sword from grave No. 29 has cutting edges welded onto a middle portion (a common construction scheme for Great-Moravian swords), the other blade, from grave No. 10, seems to be made of a single rod of steel (with no welded-on cutting edges), thus in very rare construction scheme at the time. In addition, while sword from the grave No. 29 has a simple iron crossguard and pommel with no decoration, sword from the grave No. 10 has richly decorated pommel and crossguard, having an exact analogy in hilt of a sword found in Schelde River near Dendermonde (Termonde) in Belgium. Comparison with all the 9th-to-10th-century metallographically examined swords from territory of the Moravian Principality as well as with other contemporary European swords will be presented, and importance of restoration-conservation survey for the overall interpretation of archaeological objects will be stressed upon.

ORGANISATION OF ARMOR PRODUCTION IN 16TH CENTURY ARMORER WORKSHOPS: THE EXAMPLE OF VALENTIN SIEBENBÜRGER

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At the end of the Middle Ages, armor was considered both an object for everyday military use and a luxury attire. Furthermore, war practices have undergone major changes both on the technological level (appearance of english longbows or firearms) as well as the organizational one (development of mercenary companies). Accordingly, defensives arms were adapted to suit these new needs. Following the wider socio-economic conditions, it became a marketed commodity with a range of diverse products addressing an equally diverse range of customers. Its fabrication dominated by several prestigious centers like Milan or Nürnberg, required specific technical skills to shape the ferrous alloys. Therefore, the study of armor manufacture and trade offers great opportunity to understand the European exchange of war materials, techniques and skills, as well as metal selection based on the artifact's purpose.

In that perspective, several dozen artefacts fabricated in European centers and more precisely in Nürnberg were sampled and studied in detail. Several of them share the same famous origin, Valentin Siebenbürger's workshop. Active in the 16thc, many of this workshop's pieces can be identified in museum collections thanks to the city's and his own stamped markings. Through this example, the study of armor materials, manufacture and trade may provide a crucial insight into the practices of the armorers in terms of technical skills and supplies, as reflected in the preserved artefacts.

Armors were examined following the methodology developed in NIMBE/LAPA laboratory (sampling, metallography, MEB-EDS and LA-ICP-MS analyses), (Disser et al., 2014), (Dillmann et al., 2017). With regard to V. Siebenbürger's pieces, the results show differences in the nature, quality and thermic treatment of the metal employed for a same artefact and between artefacts of similar quality. However, despite these heterogeneities, the origin of the metal employed seems close which could suggest a common supplier. These results have been integrated into a larger group of European armors for discussion in a broader context.

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METALLOGRAPHIC INVESTIGATION OF THE MIDDLE BRONZE AGE AXES-INGOTS OF LOYETTES: NEW INSIGHTS ON THE ALLOY PRODUCTION

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The MBA hoard found in Loyettes (France) consists of 70 axes-shaped ingots without any residual casting cone or burrs (Delrieu, et al. 2015). Interpretation of the function of axes-ingots is still intensively debated since they may have served as raw material to be cast for the further productions (ingots); pre-forms of axes; functional axes or means of exchange. Particularly, all the axes-ingots found in Loyettes feature a raw appearance with no evident finishing treatment, and similar morphologic characteristics, which might result from the usage of the same casting mould.
The present work discusses the metallographic investigation of a selected corpus of 20 axes-ingots to verify the chemical composition of the alloys (major and minor elements without trace elements) and the thermomechanical history of different morphologic groups. Observations and chemical analyses were performed according the classical metallographic techniques (ASM Handbook, 2004). LOM and SEM-EDS analyses showed that ingots are made of a bronze alloy, containing from 0.6 to 4.8 wt% of Sn, and up to 2.8 wt% of Fe in a non-homogeneous repartition. Two typologies of microstructures were identified: dendritic grains, typical of as-cast microstructures, and polygonal grains, typical of recrystallization mechanisms, which might indicate a temperature holding during the manufacture process (use of a refractory mould during casting or application of a local thermal treatment). Furthermore, the characterization of the chemical composition of non-metallic inclusions within the metal microstructure allowed the identification of like the smelting mineral (e.g. Chalcopyrite $CuFeS_2$), the mineral used for the slag separation (e.g. Fayalite Fe_2SiO_4) and a potential source of tin (e.g. Cassiterite SnO_2). The correlation of microstructural and compositional details with macroscopic aspects helps to the formulation of consistent hypothesis, about the provenience, trade and exchanges of metallic raw sources and artefacts in wider European context.

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INTEGRATION OF ELEMENTAL ANALYSIS AND IMAGING METHODS IS STUDYING PRODUCTION AND USE OF BRONZE SPIRALS IN THE 2ND MILLENNIUM BC CARPATHIAN BASIN

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Asymmetrical bronze ‘coils’ with spiral ending are well-known artefact types of Bronze Age Europe. Within the Carpathian Basin, the first specimens appeared in the Middle Bronze Age, between 1900-1600 BC. Their size and shape can be separated from the Late Bronze Age pieces, that can be dated as late as 1000 BC. Due to some fortunate discoveries latterly, similar, but oversized bronze coils (e.g. bronze spiral that was found at Abaújdevecser, North-eastern Hungary, weighing 12 kg) have come to the forefront of Bronze Age research (Hellebrandt 2011; Kiss et al. 2015). Most of these latter objects, however, are stray finds or belonged to bronze hoards, that is why the exact chronological position, production technology and possible function of these so-called ‘megaspirals’ is still highly debated. Based on some representations and a few of normal sized variants from burial context, these items were interpreted as jewels, or as protective armour parts in the Late Bronze Age (Mozsolics 1967; Tarbay 2015). Our presentation focus on the chronology, distribution, production, context of use and deposition of these spiral arm or ankle rings, regarding either several oversized bronze spirals and their normal size versions. The paper provides a brief introduction to current research of these bronze ornaments, granted by the Momentum Mobility research project. We summarize results of various processes, including non-destructive neutron based methods i.e. prompt gamma activation analysis (PGAA), time-of-flight neutron diffraction (TOF-ND) and neutron imaging.

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NEUTRON DIFFRACTION FOR ARCHAEOMETRY: RESULTS OBTAINED ON ANCIENT SARDIANIAN BRONZES USING THE ITALIAN NEUTRON EXPERIMENTAL STATION INES

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The Italian Neutron Experimental Station INES, located at the pulsed neutron source ISIS (UK), is a general-purpose powder diffractometer built to focus its use on material science and in particular cultural heritage studies. Thanks to the high penetration power of thermal neutrons, archaeometric measurements performed through neutron diffraction allow for quantitative determination of bulk properties of the sample in a non-destructive way, in particular regarding composition and microstructure. This opens up the possibility of scientific investigation on objects otherwise unsuitable, due to their cultural and/or historical importance. Here, we describe the INES diffractometer and present the results of some recent measurements on bronze objects from Sardinia, Italy.

Sardinian bronze metallurgy represents an important example concerning the study of the development of bronze technology in an insular area located in the centre of Mediterranean sea, isolated but with important links with the surrounding lands.

Three bronze swords of the so-called "Monte Sa Idda" type, named after the important eponymous hoard found in the early 1900s in Sardinia, and a nuragic boat model from an Etruscan tomb in Vetulonia, Tuscany, presenting a detailed representation of animals on the body, were studied through neutron diffraction [1,2]. The obtained results show a very specific procedure for sword forging: the bronze composition, the presence of dendritic segregation and the microstructure are very peculiar. A comparison with micro-structural characteristics of contemporary swords produced in the other areas of the Mediterranean, in particular the Iberian peninsula, adds important details about the exchange of knowledge and artifacts in this geographic area. We could also add important information about the composition, casting technique and conservation status of the boat model.

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THE IMENA PROJECT. METALLURGY AND TRADE DURING THE NAVIFORM PERIOD (BALEARIC ISLANDS, 1650-850 CAL BCE)

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The Balearic Islands (Western Mediterranean, Spain) were the last islands of the Mediterranean to be colonized. This happened at the end of the III millennium cal BCE by settlers related to groups of Bell-baker traditions. During most of the II millennium BCE, they were settled by groups more or les homogeneous, known as Naviform societies, where isolation or connectivity and external influences have been under discussion in order to explain some of the social and archaeological changes identified. In the Balearic Islands, Cooper ores are so scarce and the amounts of metal documented in different contexts during the Naviform period suggest that much of the metal could arrive from outside of the archipelago. According to this, during this talk I will present different data, most of them produced under the ongoing IMENA Project. Metallurgy and trade in the Naviform period (c.1650-850 cal BCE). The main objective is to explore the role of metals and approach how the metallurgical exchanges have influenced (or not) the production, and historical dynamics of Balearic populations throughout the Prehistory. Different kind of metallurgical artefacts and production remains have been recovered for

this project from different sites representing each island of the archipelago. The applied methodology consisted of elemental analysis performed by a pXRF, lead isotope analysis (LIA) performed by MC-ICP-MS) and metallography. The main goal of this research is to approach the technology and provenance of these metal and metallurgical remains and, if possible, relate them to

the original ore source. Firsts results show that some objects present isotopic coincidences with Minorca copper ores while other artefacts can be related with more external areas as Catalonia, Languedoc, Alpine or SE Spain. Thus, this information seems to be relevant for a better understanding of the metal production dynamics, practices, and also to approach metals trade and islands connectivity.

TRANSITIONAL LATE BRONZE AGE/EARLY IRON AGE COPPER SMELTING IN THE CAUCASIAN MOUNTAIN REGION OF ANCIENT COLCHIS (WESTERN GEORGIA)

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Two short reconnaissance expeditions from the Georgian National Museum, in 2013 and 2014, established that Lechkhumi and the surrounding Caucasian mountain region were exploited for copper during the late Bronze Age. This region is also central to the legendary late Bonze Age visits to Colchis (Western Georgia) by Jason and the Argonauts as mentioned in Homer's Odyssey and recounted in more detail by Apollonius of Rhodes.

However early legends and past chance artefact discoveries in the Lechkhumi area (of ancient Colchis) together imply the former existence of a prehistoric copper/bronze industry in this mountainous area of the Tskhenistskali and Rioni river basins. Before the current project no early metallurgical sites had been identified here but the potential of this mountain region was clear from earlier accidental discoveries of many transitional late Bronze/early Iron Age copper or copper alloy artefacts - particularly 12 metalwork hoards. Recent archaeological work in this region has also shown that early settlement evidence and the prehistoric copper smelting evidence are likely to be related.

During 2016 to 2018 the earlier reconnnaisance visits have been followed up both by further exploratory work plus more detailed archaeological, analytical and geological investigations at the Dogurashi group of sites north-east of Tsageri which has been dated as being active at least during the 13th to 9th centuries BC. The group of three Dogurashi sites is being investigated as is the associated ore extraction. Previously this industry was known only from chance discoveries of metalwork hoards which included broken-up copper ingots, smaller copper alloy cakes, finished artefacts, as well as some copper smelting production remains, mainly smelting slag and related coarse crucible remains, with no smelting sites having been recognised. Now 10 copper smelting sites – exploiting local chalcopyrite ore sources – have now been identified, and a group of three sites are being archaeologically investigated to examine the prehistoric copper smelting processes used here. Geological survey work is also underway to investigate the whereabouts of likely ore sources and to look for traces of early mining.

EVOLUTION OF NOMADIC IRON SMELTING IN THE ALTAI REGION

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In this decade, a lot of iron production sites have been excavated in the Altai region. This region is bordered by Kazakhstan, Mongolia, Russia and China. Especially in Sayan-Altai and Minusinsk Basin, it was Ya.I.Sunchugashev who excavated many iron production sites and promoted his research on ancient iron production between the 1950s and 70s (Sunchugashev, 1969,1979). He clarified the structure of iron smelting furnaces and also discussed smelting technology in the Early Iron Age. However, based on the results of recent excavations and experimental smelting based on them, it is necessary to reconsider his interpretation on the technology of iron smelting (Murakami, 2013).
It should also be noted that abundance of the number of iron production sites and their density in the Early Iron age. For example, at Gung site located in Uvs prefecture, Mongolia, more than 30 steel furnaces are densely distributed. The site is located at the foot of an iron mine with a forest area nearby. There are also iron production sites of various periods times distributed in the surrounding area. It is assumed that the nomads in this area were not only moving for food production, but for mineral resources and forest resources for iron production as their economic strategy (Murakami, 2017).

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TRØNDELAG, DELIVERING A P-FREE IRON FOR CELTIC AND ROMAN SWORDS

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Achaeological excavations and studies of literature have revealed three consequtive periods of bloomery ironmaking in Norway, with techniques which after successful operation for centuries were discontinued around year 500, 1300 and 1800 AD. The first method seems to have a great potential for comparative European scientific studies. The sites from the period consisted of shaft furnaces with slag pit for repeated use. Until now 684 sites with very similar character from this period have been registered within the region in Mid--Norway named Trøndelag.

Archaeological excavations led from the University in Trondheim with emphasis on the remains of furnaces and the slag dumps have since 1983 been carried out at 6 sites, representing this first method. The uniformity of the sites makes it permissible to generalize special finds such as air inlets and informative pieces of slag as valid for a common technology.

The ironmakers had access to rich bog iron ore without phosphorus. Provided the content of silica did not exceed 5 % on could expect an output of iron equal to the weight of the slag. One bloom of iron has been studied by metallography, weighing 17 kg and with 0.28% C, i.e. an excellent metal. The metal is slag free, but is vescicular.

Fortunately the type of wood used as fuel was determined and was found to consist exclusively of pine, in spite of abundant birch. There was little spilling of charcoal around the furnaces; this led to the hypothesis that the furnaces were fired with wood and that charcoal was created inside the furnaces. The combustion of kernel wood with resin and tar creates high flames. This chimney effect was used to create the necessary draft, evidenced by the find of an air inlet measuring 8 cm. No use of bellows!

Selected pieces of slag show ripples, expressing decantation of some 10 kg at a time, probably every time wood was added.

The method was used for some 1000 years and kept as a secret by a guild of wealthy farmers, having serfs.

As no habitat has been found it is likely that the iron production took place at summer time end that the operators lived in tents.

Recently a smithy with 8 or 9 hearths has been discovered near the rivers Forra and Gaula, well dated back to 500 BC. Thus the whole iron age back to the Bronze age is documented in Trøndelag.

The operation of the furnaces reveals a complex cyclic process, which does not seem to have been developed locally, rather an import from Noricum, as indicated by the finds of the Austrian archaeologist B. Cech.

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SYNCHROTRON LIGHT INTO THE ARCHAEOMETALLURGICAL REMAINS OF COPPER-ARSENIC SLAGS AND SPEISS FROM "KONAR-SANDAL" (3TH MILLENNIUM BC), JIROFT, SOUTH ESAT OF IRAN

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New excavations at prehistoric site of Konar-Sandel (3th Millennium BC) in Jiroft province led to a magnificent opportunity for re-examining the metallurgical records about the archaeometallurgy of Cu-As alloy long south-eastern cultural zone of Iran. The triangle of Jiroft-Tepe Yahya-Shahdad and the metallic Bronze objects from these areas are amongst the most important marks for considering the technology of producing of arsenic Bronze (Lamberg-Karlovsky, 1972). Geochemical analysis using optical microscopy, metallography, QXRD, WDXRF including micro-XRD beamline at CELLS-ALBA in Barcelona suggest that metallurgical remains (slags, speiss) were rich in As, Sb. Data collected at the High-Pressure/Microdiffraction endstation of MSPD beamline at ALBA synchrotron. High resolution powder microdiffraction analysis was carried out at more than 100 points within the slags and speiss which have refined with Rietveld algorithm.

Based on the investigations on the copper ores probably metal extraction was processed from provincial ore deposits. These mines possess a type of hydrothermal mineralization zones which has produced by dynamothermal metasomatism along the Zagros subduction orogeny zone. The distribution and composition of the archaeometallurgical remains suggests that the definition of arsenic Bronze could potentially be accurate, due to the existence of these semi-metals in association with other trace elements (Pernicka, 2014). Indeed, the metallurgical remains which have been recently found from Konar-Sandal can suggest the emergence of reconsidering to the metallurgical activities along south-east of Iranian plateau.

This study will focus on the development of characterization of archaeometallurgical remains in south central Iran during the third millennium BC with an essential emphasise on synchrotron application for characterizing the crystalline phase determination (Mahnke, et al., 2009). Another benefit of the consideration of these remains from Jiroft was the estimation of possible natural sources that traced and recycled in this region as opposed to resource-poor Mesopotamia.

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THE APPEARANCE OF THE SNNI PHASE IN THE BRONZE OBJECTS OF THE HA D1 PERIOD OF THE CARPATHIAN BASIN, TECHNOLOGICAL CHANGES IN COPPER ALLOYING

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During the archaeometallurgical examination of Pannonian findings from Regöly, Sn-Ni phase was discovered in multiple bronze objects, previously unseen in Middle-Europe. As research began to reveal the background of the phenomenon, multiple pieces of data started to support a new method of copper alloying which was not known on the territory. The examined objects (cauldron, incenser chain links) were found in an environment which has an evident connection system to Asia Minor and Central Asia. The new data, together with the information on historical background, support a view according to which the manufacturization showed by the findings and the technological development were not results of the internal development of the Hallstatt cultural circle. In the last third of 7th c. BC, refugees from beyond East Asia Minor arrived in Europe, bringing expertise in high-level handcraft and knowledge in serial manufacturing, as well as the technology of directly alloying copper with metallic tin.

ARCHAEOMETRY OF COPPER ALLOYS IN CENTRAL EUROPEAN IRON AGE

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Central Europe in the Iron Age a highly dynamic space and time, with extended mobility, contact networks and circulation of artefacts. So far, little attention has been given to the archaeometry of metals in the Iron Age on account of supposedly biased data due to recycling and mixing of sources. However, we believe that a large-scale sampling of copper alloys across different social and historical settings does have a great potential to give us a new and unique perspective for reviewing the traditional narration. In this paper we would like to present our project dealing with the archaeometry of coppers alloys in Central Europe between the 4th and the 1st century BC/AD. Our approaches involve bulk and trace compositions together with both common and unique isotopic or elemental tracers. Through mobility of materials and/or artefacts studied by provenance analyses and mixing models we can examine socio-economic and cultural processes behind them. Even in periods when traditional provenance questions are much more difficult to answer, we believe that even the mixing of sources tends to follow certain trends that can be traceable by available analytical methods. We would like to discuss the introduction and standardisation of different alloys, the question possibly related to the primary acquisition and/or recycling of various material sources and their changing patterns in time.

THE PROVENANCE OF NABATAEAN BRONZE COIN MATERIALS: CHEMICAL ANALYSIS AND LEAD-ISOTOPE STUDY SET IN A REGIONAL CONTEXT

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The aim of this study is to shed new light on Nabataean trade and economic networks, based on the chemical composition (bulk chemistry [ICP-AES, MS] and lead isotope ratios [MC-ICP-MS]) of Nabataean bronze coins in order to detect diachronic changes in patterns of acquisition of raw materials throughout the history of the kingdom. Applying both methodologies will help identify more accurately the source of the raw materials. As part of this study we sampled 57 copper-alloyed coins from the Israel Antiquities Authority's collection (with the kind assistance of D. Ariel). These coins originated from various sites and date from ~200 BCE to 106 CE. In addition, 11 bronze and lead artifacts excavated from Masada, Israel, dating to the reign of King Herod (37-31 BCE) were also analyzed and used as comparisons. Although Nabataean bronze coins are assumed to have been minted at Petra, the source of the raw metal has not been identified prior to this current study. Our preliminary results show that 1) the raw materials for Nabataean coinage included high amounts of added lead (>4.0%), 2) the copper and lead raw materials originated in at least two distinct, albeit changing and as-yet indeterminate ore sources from the Mediterranean Basin, and 3) Nabataean coinage can be separated into three distinct groups based on their lead-isotope ratios. This last result leads to the observation that obscure coins can be partially or completely identified by monarch based on their lead-isotope ratios. The robust chemical and isotopic dataset provided by this study offers new information on Nabataean numismatics prior to annexation by Rome and the creation of Provincia Arabia, as well as insight into the common use of leaded bronzes and the changing standardization in raw material composition throughout the ancient Mediterranean world.

PRELIMINARY STUDY OF ANASTASIUS EMPEROR'S COINS (VI AD) EXCAVATED IN THE MACELLUM BUILD IN HIS HONOR, IN DURRËS, ALBANIA

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Macellum monument, excavated since the year 1986 in the center of Durrës, was built in honor of Anastasius emperor. Ceramics and metal objects were the main findings in this archaeological site, among which the ten coins introduced in this study. (Hoti, 1987; Hoti, 1988; Hoti, 1996) Archaeological investigation of coins is challenging because of the sampling difficulties but at the same time very important to understand the political and economic developments of a certain region and period. (Howgego, 1995) Very small amounts of sample were possible to be removed from these coins in order to study the alloy, the possible raw material and the production technique used in the VI century AD. The analytical methods used to achieve these goals include µ-XRF, OM, XRD, SEM-EDS, Vickers microhardness test. From the analytical data these coins resulted pure Cu, Cu-Pb and Cu-Sn-Pb alloys with minor elements such as Fe and Cr that could originate from the fluxes used or from the soil. At the beginning coins were produced using gold and silver but later these elements were mainly substituted by copper alloys in order to reduce the production costs. The corrosion products include oxides/carbonates of the alloy metal elements such as cuprite, cassiterite, cerussite but also atacamite/paratacamite, albite, nantokite, quartz, calcite and anorthite. The main microstructure inclusions are composed of Pb, As, Sb, Si, Fe, Zn, Ag, Bi, Ni which usually are either used as fluxes during the production process or are associated with sulfite copper minerals. Last but not least the bended twins in the coins' microstructure suggests that the alloys might have been annealed/hot worked after being casted and then cold worked causing the twins to bend. Only in one case dendrites were present in the microstructure which suggests that the final stage of production was casting and no further work was performed on the coin's alloy. (Scott, 1991; Scott, 2011)

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NON-FERROUS METALS IN ROMAN MILITARY EQUIPMENT

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The paper reviews the results of a systematic characterisation of non-ferrous metals present in Roman military equipment which has been carried out over the last two decades in Slovenia. The research focused on the Roman military equipment from the River Ljubljanica (Slovenia), and the early use of brass, and performed using the method of proton-induced X-ray emission (PIXE). The evaluation of the results gave new insights in the use of metals in the Roman military equipment production and led to suppositions regarding its organisation.

METAL AND MANUFACTURE OF ROMAN MEDICAL INSTRUMENTS

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Roman surgeons owned instruments of forms which are recognisable to the medical profession today, including catheters, bone chisels, forceps and needles. Of the surviving instruments, most are made of copper alloy, some with iron components and a number of them are inlaid and decorated. Although there are large numbers of medical instruments known from the Roman world, few have been the subject of metallurgical study. This project began with the opportunity to examine a set of 39 instruments said to be from Italy, now in the British Museum. Elemental analysis (by X-ray fluorescence on areas cleaned of corrosion down to bright metal) indicated that the alloy composition was surprisingly varied, for example a set of six scalpel handles, which are closely similar in form and burial patina and from wood traces on them appear to have been buried in the same box, have tin contents between 4% and 15%, one with 9% zinc and three containing no detectable zinc in the alloy (La Niece, 1986). This inconsistency suggests that the set had been built up gradually by the physician. The tin-lead solder and corroded iron fragments found in the sockets of the scalpel handles indicate that the iron blades could be changed when worn but this task could not be done rapidly, hence the need for several scalpels, perhaps with different shaped blades, to be readily to hand during a procedure.

The examination of Roman surgical instruments at the British Museum has since been greatly expanded (Jackson, forthcoming). This paper will summarize the conclusions of the study of over 100 instruments from the collections of the British Museum and other museums using the results of microscopy, X-radiography, X-ray diffraction analysis and X-ray fluorescence analysis to better understand how these specialised tools were made. Additionally the decorative inlays have been identified and found to include silver wire and the black patinated copper-gold alloy sometimes called Corinthian bronze.

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ANALYSES OF ORNAMENTS ON ROMAN CARRIAGE AND EQUESTRIAN EQUIPMENT FROM EASTERN SERBIA

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Copper alloyed items that represent functional and decorative parts of Roman carriage on four wheels, parts of horse equipment and yokes are analysed with hand held energy dispersive x-ray fluorescence spectrometer. Certified reference material was used to check the accuracy of measurements. The find originates from the territory of Eastern Serbia, the region of Pirot (Turres), on the territory of the Roman province of the Moesia Superior. This region is at the very border with Thrace where ritual of burial with wagon and horses was common practice. Decoration of ornaments on a carriage on four wheels, belongs to the theme of the cult of the god Dionys, or its chthonic part of the cult, on the basis of elements on decorative tubes from the bodywork of the car (ivy on ballheads) and applause with the bust of Menade.

Dates are hampered by the chronological insensitivity of most objects. However, we can give a complete discovery from the end of the first to the end of the second century on the basis of parts of horse equipment, 6 heart pendants with ornaments in the form of kidney breakthroughs, dating from the end of the first to the end of the second century and four large discs dating to the second century.

It is discovered that there is four groups of alloys used: gunmetal, brass, leaded brass and only two samples classified as leaded bronze. Antimony is present in range of 0,1-1% in many of samples and also vanadium (if detected) with values ranging from 0.01-0.29%. There is fable linear correlation of copper and antimony in samples representing brass, leaded brass and leaded gunmetal. Also there is fable linear correlation between lead and antimony and lead and vanadium in leaded alloys. We may say that the material used for production of these items is partly from recycled copper or copper alloys and that antimony and vanadium if present are associated both to copper and to lead. Vandium is element that is rearly mentioned in results of analyses of Roman copper alloys but it is identified in a bronze helmets found in Sremska Rača. This may direct us to some of the millitary workshops that may be involved in production of the material here presented.

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THE SOURCE OF METALS FOR THE ROMAN KITCHENWARE AT THE TIME OF THE ERUPTION THAT DESTROYED POMPEII: NEW DATA FROM THE POSITANO VILLA (SALERNO, ITALY)

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The volcanic eruption that in 79 AD destroyed Pompeii and Herculaneum affected the coast south of the Vesuvius up to the Amalfi coast were Positano is located. In 2004 during the restoration of the medieval crypt in the Santa Maria Assunta church a room of a rich Roman domus was fortunately brought to light. The discovery confirmed the presence in Positano of an important Villa only known from historical sources and sporadic surface finds (MAR 2018). The excavation campaigns completed in 2016, unearthed 7 m high walls covered with perfectly preserved frescoes, together with numerous remains of forniture and objects of different materials, including a set of metals (mainly Pb and Cu-alloys).

A set of 7 finds (mainly kitchenware) were selected for the archaeometric study in order to investigate the chemical composition of the different types of objects, the working processes and possibly the origin of the metals used. A complete chemical, textural and isotopic characterization was performed using optical microscopy, SEM-EDS and ICP-MS analysis, metallography and LIA measurements. The results are extremely significant showing that a large variety of metals and alloys were used: pots were made both in bronze and copper; vases are in bronze and lead; and the only analysed furniture decoration is a ternary alloy of Cu-Sn-Pb. Notably, brass, gunmetal and leaded alloy that are reported in several studies as the more diffuse type of metals in Roman time (Dungworth, 1997; Giumlia Mair, 2005) are not present or rare in the Positano finds. Our data have a good comparison with the results of a study on kitchenware from Pompeii (Wagner at al., 2000), but the presence of pure copper pots is a novelty, to our knowledge.

The LIA results are interpreted with the help of two comprehensive database of geochemical and isotopic data of: 1) copper, and 2) lead mineralizations derived from our ore analysis and from the critical revision of literature data (Artioli et al., 2016). The database includes deposits from the whole of Europe, Anatolia, the Levant and some data from North African deposits. The copper used for the Positano items are consistent with the signature of the Sardinian ores, even if Iberian or central France origins cannot be excluded for a couple of objects. The Pb used in a vase and in the ternary Cu-Sn-Pb alloy is consistent with the mixed-Pb signal of the lead circulating in Roman times.

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LATE ROMAN SILVER FROM TRAPRAIN, SCOTLAND: RECENT INVESTIGATIONS

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The Traprain silver treasure is the largest and most important hoard of late Roman silver from beyond the edge of the Roman Empire. The hoard consists of about 200 fragments and was found in 1919 at Traprain Law, about 32 km east of Edinburgh in Scotland. It was excavated in 1919 and published shortly afterwards (Curle, 1923). The hoard mainly consists of Late Roman silver plate, but also contains some belt fittings and small packets of folded metal. The provision of an up-dated scholarly catalogue has given the opportunity to explore many facets of the hoard in a wider context. The contents of the hoard had been extensively cleaned and some pieces reshaped during restoration in the 1920s. However, with care, it was possible to investigate a selection of the silver fragments using X-radiography, optical microscopy, X-ray fluorescence / particle induced X-ray emission analysis and scanning electron microscopy, combined with metallographic analysis. The topics discussed in this presentation include (1) the composition, aspects of functionality and a comparison with other later hoards in Scotland; (2) fabrication, including decoration such as niello and gilding; (3) the hacking processes.

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THE ARCHAEOMETALLURGY OF ARMS AND ARMOUR.

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We study the metallurgy of earlier centuries in order to find out how and when artefacts were made, and how their use may be determined. Then, as now, the most advanced technology was to be found in arms and armour, because the incentives for their use were the most pressing. So, the study of the metallurgy found in arms and armour (especially those examples of the highest quality) will show how metallurgy developed historically.

Examples of swords and armour are discussed, including European helmets of royal ownership, and their metallurgy related to the development of steel-producing furnaces.

POSTERS

GRUMENTUM: RECYCLING OF SPACES AND MATERIALS

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In ancient times, Grumentum (today's Grumento Nova, Basilicata, Italy) was an important settlement of the upper Agri Valley at the crossroad between commercial routes connecting the Thyrrenian and the Ionic Sea. The city was founded in the first decades of the 3rd century BC and remained a thriving centre until the 4th century AD, when a moment of crisis led to the abandonment and consequent reorganisation of some of its urban spaces: on this occasion, an area next to one of the most important temples of the Forum square was turned into a metalworking structure.

The late antique stratigraphy from the south-eastern corner of the Forum has yielded a set of pits and hearths, a considerable amount of metallurgical remains and tools, all pertaining to an intense metalworking activity which took place in two different phases, characterized by the use of different kinds of furnaces.

The slag pertaining to the first phase of activity of the furnace has been analysed and discussed in a previous contribution presented at the International Symposium of Archaeometry in 2016 (Bison et al., 2017), and the present work is focused on the second phase of activity, considering both the structures and the debris, in order to complete the data set and trace a comprehensive picture of the phenomenon.

This work aims at providing an insight into the productive cycles performed, aimed at understanding the kind of activity, mark the potential differences with the previous phase and reconsider the whole metallurgical activity in the Forum. Consequently, we hope to gain a better understanding of the reasons that led to the transformation of this public space into a productive one, as well as some indications on the final scope of this metal production.

Our investigation has focused on 20 samples, which were analysed by X-Ray Fluorescence (Oxford ED 2000 with silver tube),Diffraction (Bruker D8 Advance equipped with copper tube and Lynxeye Position Sensitive Detector) and Scanning Electron Microscopy (Zeiss V35 Supra Field Emission Gun equipped with Octane Super EDAX energy dispersive spectrometer).

The samples have indicated a complex organisation of the metallurgical activity, in particular concerning the mixed use of recycling and virgin raw material for the metal production. In depth investigation of recycling and alloying technology indicate a wide variability in the technologies used.

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A COMPOSITIONAL STUDY OF CYPRIOT COPPER ALLOY ARTEFACTS DATING TO THE LATE BRONZE AGE USING PORTABLE XRF SPECTROSCOPY

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The present analytical study concerns the interdisciplinary investigation of more than 200 copper alloy artefacts, coming from the very important Late Bronze Age settlement of Enkomi (Dikaios, 1969), located on the east coast of Cyprus, dating to the 16th-11th centuries BC (Kassianidou, 2016). The assemblage consists of various categories of objects, such as weapons, tools, jewelry and vessels. The material was chemically analysed using a handheld pXRF instrument. The basic aims of the present work are the determination of the alloy type of the artefacts and the comparative study of the copper alloys used in the different chronological phases of Enkomi's settlement. The results show that the large majority of the analysed artefacts are made of a copper-tin binary alloy (bronze) with a tin concentration lower than 10wt%, while some artefacts were made of pure copper. Among the bronze artefacts, there is a group of objects which was found to have a significantly higher tin concentration (>13wt% Sn). Regarding the other elements, arsenic is found only in 22 artefacts; 10 artefacts are copper-arsenic alloys (>1wt% As), while the remaining 12 (<1wt% As) contain much higher concentration of tin (Cu-Sn alloys), suggesting the possible use of recycled metal deriving from copper-arsenic alloy artefacts dating to the Early and Middle Bronze Age, with originally much higher concentration of arsenic. Moreover, the lead (Pb) concentration in the assemblage ranges from 0.1 - 2.9wt%, although the large majority of the artefacts have lead concentrations lower than 1wt%. Because lead concentration in local Cypriot ores is unusually low (Constantinou, 1982), its presence is interpreted as a deliberate addition even at these low concentrations. Iron, detected in all artefacts, and zinc and antimony, traced in a limited number of artefacts, are believed to be non-intentional additions to the alloys, resulting from the smelting process and originating in the copper ores.

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ANALYTICAL INVESTIGATIONS ON PLATE SLAGS FROM THE LATE URNFIELD PERIOD COPPER MINING SETTLEMENT AT PRIGGLITZ-GASTEIL

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The Late Bronze Age site of Prigglitz-Gasteil represents the largest known copper production site at the eastern end of the Greywacke zone in Lower Austria. Excavations from 2010 to 2014 brought to light evidence for all stages of the copper production chain, from copper ore extraction to the final casting of bronze objects. Generally speaking, thin plate slags prevail among the ca 250 excavated slag fragments, coarse slags being the rare exception at the site. The concentration of slags, copper or bronze droplets, fragments of casting moulds finds in those horizons provide evidence for copper and bronze metallurgy (Trebsche/Pucher 2013; Haubner et al. 2017a). The metallurgical activities were dated into the late Urnfield period (ca 1012 to 907 BC) by a series of radiocarbon analyses (Trebsche 2015).

The aim of the archaeometallurgical investigation was to investigate whether the macroscopically rather uniform thin plate slags can be differentiated and attributed to different steps in copper refinement, alloying or casting. The slags were investigated by XRF (x-ray fluorescence), metallography, light optical microscopy (LOM) and scanning electron microscopy (SEM).

XRF analyses confirmed similar composition of the main oxides SiO2, Fe2O3, CaO, Al2O3 and MgO. The CuO content was also relatively constant between 0.35 and 0.5 wt.%. Some samples contained up to 0.5 wt.% SnO. This indicates that some slags were formed during copper smelting and others during bronze casting. On one slag sample a green particle was observed. SEM-EDX analyses showed that the particle´s core was Sn- and O-enriched and covered by malachite.

Their microstructure was quite compact because they were completely molten during the metallurgical process. Area and spot measurements by EDX and calculation of the oxide ratios allowed the estimation of the melting point from the FeO-SiO2-CaO phase diagram (Haubner et al. 2017c). The melting temperatures of the different slag phases were between 1120 and 1090°C. This is only a rough estimation because the other trace elements Mg, Al, K and S have an additionally influence on the melting respectively solidification temperatures of the slags.

The microstructures are characterized by large, compact olivine crystals with mainly Fe- and small amounts of Mg- and Ca-silicate. During final solidification of the residual melt elongated olivine crystals, together with the glass phase, are formed. Moreover cupreous inclusions were observed in the slags, varying in their elemental composition. Metallic Cu, chalcopyrite and pyrrhotine were observed additionally.

To sum up the results, the analyses show that thin plate slags originate both from the process of copper refinement and from the process of alloying with tin. It is interesting that at Prigglitz-Gasteil these final steps in metal production took place at the same site where copper ore was extracted and beneficiated.

QUESTIONS, HYPOTHESES AND TASKS CONCERNING THE BRONZE AGE CASTING MOULDS OF THE CARPATHIAN BASIN

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In 1988-89 the author excavated at Gór-Kápolnadomb (Western Hungary) a Late Bronze Age pit with casting moulds and human remains. Following the publication of the assemblage and new moulds from further features (1992, 1996, 2003), the collection of similar finds was extended to the complete territory of the Carpathian Basin. Relevant data were also incorporated into the Industrial Archaeological database. The collection was planned to be published together in a dedicated volume of PBF; however, its realisation became increasingly unrealistic. A preliminary cadastre was reviewed (2006) and efforts made to describe various level centres of the craft and interpret their connections (2007). Later on, in 2017 thanks to the understanding of the project leader for the project Lendület (Momentum) (L2015-3.) I could complete my collection of data and visualize them on a map. Summarizing several decades of collecting moulds we can state that its utility, i.e. supporting important and well-founded consequences is rendered problematic by several factors. Just to mention a few: 1, access to publications; 2, the random occurrence of moulds in excavation context; 3, the readiness and openness of the excavator, i.e., speed and quality in the publication of the finds - in text or with proper illustration.In spite of all difficulties I could collect several series of moulds, from the Early Bronze Age 32 pieces (Fig. 1.), the Middle Bronze Age 70 pieces (Fig. 2.) and the Late Bronze Age 93 pieces (Fig. 3.). It is obvious that concentration of sites with metallurgical production took place already in the Middle Bronze Age (20 workshops) Centralisation during the Late Bronze Age involved, however, new sites and centres (21 workshops) and comprised larger series of objects (more moulds in the ateliers and increase in total number of finds). In the case of moulds found on the settlements we can only infer the presence of workshop when several pieces of moulds turn up in one 'house' or other specific feature, or one piece accompanied by other metallurgical production items (e.g., bronze slag, ingot or blow pipe) denoting unambiguously the practice of metallurgy. A central workshop, i.e., supplying more than just one settlement, can be supposed for sites with more than 3 pieces of moulds. Mapping the sites show that all significant copper ore regions were known since the beginning of the Bronze Age. Only the Early Bronze Age use of the Rudna Glava mine is not documented. I assume that in the centuries of the Bronze Age the workshop sites were primarily supplied with copper ore along the waterways. The considerations presented above mark the tasks for the future. Obviously advantageous for further research, all the Bronze Age casting moulds should be published in illustrated form at the same place. With international collaboration project, it would be worth while to set up a dedicated database. For this, all facets of the casting mould should be registered at least on a digital photo, relevant dimensions measured and petrographical features analysed. On the basis of these studies, moulds from clay or artificial material could be separated and those made of rocks potentially identified by place of provenance. The latter data might indicate connections between the individual communities as well as division of the labour within the specific cultures.

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MICROSTRUCTURAL AND PROVENANCE STUDY OF LATE BRONZE AGE COPPER INGOTS HOARD FROM SOUTHERN BOHEMIA, CZECH REPUBLIC

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This paper presents an archaeometric and archaeological study of a set of copper ingots from the site Nove Hodejovice located in southern Bohemia. The artefacts were discovered in 2014 at the building site of new family houses. Unfortunately, the hoard was discovered in a secondary position, in the soil that had been removed from the building site. The hoard consists of 17 bronze artefacts (fragments of pins, sickles, knives, etc.) as well as more than 200 ingots; the total weight of the hoard is about 30 kg. Some artefacts date the hoard with certainty to the early Urnfield Period, i.e. the thirteenth to twelfth century BC (Reinecke Phase Br D – Ha A1).

Selected ingots and lumps have been studied by metallographical methods in combination with an SEM/EDS a µXRD analysis in order to identify intermetallic phases and non-metallic inclusions. The chemical composition of the whole set of artefacts was analysed by the ED-XRF method. The analyses of the stable lead isotope ratios by MC-ICP-MS and of the trace elements composition by NAA were used for a discussion of the provenance of selected ingots.

Preliminary results show that the analysed set is represented mostly by unrefined or slightly refined and unalloyed copper ingots and lumps in the form of fragments. The purity of copper varies between 65.2 and 99.6 %, with an average value of 94.85 %. The analysis of lead isotope ratios and trace elements composition has discovered that the copper material was likely transported to southern Bohemia from different ore deposits located in the Southeastern and Eastern Alps. The subsequent refining, alloying and casting of the resulting alloy took place in southern Bohemia. On examples of few inhomogeneous plan-convex ingots is visible high heterogeneity in trace elements composition and lead isotopes ratios, caused by the probable reduction of ores coming from different Alpine deposits. Obtained analytical results refute the idea of significant copper recycling in the late Bronze Age and also the presumption of the origin of copper from Alpine bearings was confirmed.

COPPER AND ITS ALLOYS AS RAW MATERIALS OF METAL ARTEFACTS IN PREHISTORY AND PROTOHISTORY OF SOUTH MORAVIA (CZ)

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Paper focus on development of elemental composition of archaeological artefacts of copper and copper alloys from South Moravia (Czech Republic). Research begins with artefacts from beginnings of local metallurgy in Late Neolithicum (ca. 2800 BC) and ends in Early Middle Ages (ca. 1000 AD). Main research focus lies in Roman period (ca. 50¬–450 AD). Research is based on extensive sampling in order of thousands of artefacts, which originate mainly from metal detector prospection registered by local museums and research institutes. Elemental composition analysis of metal core of artefacts is done by XRF and SEM/EDS.

Results of elemental composition analysis are evaluated by methods of multidimensional statistics on the basis of artefacts data – function, typology, dating, cultural affiliation, location and elemental composition. Paper introduce development of raw materials and technological implications of copper alloys metallurgy during main metallic periods. By case studies selected hypothesis are tested, e.g. elemental composition of different parts of various types of Roman and Germanic fibulas etc. Paper also focus on chronological and spatial spread of types of raw material, technologies on the basis of comparison with results of analogous foreign artefacts.

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AACP DATABASE: A POWERFUL TOOL FOR THE INVESTIGATION OF THE METAL PROVENANCE

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n the context of the archaeometallurgical research, an important goal is to investigate the metal origin of objects and, then, reconstruct trade networks. About this, the use of Lead Isotope Analysis (LIA) coupled by trace element geochemistry has widely started to be applied in archaeology.

In the last decade, within the Alpine Archaeocopper Project (AacP: http://geo.geoscienze.unipd.it/aacp/welcome) an extensive revised database of geochemical and lead isotope data for copper deposits located in Europe, North Africa, Levant and Near East was assembled(Nimis et al 2012;Artioli et al. 2016a). The majority of the data, from the literature, have been geologically and geochemically screened, and the database has been complemented by analyses of a large set of ores from the Alps and the North-Central Italy Apennines. The database encompasses more than four thousand entries which are grouped in mineral districts according to the ore geological, geochemical, and mineralogical characters.

A multi-analytical approach and, for lead isotopes, the comparison with the database proved to be a powerful tool for the identification of the copper origin of different archaeological finds. An important results on notable Copper Age objects, such as the copper axe of the Iceman mummy (Artioli et al. 2017), will be presented and discussed in the context of the data obtained on materials from coeval Italian producing sites (Artioli et al 2015; Artioli et al.2016b).

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CASTING NEOLITHIC BRONZE – AN ITERATION PROCESS

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Fantastic Neolithic bronze objects as the Axe of Ahneby (Freudenberg et al. 2017) have raised questions about how the craftsmen of their time have done the work. In a combined effort of members of the casting museum in Kiel (Howaldtsche Metallgiesserei), experimental archaeologists from Gottorf Castle in Schleswig and Physicists from Hamburg successive casting and investigation cycles were performed. Bronze objects were cast and non destructively analysed with storage ring based X-ray methods (mainly X-ray Fluorescence and X-ray powder diffraction). In parallel original pieces were measured as references. The casting process was then modified and the new objects again put to the test. Several years and iteration cycles later a lot has been understood, some "originals" had to be redated, making them more than 3000 years younger (Freudenberg et al. 2015) and of cause new questions arose: If your cast is bad, how do you fill a blowhole and did the craftsmen in the past come up with a different solution? Different oven types, casting methods and moulds are presented including the bronze objects produced with them. A comparison between different originals and between originals and their reproduction are given. Some measured features are very unique to groups of objects and thus may e.g. help to distinguish a real Neolithic bronze objects from a modern replica and again from a 19th century reproduction.

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WHAT STRAIN REMEMBERS – NON DESTRUCTIVE XRD MEASUREMENTS TO EXPLORE AN OBJECTS HISTORY

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Non destructive material analysis was performed to investigate an objects post cast processing, as in case of Neolithic bronze axes or to understand the raw material of sheet metal objects, as gold discs. Additionally the former imprints of letters in iron was revisualized, after the letters were filed off. The method of X-ray powder diffraction was used, with measurements performed at the storage ring facility DESY in Hamburg (Germany). Replicated and original objects (iron, bronze and gold) were investigated. Point measurements, line scans and area maps were used to identify position and components of the local strain state within an object. The origin of the strain can be identified whether that strain originated from forging, emossing or if the strain was inflicted by e.g. initially rolling of sheet metal as done in modern production (Glaser et al. 2018). In case of thin gold metal objects it is possible to identify modern raw material production methods in the finished object and thus may help in cases of unclear authenticity. The same methodological approach allows to identify post cast treatment of material as e.g. blade hardening of bronze axes (Freudenberg et al. 2017, Glaser et al. 2016), and thus differentiate between objects that have actually been used from those that have never fullfilled the purpose the objects desgn suggest.

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THE CHARACTERISATION OF HEAVILY CORRODED BRONZE

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The state of corrosion of ancient copper alloys has always been a challenge for elemental analysis. The problems posed by corrosion for drilled samples and for X-ray fluorescence have been well aired. In contrast, where solid samples have been removed for metallographic study and/or electron probe microanalysis we can have a rigorous approach to characterisation of corroded material.

One area where the problems of corrosion are severe is in the study of metal grave goods, the micro-environment created by the decay of human and animal remains being particularly inimical to bronze. This is especially true when the grave groups are of a class that has received very little technical study. The case study chosen for this work comprises bronze grave goods from Han Dynasty tombs in Guangxi province in China. The project was initiated to expand our knowledge of Han Dynasty bronze but the heavily corroded nature of much of the metalwork meant a new approach to characterisation to maximise the return in information.

This approach is based primarily on electron probe microanalysis and optical microscopy, the latter also used quantitatively. A total of 34 samples were taken, ten from vessels from a single tomb. Sub-samples will be used for X-ray diffraction to identify corrosion products where the sample is completely corroded and without recognisable microstructure. When samples are in this condition an elemental analysis is still made to obtain further clues as to the nature of the original alloy and its impurities.

The remainder of the samples cover a spectrum from uncorroded metal to those that are more-or-less completely corroded save for a recognisable ghost of the original microstructure. In the best preserved a bulk analysis can be made; in more corroded examples quantitative metallography can be used to estimate the lead based on the corroded lead inclusions; these samples are still amenable to etching and features such as dendrite arm-spacing measured. As the amount of uncorroded alpha phase decreases the nature of dendritic segregation means that the estimate of tin and impurities decrease in accuracy, but the data are still useful in grouping similar compositions and structures. Where only a ghost structure remains a broad estimate of alloy may be made, and an impurity pattern recognised. Taking the results together we can see how alloys, impurity patterns and corrosion condition correlate with individual graves.

THE STUDY OF THE CHEMICAL COMPOSITION OF PRODUCTS AND INGOTS OF NON-FERROUS METALS FROM THE TERRITORY OF THE MIDDLE VOLGA REGION OF THE FIRST MILLENNIUM AD

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Brass and bronze ingots used as foundry billets are known since ancient times throughout Europe and North Africa. They became even more widespread in the Late Roman time and reached their maximum in the Viking Age.

Possibly prototyped by Late Roman golden bars being collected as taxes, the non-ferrous ingots appeared in the Middle Volga region in the very beginning of the Migration period together with new groups of migrants from the South-West. Those ingots are of similar shape and weight, and were made in special casting molds in a shape of rods (sticks) with a triangular or quadrilateral section and look very similar to those that were in use on the territory of the Roman Empire. Once appeared in the region in the 3rd-4th c., they were in use during three centuries. To understand their functions and role in economic and cultural relations, we undertook a comprehensive study including examination of chemical composition, spatial and archaeological analysis. For the comparative analysis, we took over 100 non-ferrous items, mostly costume details, as well as 75 ingots from the sites of the Migration period.

Examination of the chemical composition was carried out by emission spectral and X-ray fluorescence analyses. The results of the research reveal four types of compounds: almost pure copper, bronze, lead-tin alloy and brass (copper + zinc) as the dominating one. The average quantity of zinc in the ingots ranges from 5.34% to 20.67%. The comparative analysis of the composition of ingots and casted items makes possible to suppose the brass ingots to be the main raw material for non-ferrous metalworking. Their origin and incoming routes of them is an issue for the forthcoming investigations.

FAR-REACHING CONNECTIONS IN THE 7TH CENTURY A.D. STUDIES ON BIERINGEN TYPE BELT SETS

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If you had wanted to buy a high-quality belt in Central Europe in the 7th century AD, you would have chosen the Bieringen type. In contrast to most of the multi-part belts of that time, which were made of iron, this belt was made of bronze. Material tests on the fittings show that different alloys were used, which show clear differences in quality. Even more surprising are the results of the lead isotope analyses, which throw a new light on the metal resources of this period.

METALLOGRAPHIC EXAMINATION OF THE HUNNIC CAULDRON FRAGMENT FROM ÓCSA, HUNGARY

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The fragment of a Hunnic cauldron, the second of its kind from the Hungarian Plain, came to light a few years ago on the outskirts of Ócsa (County Pest, Hungary). These unique cast metal vessels composed of copper or copper based bronze alloys have unambiguous connections with the Eastern-European and Inner-Asian Hunnic-period archaeological material. The examination of the fragment of this extremely rare find type yielded new information on its metal composition and on its usage.

Besides the non-destructive analysis of the cauldron fragment (handheld, portable XRF), samples were also taken from the fragment for metallographic examinations. The examined surface is etched normally and colour etching also was made. Optical microscopic and SEM-EDS analysis were made to a full description of the microstructure, phases and chemical composition. Based on the results the manufacturing process and the specialties of the estimated usage were analysed.

Fine uniaxial dendrites built-up the microstructure. Sulphide and fine lead inclusions were discovered. Around the lead particles the results of the monothectic reaction is clearly visible. Intensive grain boundary corrosion was realized and Cu-Cu2O eutectic also revealed on the grain boundaries.

The archaeological study takes questions to the production and usage of this type of metal cast cauldrons. The aforementioned aspects give estimations and answers to these questions which help to identify the role of the cauldrons. This presentation displays the questions and the results with the detailed analysis of metallographic observations.

THE METHODICAL AND INTERPRETATIONAL PROBLEMS OF THE RESULTS OF MODERN INSTRUMENTAL ANALYTICAL EXAMINATIONS OF BRONZE OBJECTS

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During the last century significant changes were made in the aims, methods and equipment of bronze object examinations. Research was for a long time was focused on the composition of archaeological findings, the proportion of alloying elements and contaminants, the presence of certain microelements. As spectral analysis became more widely available from the 1960s, samples were taken from tens of thousands of objects, however, in only a handful of the cases were metallogrphic samples made or the lattice structure examined beside the composition. A new generation of materials testing instruments appeared in the 1990s (neutron activation and laser microspectrochemical analysis). Hungarian researchers already realized at the end of the last century that compared to early wet chaemical analysis methods instrumental examinations revealed unusually high concentrations in several cases where no explanations could be made from the metallographic aspect. Focused archaeometallurgical examinations and experimental archaeological observations proved that there is a significant difference between the real composition of the findings and the results of trending examinations performed on the surface of the objects. Aside from providing an explanation to the reasons of the phenomenon, this presentation also aims to direct attention to the methodical problems of unfinished standardized sampling protocols and the interpretation of the results.

OPTICAL MICROSCOPY AND SEM-EDS STUDY OF LAMP-STAND TRIPODS AND TRAYS BELONG TO ISLAMIC PERIOD OF IRAN

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Islamic metalwork have been the subject of study by numerous scholars (Allan 1976; La Niece et al., 2012; Scott 1911). However, there are lack of technical information on lots of metallic artefacts of the Islamic World. Different typologies of copper alloy lamp-stands belonging to 12th and 13th centuries have been identified in Iran. In this paper, two different tripods and circular trays of lamp-stand (late 12th century) belong to Birjand museum, Southern Khorasan province, have been investigated for their chemical composition and microstructure with the aim of tracing their connection as parts of two distinct lamp-stands. As a part of systematic analytical research, different parts of lamp-stands were studied using optical microscopy (OM) and field emission scanning electron microscope (FE-SEM) with energy dispersive X-ray spectroscopy (EDS). The results of analyses showed that all parts have been made of a quaternary alloy consisting of copper, tin, zinc and lead which was known as shabah mufragh [Allan 1976]. In addition, silver was identified in two samples (tripod and tray). Microstructural investigation showed that all parts have been cast to shape [Scott 1991]. Metallographic images revealed a cored structure with scattered lead globules in the cross-section. As a result, analyses showed some similarity between tripods and trays of lamp-stands. Degree of resemblance between different parts (tripods and trays) of two lamp-stands was noticeable. Accordingly, Tripods and trays can be related to two lamp-stands.

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A COMPARISON OF NEUTRON DIFFRACTION AND METALLOGRAPHY APPLIED TO PREHISTORIC AXES FROM THE ALPINE REGION

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The use of neutrons to study archaeological material is becoming more and more widespread. One particular technique is neutron diffraction, used to analyse the crystallographic structure of objects without sampling them. The aim of this study is to evaluate the quality of information obtainable with neutron diffraction and compare it with that obtainable by taking samples and analysing them optically using a metallurgical microscope.

We investigated axes from the Alpine region, owned by the Ashmolean Museum, dated to the Neolithic-Early Bronze Age (c. 3600-1600 BC). This project is in collaboration with the University of Oxford and the neutron spallation source ISIS, Rutherford Appleton Laboratories in Didcot. Moving from the Neolithic to the Bronze Age there was a change in production of metal artefacts from an experimental period to a more standardised production of tin bronze artefacts.

This transition was not linear, and in different cultural areas different working techniques emerged. To better understand the evolution of the metalwork in the Alps (and considering possible differences among different cultural zones), more analyses are required that have been carried out thus far. Unfortunately, traditional metallographic techniques require sampling, and this is not always possible. Previous work on a limited number of similar artefacts, using either neutron diffraction or optical microscopy, produced differing results, but these differences might be due to the different techniques applied. In this work, we present the results obtained on the same set of prehistoric axes.

For our experiments, axes dating from the Neolithic to the end of the Early Bronze Age in the Alps were first analysed using time-of-flight neutron diffraction (TOF-ND) using the GEM (General Material Diffractometer) at ISIS. The beam was directed to include the zones from which small samples would later be taken for metallography. The data obtained have been processed by Rietveld refinement using the software packages GSAS and MAUD for phase and texture analysis respectively. The preliminarily results show a general correspondence between the two techniques, both of which are able to discriminate between objects with very little manufacturing work applied and objects that have been heavily worked, with cycles of hammering and annealing. The results demonstrate that there is not a simple, linear narrative in the production of axes in the prehistoric Alpine region. Neutrons can help to improve knowledge because they can provide information on objects for which sampling is not possible.

WHAT IS A DAGGER? A CASE STUDY WITH THREE PREHISTORIC DAGGERS FROM SWITZERLAND

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The role of daggers in prehistoric European society has been long debated. They have been considered as prestigious and socially outstanding goods, they are often found as burial goods, and they have been represented in petroglyphs. Their function in ceremonial battles has been hypothesized, while, more recently, there are statements about their use for slaughtering.

Within this discussion, we may add some hints to understand the human choices behind daggers' production, in a study in combination with the University of Oxford and the University of Geneva, that combines their shape, the metal used for them, the working production techniques. We can also inform about the use, reuse and reshape of the objects. 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.

The study reveals a variety of shapes and compositions. The composition of the oldest blade is unusual, only copper being present, with some traces elements being below 0.1%, whereas in the other cases good quality metal was found: even if tin was not used as alloying material, the presence of Sb and Ni in one case and As and Ni in would assure their functionality as cutting tools. In two cases the shapes reveal a long history of use, re-use, and re-working.

Conversely the metallography only in one case shew patterns of cold work as final stage of production. In the case of pure copper the micromorphology can be hard to individuate, but in the other case we can hypothesize that some further hardening work was intended and never completed.

Their macroscopic and microscopic features and the chemical composition of the daggers suggest that they were functional tools rather than 'prestigious' objects. These daggers do not seem to have features that relate them to be 'prestige' objects, i.e. as rarely-used objects, in ritual occasions. Nor they were produced as burial goods. They could have been a multifunctional cutting tool.

The results here presented can only be seen as preliminary because of the small number of artefacts analysed. More analyses on daggers are needed to understand the role of this kind of artefacts within the prehistoric society.

AN INCENCE BURNER FROM THE CITY BOLUMAR OF THE KAZAN KHAGANATE AND THE LOCAL COPPERSMITH WORKSHOPS

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In recent years, the expedition of Kazan University is open new city center 15th century, which, currently, can be identified with the city of Bolumar known by the few written sources. The city was the local center of the craft, first of all, metalworking, and international trade. In 2009 in the study of complex coppersmith workshop with the remnants of the 2 furnaces discovered a unique copper incense burner (Fig.1). Perhaps it was taken to the workshop for repair. Product height of 37.5 cm and a weight of 12.3 kg consists of 3 cast elements: a bowl with a rim, biconical the middle part and the conical pan. Parts of the censers were cast in plastic forms and greatly improved after casting forging. Three samples from different parts of the incense burner, were investigated by means of Optical emission spectral analysis and scanning electron microscopy (SEM) showed that all parts are made from one portion of the metal which is copper with small additives of lead (with 0.9-1.3 percent).

Comparative analysis of 56 samples of items made of alloys of copper shows that copper of good cleaning was the basis for the preparation of alloys by local craftsmen. Copper with small additives of lead can be considered as the result of inadequate treatment, and as specially made alloy having high fluidity for good filling of the mold cavity during the casting of bulk products. Household cookware in the settlement was made of pure copper.

Censer for burning incense was widely used in the Islamic culture, but their archaeological finds are extremely rare. The brass Ottoman censers of 15th century, with complex fine form and proportions are well known. Incense burner from Bolumer follows this tradition. It obviously made on site from local raw materials (brass almost unknown in local non-ferrous metalworking) or a visiting craftsman, or on the sample.

Work on the model confirm the findings in the settlement few fragments of a cast vessels of tin-lead bronze, made in imitation of the Middle East the vessels of brass.

LOST WAX CASTING TECHNOLOGY AND THE EVIDENCE FROM PYROTECHNICAL CERAMICS

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Ancient pyrotechnical ceramics were functional ceramics fabricated for applications at extreme temperatures, such as metal casting. For this, they had to fulfill specific performance requirements, concerning refractoriness or inertness at high temperatures, resistance against thermal stresses and heat transfer (Hein and Kilikoglou 2007). In the fabrication of suitable ceramics the knowledge and availability of raw materials was essential as well as the preparation of the clay paste, in terms of clay mixing and the addition of temper materials. Ceramic tools used in a typical lost wax casting process included crucibles, tuyères and casting moulds. The microstructures of moulds were commonly quite similar to those of crucibles as the operational requirements were basically the same (Evely et al. 2012, Hein et al. 2013). Heat transfer was required to be suppressed, commonly by a intentionally porous ceramic matrix, so that the solidifying of the metal after pouring was decelerated. Furthermore, distinct internal layers can be usually observed, which present a finer microstructure with less or smaller non-plastic inclusions (Schneider and Zimmer 1984, Zimmer 1990). This indicates the preference of a more plastic clay paste for being coated directly on the wax model. In the present study assemblages of pyrotechnical ceramics, crucibles, tuyères and moulds, from Classical casting workshops in Mainland Greece (Athens and Kalapodi) and Peloponnese (Olympia) (Schneider and Zimmer 1984, Heilmeyer et al. 1987, Hein et al. 2017) were investigated for their microstructure, their composition and for potential metal or slag residues. The results were compared with studies of residues of casting ceramics sampled from bronze artefacts of the Protogeometric and Geometric Period, representing assumedly internal layers of the original casting moulds (Kiderlen et al. 2017). With the evidence of the ceramics conclusions can be drawn concerning the chaîne opératoire of bronze casting during the Protogeometric, Geometric and Classical Period.

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THE BRONZE FURNACE OF KERMA REVISITED: A UNIQUE CASTING TECHNOLOGY RECONSTRUCTED THROUGH EXPERIMENT, (RE-)EXCAVATION AND ARCHAEOMETRY

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Kerma is a key site in ancient Sudan, at a cross-roads between ancient Egypt to the north and sub-Saharan Africa to the south, but also the east-west trade routes crossing the continent. Its material culture reflects these different influences but equally represents strong local traditions.
During the Classic Kerma period (eighteenth to sixteenth century BCE), a metallurgical workshop was constructed in the middle of the religious quarter, which was first discovered by Bonnet (1986). He identified a particularly shaped furnace as related to bronze metallurgy, but its precise functioning was never fully reconstructed. Similarly shaped furnaces are known only from New Kingdom Pi-Ramesse (Egypt), but these are several centuries younger and their functioning remained similarly unclear.
Having the foresight to leave part of the furnace unexcavated and its remains carefully covered at the time, Bonnet now offered the opportunity to a new generation of archaeometallurgists to re-excavate this furnace during the 2018-2019 campaign and create a full photogrammetry 3D model. Drawing on insights from pre-excavation experimentation (based on the original excavation reports), newly discovered features and in-situ pXRF measurements, a completely new interpretation of this furnace is now proposed. Its functioning within the chaîne opératoire of bronze production offers exciting new perspectives on the existing technological know-how in the region at this time. So far, it represents the first example world-wide of this particular ancient casting technology.

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EXPLORING THE COURSE OF METALS BETWEEN THE SARDINIAN BRONZE AGE AND IBERIA. NEW DATA FROM MONTE SA IDDA HOARD PROVENANCE STUDIES.

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The hoard of Monte Sa Idda (Decimoputzu, Cagliari), is one of the classic metal hoards of Nuragic archaeology in Sardinia (Taramelli 1921). The hoard was uncovered with all its goods grouped into a large pottery container, and located within a Nuragic building. It was composed of over three hundred artefacts, most of them fragmentary, which are characteristic of the Late Bronze Age period in Sardinia. In addition, some of the represented objects within this hoard are usually related with Iberian typologies as, for example, the Sa Idda swords. Furthermore, other Iberian artefacts have been also connected within Sa Idda's types like the wax-lost handles.

The present study focuses on a group of 11 copper-based artefacts recovered from this hoard and are composed of six copper ingots, one socketed axe, one ferrule, one dagger and two swords. The applied methodology consisted of elemental analysis performed by a pXRF and lead isotope analysis (LIA) performed by MC-ICP-MS in the Frankfurt Laboratory (Klein et al. 2009). The main goal of this research is to approach the provenance of these metal artefacts and, if possible, relate them to the original ore source.

Results show that six objects and ingots present isotopic coincidences with three different Iberian copper ore areas and the remaining five artefacts can be related with local Sardinian minerals. These results, in combination with other lead isotopic results from Late Bronze Age metal artefacts in Iberia and also in the Balearic Islands, permit us to reconstruct the trade dynamics that would have connected the Iberian Peninsula and Sardinia during this period. Thus, this information seems to be relevant for a better understanding of the hoarding practices, and also to follow Late Bronze Age metal trade courses in the Central and Western Mediterranean.

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ANALYSES OF COPPER-BASED ALLOYS OBJECTS AND SPECIMENS OF WASTE FROM THE CELTIC-EARLY ROMAN PERIOD LAYERS OF MEDIOLANUM-MILAN (LOMBARDY, ITALY)

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This paper presents the analytical results of some specimens of the waste from the production of copper alloys objects from the Celtic metalworking district of via Moneta in Milan (4th- 3rd century BC – 1st century AD). In this district, copper-based alloys were used for the production of nails, rivets, upholstery nails, thin bronze sheet was made in order to cover the heads of iron nails and possibly, La Tène fibulae of Nauheim type or of related types were made too.

This research was carried on with a scanning electron microscope (SEM) equipped with an energy dispersion system for microanalyses (EDS). Our specimens were a stud, a cover of a nail head, a concretion found at the bottom of an amphora used in a metal working atelier and a slag from the smelting of copper alloys. Only seldom, these alloys were real bronzes, oftener they were bronzes with Pb or binary Cu-Pb alloys. Because of this, the resulting metal was fragile and some parts of the finished products had the tendency of breaking off thus leading to the rejection of some of them. The slag analyses have proven that crucibles were used for the smelting of metals, the coppers salts forming one slag show that in these ateliers bronze objects were polished using water and stone tools.

The concretion at the bottom of the amphora proves that in these ateliers both iron and copper alloys were worked in order to make composite objects.

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LATE ROMAN FORGES FROM CASCINA CASTELLETTO (MILAN, NORTHERN ITALY)

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During the construction of a gas pipeline in the Po plain 10 km to the East of Milano in Northern Italy, the remains of an agricultural and productive settlement belonging to the Roman period were found. In 2017, the National Archaeological Service explored the site. This area of the Po plain belonged to the Roman town of Milano/Mediolanum, which was one or the Roman Empire capitals from 286 until 402 AD. This site was close to the road linking Mediolanum with Bergomum and its iron rich mines and to the waterways (the Adda and Lambro rivers) which lead to Lake Como and to the other iron mines in that area.

The remains of the iron works belong to the second phase of the operative chain in direct iron metallurgy, i.e. the forging phase. In the late Roman period, there were some forges on this sitetransforming the semi-finished products into finished objects. The large amount of slags discovered was studied macroscopically. They are plane convex slags (PCB), glassy clayey slags (SAS) and iron fragment detached during forging. Ten specimens of PCB slags were selected and analysed using a SEM-EDS. The smiths worked according to a standardised,well-controlled and constantly repeated procedure. Unfortunately, the high temperatures employed caused the passage of metal into the slags. The plane convex slags are very dense and compact, their dimensions and their morphological and technological characteristics are homogeneous. The metal in these slags under the form of droplets and clusters is pure ferrite. Its low amount of impurities suggests that its ore was mined in the hydroxides deposits in the nearby mountains.

MIDDLE BRONZE AGE GOLD SHEET FROM ALBARETO (PARMA), ITALY

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The site of Albareto was discovered in 2017, during the construction works of the methane pipeline Pontremoli-Cortemaggiore and is still being excavated under the scientific direction of Roberta Conversi, Soprintendenza ABAP of Parma and Piacenza. The archaeological site is located in the Apennines, at 676 m above sea level on a flat and humid area, and there are traces of human occupation from prehistory to early medieval times. The prehistoric phase, identified on two layers separated by an alluvial stratum, can be referred to a production site, on which especially steatite beads have been found. The ceramic fragments collected in this phase allow us to date the site to the early phase of the Middle Bronze Age, but C14 investigations are on the way. The excavation brought to light the remains of two wooden structures, one circular and the other rectangular, built next to a still now active spring located at the prehistoric level. Possibly because of the humid environment, no metals were found with the exception of two fragments of gold sheet strips, recovered with tiny fragments of amber.

The investigations and XRF and SEM-EDS analyses carried out on the gold fragments indicate that the material is a gold-silver-copper alloy. The SEM micrographs show the imprints of the skin employed in the production of the gold sheet. Traces of tiny particles embedded in the gold have been identified as very fine clay, employed on the skin to avoid the adhesion of the gold on it. One side of the sheet is opaque, with traces of organic materials such as beeswax and/or vegetable resins. We suggest that this was the material employed for fixing the sheet while polishing it. The strip was cut with a chisel blade and some regular tears on the sides and a small intact hole indicate that the strip was stitched on a fabric as decoration. The other side is polished and shiny and on it some small quartz-like particles have been identified. Their shape and size suggest that they are organic and come from the plants (such as equisetum or husks) used for the polishing of the sheet. To our knowledge these materials have never been identified before on ancient pieces of gold. This examination allows us to reconstruct the entire production process of the gold sheet.

NEW EVIDENCE FOR SOPHISTICATED GOLDWORKING TECHNIQUES FROM MIDDLE MINOAN CRETE

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The cemetery of house tombs at Petras, which is under excavation by Metaxia Tsipopoulou, is a large burial place associated with a Minoan palatial site in eastern Crete. The earliest evidence from the tombs dates to the Early Bronze Age (EBA), and the cemetery reached its greatest size in Middle Minoan (MM) II, during the Middle Bronze Age (MBA). The MBA house tombs consisted of several rooms used for burial and other purposes. Most of the burials from this period are secondary deposits consisting of disarticulated bones that were moved to this location from another place. The authors are publishing the metal finds from this large cemetery.

Among the discoveries from the early part of the Middle Bronze Age are gold ornaments that were moved to their final locations along with the bones they accompanied in the primary burials. The joining of gold to gold was accomplished by Bronze Age metalsmiths in various ways: mechanically, by soldering, and by diffusion bonding. The earliest identification of the technique seems to be from the Troad in Anatolia during Early Bronze II. This method has been now documented for the first time in Minoan Crete on a gold ring.

The use of gold or silver to cover the heads of rivets on daggers found both in Crete and in the Shaft Graves at Mycenae has been known for several years. This decorative technique, produced by diffusion bonding, as well, has now been identified on riveted tweezers found in House Tomb 2 in the cemetery at Petras.

LATE BRONZE AGE ARCHAEOMETALLURGICAL SURVEYS OF HOARDS FROM FRANCE (1250 TO 800 BCE)

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Metal artifacts, constituting hoards, is deliberately abandoned for various reasons. In order to study hoards, an interdisciplinary database of the latter, mainly metallic, was created as part of the DEPOMETAL research program and work on the basic compositions of copper-based artifacts was carried out on a national scale for the period from 1150 to 800 BCE. This study will ask questions about the importance of natural and cultural factors in the metal artifacts of the two cultural complexes Atlantic and Alpine. A statistical protocol allowing chronological and geographical clustering of artifacts has been developed and combined with a GIS to characterize the elementary compositions. For the period between 1250 and 1150 BCE, the elementary compositions differ significantly between East and West France. Between 1150 and 950 BCE, we will notice the strong influence of the Alpine culture up to the mid-western part of France. This observation highlights relationships already observed for previous periods but never demonstrated for these dates. Between 950 and 800 BCE, the major difference with the previous period is the revival of the Atlantic networks in west-central France. Thus, it seems possible to show that the cultural factor, and therefore the identity factor, strongly influences choices in supply networks and influences the location of exploited deposits. The study offers a new perspective on supply networks for the end of the Bronze Age in France by revealing the independence of exchange networks according to cultural background. The cultural and therefore identity factor strongly influenced supply network choices and influenced the location of exploited deposits. This conclusion is particularly innovative for the Atlantic coast, which is often still presented as copper-free and dependent on alpine imports. It turns out that the copper used in Brittany and north-west of the Massif Central have different chemical signatures than alpine copper. It is now necessary to determine whether these are local copper instruments, the Armorican Massif or the Massif Central, or imports other than those of the Alpine.

RAW MATERIAL PROVENANCE OF EARLY AND MIDDLE COPPER AGE COPPER ARTEFACTS FROM WESTERN HUNGARY

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Our project studies the spread of the products and technology of copper metallurgy in the Carpathian Basin from 5000 BCE to 3000 BCE. The current presentation discusses the first results on the provenance of copper artefacts from Western Hungary in the Early-Middle Copper Age (4350–3800 BCE). This was the earliest period from which traces of local metallurgy was found in Hungary, in a territory laying far from raw material sources. Based on typological considerations Nándor Kalicz regarded these items as the products of the Eastern Alpine region (Kalicz 1992), however, archaeometallurgical research of this region has not found any traces of copper extraction during this period (Höppner et al. 2005; Lutz et al. 2010). The metal finds of the Balaton-Lasinja and Furchenstich cultures representing the Early-Middle Copper Age in Western Hungary show cultural contacts especially with the territory of present-day Slovakia and Austria.

This case study shows results from two sites (Zalavár-Basasziget and Zalavár-Mekenye) which are located very close to each other and represent two consecutive periods in the Early and Middle Copper Age. A unique copper disc and flat axes were found in the earlier, Zalavár-Basasziget settlement (Balaton-Lasinja), and small copper ornaments and a crucible were revealed in the later, Zalavár-Mekenye settlement (Furchenstich). The question still arises from where the copper raw material derived that was used for preparing these artefacts, and whether the sources changed between the two periods.

Our multidisciplinary research team integrates various methodology (lead isotope and trace element analyses, Bayesian modelled AMS dating and network analysis) to reveal the spread of the products and the technological knowledge of copper metallurgy. The first few data indicate that the raw material sources used in the two periods did not change. The project is financed from the NRDI Fund (NKFI FK no. 124260).

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METAL COMPOSITION AND DECORATION TECHNIQUES OF POLYCHROME FINE GOLD AND GILDED SILVER ARTEFACTS FROM A HUNNIC-PERIOD SACRIFICIAL ASSEMBLAGE (TELKI, HUNGARY)

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A ritual deposit comprised of more than one hundred gold and gilded silver objects, dated to the late phase of the European Hunnic period (mid-fifth century AD), was found in Telki (Central Hungary) in 2016. According to the spatial distribution of the finds, the assemblage is a structured deposit buried during a single ritual. It consists of the elements of one or more horse-gear sets, the remnants of personal adornments (mounts of a shoe-set and at least three belts) and of weaponry. The objects belong to the supra-ethnic elite culture dating from the late fourth to the mid-fifth century, with analogies originating from the vast territories between the Caucasus and the Crimea in the East and Western Europe and North Africa in the West. From typological point of view, the assemblage incorporates the artefacts of several – at least three – chronological and cultural groups. The objects and their decorations were analysed non-destructively by using handheld XRF, EPMA/SEM-EDS and μ-XRD techniques in order to determine their chemical as well as mineralogical composition. Gold objects were produced from high-quality gold, and they form different groups based on the proportion of gold, silver and copper, indicating the use of different ore sources. The different chemical groups coincide with the different typological and chronological groups. Objects with gold content higher than 99 wt% were most probably manufactured from solidi. Most of the objects are inlaid with tiny pieces of garnets mounted in single bezel or cloisonné cellwork. Based on their chemical composition, the garnets originate most probably from the placer deposits of Sri Lanka.

The silver objects were made of high-quality silver (> 90 wt%). Copper was added intentionally as an alloying element. The objects can be grouped based on their gold and lead content indicating the use of different ore sources. Most of the silver objects are decorated with fire-gilding. A gilded silver buckle is adorned with niello inlays composed of silver sulphide (acanthite, Ag_2S).

COMPOSITION, RAW MATERIAL PROVENANCE AND MANUFACTURE OF A UNIQUE LATE ROMAN SILVER FOLDING STAND (QUADRIPUS) FROM KŐSZÁRHEGY, HUNGARY

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The late Roman silver folding stand (quadripus) from Kőszárhegy (near Polgárdi, Hungary) is the most decorated and only known silver quadripus from the Late Roman Imperial Age, dated to the 4th century AD (Mráv, 2012). It is the largest and heaviest among the known Roman folding stands. Archaeological evidence indicates that the quadripus has close connections to the Seuso Treasure.

The folding stand with two original feet was analysed using various chemical methods in order to determine the elemental composition, provenance of raw material and the production technology. Preliminary non-destructive chemical analysis was performed on the different parts of the object using a handheld X-ray fluorescence spectrometer along a pre-designed grid at several points. Samples taken from the different parts of the object were analysed by using LA-QICP-MS and MC-ICP-MS in order to determine the bulk elemental and lead isotopic composition and to verify the handheld XRF results.

The silver quadripus consists of rather pure silver (92.5–96.5 wt%) intentionally alloyed with copper. The different trace element composition (Bi, Au, Pb) of the different parts (base, lower part, griffin, upper part, finial, cross bands) indicates the use of different silver ingots implying that the different parts were made separately, and then soldered together with hard solders. The same parts of the two original feet are very similar regarding their minor and trace element contents, therefore series production is supposed. The nearly constant gold and lead contents of the object indicate that not re-used or re-melted, but primary, cupelled silver was used for manufacturing the artefact. The lead isotopic composition of the quadripus covers a quite narrow range (208Pb/206Pb: 2.073–2.086; 207Pb/206Pb: 0.837–0.845). Comparing our results to the lead isotope data of the European lead-silver ores, and taking into consideration the archaeological evidences, the ore used for manufacturing the quadripus could come from the Balkan area.

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NIELLO BEFORE THE 11TH CENTURY – AN EXPERIMENTAL STUDY ON THE PREPARATION AND APPLICATION OF LEAD-FREE NIELLO INLAYS

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Niello is a bluish-black metal sulphide, which was widely used to decorate various metal objects in the Roman Empire. However, our knowledge concerning the exact Roman-period niello technique, the appearance of binary silver-copper sulphide niello decorated silver objects is very obscure. According to the previous works, Roman-period niello is generally composed of one metal sulphide (silver sulphide for silver objects and copper sulphide for copper, brass and bronze objects), and two metal sulphide niello was apparently introduced only at the end of the 5th century AD (La Niece, 1983). However, a recent detailed study performed on the niello inlays of a late Roman (last third of 3rd century) silver object revealed that niello with elevated copper content was already used by the Roman craftsmen (Mozgai et al., in press). No contemporary written sources or recipes are available, therefore the exact preparation and application of Roman-period lead-free niello is still unknown. It is well-known that niello without lead behaves a completely different way than silver-copper-lead sulphide niello, which is in use from the 11th century.

The aim of our study was to make an attempt to reconstruct the preparation and application of silver sulphide, copper sulphide and silver-copper sulphide niello. During the experiments, we prepared nielli with different silver/copper ratio (10:0; 9:1; …; 1:9; 0:10), and then applied them in a pattern previously carved into the metal surface. The physical and chemical properties and the behaviour of the nielli during the experiments were observed and compared. The prepared nielli were analysed by using EPMA and μ-XRD techniques in order to determine their chemical and mineralogical composition. The results obtained can be used to reconstruct and better understand the Roman-period and early Medieval niello technique.

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NEW INVESTIGATIONS MADE ON 5TH-CENTURY HORSE TACK FROM UNTERSIEBENBRUNN (AUSTRIA)

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The analysis and the periodization of horse trappings dated to the Late Antiquity and Early Migration Period were usually performed in the publication of the excavated sites. Recently, it is more accurate to examine them in context together with their analogies. Their detailed analysis could help to determine the potential provenance and the various impacts, which affected the manufacturing and decorating techniques used. The assemblages can include the following objects: parts of the bridle (bit, mounts, buckles, strap-ends), parts of the saddle (mounts, buckles) and other objects linked to horses (e.g. whip, horse-shaped figurine). The material of the mounts is mostly copper or silver, ornamented with gilded silver plaque (e.g. finds from Hungary), gold plaque (e.g. finds from Nyíregyháza-Oros (Hungary)) or in the case of a silver sheet with fire-gilding (finds from Untersiebenbrunn (Austria)). Almost every mount (bridle and saddle) has a punched, stamped or pressed ornamentation. In the course of the current research, we realized that the pendants, which were manufactured in pairs or in multiple pieces, do not have the same punched/stamped/pressed motifs. We discovered small differences in their decoration, for example, one of the axe-shaped pendants from Untersiebenbrunn is finer in contrast to the other, which has some mistakes (e.g. carved lines to punch in a straight line, varied number of punched motifs). A potential conclusion could be that either one of the objects was broken, so a new simpler one was made, or the goldsmith master worked together with his apprentice in the workshop, who was not so experienced.

In this present study, we investigated the 5th-century horse tack from Untersiebenbrunn (stored in the Kunsthistorisches Museum, Wien). In order to determine the elemental composition of the metal objects, a non-destructive handheld X-ray fluorescence analysis was used due to their high value. Because of the newest research on the Sösdala finds (Dal, 2017), it was obvious to examine another ensemble of the Sösdala-horizon. Therefore, we can compare their material and examine them in context.

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IDENTIFICATION OF SILVER SURFACE ENRICHMENT IN HISTORICAL SILVER COINS — A METHOD IMPROVEMENT AND A STUDY OF TRACE ELEMENT BEHAVIOUR

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A common issue in non-destructive analysis of historical silver coins is depletion of Cu from near-surface areas, which in turn results in higher Ag content on a surface of a coin. The paper presents an evaluation of previously reported non-destructive method for identification of Ag enriched surfaces on coins based on measuring and comparing the intensity ratios of Ag Kα/Ag Lα peaks between coins and Ag standards with similar composition. A number of silver coins with different chronologies and provenance were analysed with µXRF in order to measure Ag Kα/Ag Lα intensity ratios and subsequently compared with the peak ratios of Ag alloy standards with different composition. Coins where silver surface enrichment was confirmed were further sampled and analysed with LA-ICP-MS to observe the content of trace elements in the core and at the surface of coins. The analysis confirmed that the presence of silver surface enrichment was not detected with all Ag silver standards and that multi-standard approach allows for a more reliable identification of the phenomenon. The results from LA-ICP-MS show that beside Ag and Cu, the silver surface enrichment also affects the behaviour of minor and trace elements — namely Au, Co, Ni, As, Rh, Pt. The content of Au was significantly higher in the enriched areas than in the core of coins; while Co, Ni, As, Rh, Pt were depleted from the surface. The study propose the application of multi-standard approach in identifying the silver surface enrichment in fineness and provenance studies of historical silver coins.

PREHISPANIC GOLD OBJECTS OF EARLY QUIMBAYA CULTURE IN COLOMBIA: AN ELEMENTAL ANALYSIS BY USING A PORTABLE DISPERSIVE ENERGY X-RAY FLUORESCENCE SYSTEM

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The Early Quimbaya goldsmith has been considered one of the most famous in Colombia and Latin America, due to its advanced metallurgical techniques and the beauty of its designs. Which constitute an important sample of the legacy left by ancient societies that settled in diverse places of the Colombian territory. In this work we present the quantitative analysis of more than ten pieces of pre-Hispanic gold belonging to the early Quimbaya culture. Among these objects we have beautiful pendants and nose rings of different animal shapes and geometries, manufactured with extreme delicacy and sparkling beauty. This work has been carried out with a portable dispersive energy x-ray fluorescence (DEXRF) equipment that has been home-made, following the parameters and conditions of other portable system [1]. From XRF spectrum recorded, the results show the presence of gold, silver and copper in some objects and only gold and silver in the rest of the objects. For the quantification, the Pymca program has been used, and corroborated values using standard sheets [2]. It is the first time that these objects are studied with an analytical technique and the information obtained has been very relevant for curators and specialists of the museum (MUUA – Medellin, Colombia).

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IMAGING INVESTIGATION OF CHINESE BIMETALLIC SWORD FRAGMENT FROM 2ND-1ST CENTURY BCE

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Archaeometric studies have played a major role in the field of archaeology, especially with regard to materials transformed through human activity. Metals are generally investigated through metallography and SEM, which require sampling or surface preparation. Neutron techniques instead can provide the bulk properties of metals non-invasively.

Here we present a neutron imaging study of a Chinese bimetallic sword fragment from 2nd-1st century BCE. White beam Neutron Tomography (NT) and Neutron Resonance Transmission Analysis (NRTA) have been applied, using the IMAT and INES beamlines of the ISIS neutron source in the UK, respectively.

The earliest example of bimetallic weapons in China dates as early as the Shang Dynasty (1600–1100 BCE), where meteoric iron and bronze were combined to forge weapons. With the discovery of iron smelting technology during the Spring and Autumn Period (770–473 BCE), bimetallic swords with bloomery iron and bronze became more common (Lian et al., 2002). They have been found in many parts of central China.

The sword fragment investigated has an iron blade mounted on a studded bronze grip (probably for a twine binding) and a ricasso with three long spikes protruding on each side. The object resembles two published examples with similar form of hilts (Orioli et al., 1994) listed as originating from burials investigated in the mountainous regions of Longpaozhai, in the Min River Valley, dating from the 2nd or 1st century BCE. Similar swords are found further north and may have been introduced from further west.

NT allowed us to study the inner morphology of the sword, revealing details of its conservation status and the forging and/or casting of the different components. NRTA provided a 2D map of the elemental composition of the artefact, indicating the nature of the bronze alloy of the grip (whether tin bronze, leaded tin bronze, or arsenical tin bronze) and of the iron blade.

The study presented was complemented by Neutron Diffraction, and Neutron Resonance Capture Analysis, providing a characterisation of the object in terms of alloy composition, microstructural characterisation and elemental information, non-destructively.

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NON DESTRUCTIVE ANALYSIS OF 6 INDONESIAN KERIS FROM THE WALLACE COLLECTION BY NEUTRON METHODS

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The keris is the distinctive weapon of Malaysia and Indonesia. It is found in a variety of forms but, typically, it is an elongated dagger or short sword of slender proportions with a blade of rough pattern-welded texture sharpened on both edges [1].
All good Southeast Asian keris are made of two sorts of metal, iron (or steel) and pamor welded together in intricate patterns and subsequently brought out on the polished surface of the blade by etching. Pamor, is the etch-resistant component of the keris, traditionally used in the blades, it includes a variety of iron-alloys and it usually has multilayered, twisted structure.
In order to investigate the composite structure of the keris and the different types of pamor effectively used, we analyzed a set of six keris provided by the Wallace Collection in London, originating from different areas of Indonesia. Their typology has been extensively described in literature [3-5]. In order to obtain metallurgical information about the composite structure of the six keris, we performed a combined analysis of neutron diffraction and neutron imaging which provided an ideal combination of morphological and structural details.
Neutron tomography provided non destructively morphological information about the composite structure of the keris (welding, multilayered structures, defects), while neutron diffraction provided quantitative information on the composition and the crystalline microstructure of the different types of iron, iron alloys and steel employed for their production.

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TRACE ELEMENTS AND MANUFACTURING INVESTIGATION OF THE BA DEPOSIT OF BRIC DEL CORVO (ITALY)

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In 2006 a group of metal objects, dating back to Bronze Age, was found at the top of Rocca dei corvi, a mountain (750 MAMSL) placed in the hinterland of Vado Ligure, a small town near Savona (Italy). Most of them, specifically fragments of axes, armillae, embossed sheets, swords, pins, was stored inside a small hole probably functioning as a hoard of metallic material to be recycled. This hypothesis is also supported by the finding of fragments of plano-convex ingots.
This collection underwent spectroscopic (by ICP-MS) and metallographic investigations in order to define their chemical composition, the concentration of trace elements and the manufacturing process.
The collected data are meant to define any existing relationships among the ingots themselves and the other artefacts belonging to the deposit, and to find out possible connections with local mines eventually.
The ingots are indeed confirmed to be made of unalloyed copper possibly the result of the first casting after post-smelting concentration process. This increases the chances to create a direct connection with mineral sources. The artefacts are all made of alloyed copper (tin bronze) with various high concentrations of Sn as the main element. They represent a consistent part of the deposit and might be considered as preliminary and certified alloys to be used as a base for further production processes.

THE EXPLOITATION OF COPPER SULPHIDES AND ITS IMPLICATION ON THE ORGANIZATION OF THE ECONOMY DURING THE BRONZE AGE

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Pyrometallurgy successively knows two technical innovations between the Neolithic and the Bronze Age. The first of these innovations is the reductive fusion, allowing to extract copper from oxidized and carbonated minerals, and the second is oxidation (roasting) which, followed by the reductive melting, allows to work sulphide minerals.
Although the appearance and diffusion of pyrometallurgy is well documented for the Neolithic (Roberts et al. (2009)), the smelting of copper sulphides, occurring at the beginning of the Bronze Age, was not the subject of any synthesis at an European scale. Indeed, this sulphide mining leaves little archaeological traces: only rare grilling areas have been discovered in an archaeological context.
However, due to the appearance of this innovation, the copper mining areas have changed. Mines are initially confined to the Mediterranean region (where copper carbonates abound due to strong supergene alteration) and then opening up everywhere in Europe with the arrival of copper sulphides smelting. The Mediterranean is no longer the only region producing copper.
This work gathers the exploited copper mines in Europe and the various archaeological evidences of the pyrometallurgy (workshops having provided grilling areas, reduction furnaces). The results show that this technical innovation has led to profound changes in the European-wide exchange networks linked to copper production.

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DEVELOPMENT OF METALLURGICAL PRODUCTION IN NORTHERN EURASIA AND EUROPE

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This study is based on statistical processing of metal and slag analysis from Northern Eurasia and Europe. This made it possible to identify related technological groups: 1) smelting of native copper and oxidized ores – pure copper; 2) smelting of oxidized ores from ultrabasic rocks with arsenic minerals – Cu+As alloys; 3) smelting of fahlores – Cu+As+Sb and Cu+Sb alloys; 4) smelting of copper-iron sulphides – Cu+Sn alloys. This is a common pattern for Northern Eurasia and Europe, caused by temperature and chemical processes (Grigoriev, 2017; 2018).

The reason is simple. Smelting of oxidized ores was not able to provide large volumes of production, as this was a process without slag separation. Smelting of oxidized ores from ultrabasic rocks at low temperatures under reducing conditions made it possible to separate slag and produce arsenic copper. But after the transition to more common and rich, but refractory ores, a rise in temperature and oxidizing conditions led to the removal of arsenic. Therefore, with the transition to ores from acidic rocks and to copper-iron sulfides, the possibility of producing Cu+As or Cu+As+Sb alloys disappeared, and tin bronze replaced them.

These technological changes strictly correspond to another process – the growth of metal consumption. In Europe, this growth is most noticeable in the transition to the MBA. This is explained by the fact that many regions were drawn into the trade system. This was partly caused by the need to transport tin, but also by social processes and the growth of trade with the Mediterranean.

And here we already see a tangible difference when comparing Europe and Northern Eurasia. In the Eurasian LBA, the proportion of tin alloys depends on the cultural affinity and the distance to the tin sources. In Europe, a similar picture is observed in the EBA, but already in the MBA (which is synchronous with the LBA in the east) the dependence of the proportion of tin alloys on distance from tin sources disappeared, because this region was more economically developed, and a system of global trade formed.

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NEW DATA ABOUT THE BRONZE AND IRON HOARDS FROM TĂRTĂRIA – PODU TĂRTĂRIEI VEST

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In 2012, through a large scale archaeological excavation occasioned by the construction of a future motorway, were discovered two hoards of bronze and iron objects. These were discovered on the southern limit of a very large prehistoric site, located on the left bank of the middle Mureș valley, at Tărtăria (Alba county, Romania), preliminary dated during the 8th c. BC (the middle Hallstatt period). The two hoards were discovered within an outlining ditch (a particular fortification feature), marking the southern limit of the site. The structure of the deposits is complex and varied, containing weapons, tools, jewellery and harness objects. The first hoard comprises more than 300 objects, being one of the largest ever found corresponding to the 9th–8th c. BC period / DFS V – VI in the Carpathian basin, while the second consists of 50 objects.

As part of a PILOT project, were made a series of optoelectronic investigations upon more than 120 objects (of bronze and iron) of the two hoards. There have been made spectroscopic recordings (LIBS and XRF) on certain objects of hoards. Also a series of X-rays were made for the “nuclei” of objects from the Tărtăria I hoard. Certain objects were 3D scanned in order to obtain digital models used of high resolution. The resolution of the digital models allow to extract information about the processing/manufacturing techniques, as well as for other particular features of the objects’ shapes. These new data were introduced in the PILOT platform database, together with general information (history, location, description, typology etc.). A complex set of data was obtained in order to be used for an integrated and multidisciplinary study of the two hoards from Tărtăria, an important discovery which determines significant reconsideration about the so-called “Bâlvănești - Vinț” horizon (= DFS V – VI).

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ACCURACY OF X-RAY FLUORESCENCE AND MONTE CARLO SIMULATION METHOD FOR THE CHARACTERIZATION OF ANCIENT METALLIC SAMPLES

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In the last decade the number of publications concerning the application of Monte Carlo in combination with X-ray fluorescence to the study of ancient metallic artifacts has been constantly increasing. This is principally due to the method's capability to simulate multilayered structures, which is almost always the case for ancient metallic samples showing at least a patina/corrosion surface. In this sense, it appears to be more performing compared to other analytical quantitative techniques. In fact, it makes it possible to characterize any layer (smooth or rough) of the structure in terms of both thickness and composition. However, the nature of layers such as a corrosion/patina layer or a depleted one (for example the Tumbaga gold alloys) raises some questions about the ability of Monte Carlo simulations to estimate correctly the thickness of the layer. This is due to the intrinsically non-homogeneous structure of such layers, where several voids can be found. The presence of voids makes the density of the material lower compared to the corresponding homogeneous material, thus compromising the estimation of the true thickness [1]. In this paper we investigate this aspect and we report some results obtained from the analysis of nuragic civilization samples.

A DIACHRONIC AND STATISTIC APPROACH OF QUALITIES OF FERROUS ALLOYS: TOWARD AN AUTOMATIC ALGORITHM ?

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Studying quality on ferrous alloys is deemed to be difficult. Indeed, quality depends on many factors such as average carbon content, inclusions rate and phosphorus content. Our study aims to shed light on the notion of quality in ferrous products. More precisely, we study the variability of ferrous alloys semi-products qualities from Antiquity to Middle Age among and inside three main sites in France : Saintes-Maries-de-la-Mer, Castel-Minier and Glinet. One of our goal is to determine the factors that affect quality and measuring their variability among the sites and across the different periods. To do so, microscopic observations are coupled with micro-hardness and tensile strength measurements. Thanks to all these data, groups of qualities can be established.

As a matter of fact, a first approach was developed in Leroy et al. (2017) and Pagès et al. (2011) where the Authors mainly relied on the sole average carbon content (ACC) to classify the samples. Yet, to the best of our knowledge, the ACC estimation usually relied on a cumbersome and time-consuming manual procedure. Thus, the study of the quality of a large corpus of ferrous alloys using many quality factors was nearly impossible.

Instead, we propose a fast semi-automatic algorithm based on image analysis. Combining pre and post nital-etching images, the algorithm is not only able to estimate the ACC but also a carbon and inclusions distributions maps. Also, this algorithm guarantees a quick and repeatable estimation of carbon content almost independent of the operator. The first results show similar ACC estimations between the manual method and the algorithm. This algorithm is, as far as we know, the first one to allow one to treat a large corpus of ferrous alloys samples to study their qualities. We can, then, classify the samples using not only the ACC and inclusions rate determined by the algorithm but also the phosphorus presence. In a second time, this large corpus allows to study the correlation between the defined groups and the description of the semi-product (site, dating, morphology…).

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REVEALING THE TECHNOLOGY OF HISTORICAL EUROPEAN BRONZE CASTING BY EXAMINING THE IRON SKELETON OF ARTWORKS

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Bronze sculptures technical study has been a particularly active field in the last decades, contributing to issues of authentication, dating, and our understanding of the Modern period bronze statuary technical landscape. Nonetheless, it is essential to develop new analytical procedures that will enable us to tackle these often-elusive questions more fully by providing deeper understanding of the materials and methods used in the production of bronze artefacts.

Although iron-based structural reinforcements (such as armatures or core pins) are systematically used for bronzes casting, and potentially contain important data related to the chaîne-opératoire of bronze artefacts, they have barely been investigated. More specifically, they can reveal the technical choices made by foundry-men: what materials were used? how were they shaped? as well as informing our knowledge of chronological and geographical practices or patterns of production.

By performing an in-depth analytical study of those overlooked materials, this research provides new insights into the historical and technological aspects of bronze statuary in the European 15th to 19th centuries. A multi-scalar and multi-modal procedure (Dillmann et al., 2007; Disser et al., 2014; Leroy et al., 2017) based on a combination of chemical and metallographic characterization of iron products is carried out.

The results, combined with other technical data (including, when available: radiography, metal analysis, core analysis, as well as stylistic analysis and other art-historical evidence), offer a new perspective on the objects context of production. Direct correlation can be drowned between technical constraints of bronze casting and characteristics of the iron materials, revealing the technical choices made by craftsmen. In addition, the obtained results contribute to a better understanding of the iron technologies used in the making of non-ferrous items and, their integration into a global iron production and circulation system.

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NAILS AND ANCHORS - QUALITY AND SMITHING TECHNOLOGY OF MARITIME IRONWORK IN THE VIKING AGE

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It is likely that anchors of iron for use in Viking ships were the largest type of object that was made by forging in the Viking Age. Dated anchors from Denmark and Norway show that they most often weighed about 10 kg, but in some cases weighs up to 30 kg. It has therefore been very large pieces of iron to handle when heated in the forge, and by forging on the anvil. The production must therefore have required a specialized knowledge.

In order to describe the technology and quality of the iron used, a number of anchors have been metallographically investigated. Despite the big difference in size, there seems to be a relatively uniform technology, which however, at least in some places, seems to have been in use almost up to now. However, it is possible on the basis of the structure of the iron, and especially slag inclusions in it, to see that this is Bloomery iron, which differs significantly from the later iron. The different processes: bloomery smelting, fining of pig iron and puddling leaves slag inclusions with different compositions and can be recognized by analysis. A total view of technology, material and form may therefore form the basis for an assessment of anchors found without context. A development of technology and production of iron from the Viking Age and until the beginning of the 19th century is outlined

It has been suggested that for maritime purposes, iron with a high content of phosphorus has been deliberately used as it would provide better resistance to corrosion. However, from the studies of the anchors and a number of analyzes of iron nails from ships, this cannot be demonstrated unequivocally.

THE EARLIEST IRON IN DENMARK – OR MAYBE NOT

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The dark wavy bands on the two razors from Arnitlund and Keldbymagle have, since they were described by Montelius in 1913 and Muller in 1914, been considered to be the earliest examples of the use of iron in Denmark. Now an EDS analysis carried out in 1998 by Arne Jouttijarvi has shown that these “inlays” in both cases are copper wires that had been enclosed when the razors were cast.

The apparent inlays consists of copper corrosion with a substantial content of iron oxide. A high iron content in corrosion products on archaeological bronze finds is not unusual due to the high iron content of subsoil water everywhere in Denmark. Originally the corrosion most likely covered the entire surface of the razors, but a coarse cleaning, probably with a wire brush, has only left corrosion in a shallow groove. In a few places within the groove, a copper wire, which is probably the actual inlay, can be seen with the naked eye.

A special feature is that the inlays apparently are made by leaving a copper wire in the mould before the bronze was poured in. At the razor from Arnitlund one can see that there are two wires that are not put in the same groove but are running parallel for about 3 mm. At the razor from Kjeldbymagle it seems at first glace that there are inlays at both sides, but a drawing shows that it is the same wire which in some parts can be seen on the front and in other parts on the back of the razor.

INVESTIGATION OF THE COMPOSITION AND THE PROCESS USED DURING THE PRODUCTION OF THREE ANTIQUE SPEARHEAD WITH MULTIVARIATE METHODS

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Metal working in Illyrian cities, represented mainly by producing work tools and weapons. The artefact presented in this study designed as weapons are three spearheads which belongs to VII-V century BC, part of Historical Museum of Dibër (Bunguri, 1986). Dibër is one of 12 counties of Albania, located in the south and southeast of the Northern Region. Main purposes of this study are the determination of the composition and the process used during the production of those spearheads. The objects are analysed with µ-FRX, OM and Vickers microhardness tester in order to define the elemental composition and the production process. The carbon content of samples taken from artefacts measured using carbon & sulphur system. To obtain information about the possible technique used, various microstructure phases have been observed and analysed with SEM-EDS. The spearheads resulted steel with low carbon content presence, nearly 0.2%. From the µ - X ray fluorescence results it is concluded that objects contain iron over than 99%, also other present chemical elements (in small amounts) are Mn, Cu, As and Pb. Large ferrite grains with small pearlite grains microstructures, low-presence of pores, oriented inclusions (nodular wustite type) were observed. (Scott, 1991) The average value of microhardness measured was 180-184 HV. From the results we can conclude that these steel objects could have been produced by forging technique.

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IN SEARCH OF THE HEARTH: TRANSLATING BETWEEN EXPERIMENTAL ARCHAEOLOGY AND ANCIENT LEVANTINE IRON PRODUCTION

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With the increase of early iron workshops uncovered in the archaeological record of the southern Levant, it has become more and more conspicuous that furnace and hearth installations are missing from contexts where working debris (slag, ash, charcoal, technological ceramics), tuyères, and tools (hammers, anvils) give clear indications for production activities. Without a clear archaeological model, reconstructing early iron working installations, and thus technological practices, has proved challenging.

In order to explore the possibility of iron smelting in a pit hearth or bowl furnace, and to help explicate the disappearance of these installations in the archaeological record, experimental bowl furnaces were constructed using local, readily-available materials. These furnaces where then used in multiple iron smelting experiments employing local iron ores from the Negev and Arabah Valley, Israel. While the form and dimensions of the experimental furnaces may not have replicated those of the Iron Age, for which we have little direction, these experiments allowed for the following: (1) testing the viability of smelting in the bowl furnace or pit hearth; (2) testing the sustainability of construction materials, such as mud, subjected to high temperatures necessary for metal working; (4) creating a workable furnace/hearth that would, eventually, leave little to no evidence in the archaeological record.

The experiments produced several elucidating results, including similar waste products to those found in the archaeological record and a continuum of heat-affected sediments and earthen materials resembling those found on excavations. We will present the results of archeometric investigations (FTIR, SEM-EDS, pXRF) of material from the experimental bowl furnaces in comparison to production debris discovered at several Iron Age metal workshops. Through this, we endeavored to develop methods with which to recognize vestiges of past installations, such as hardened surfaces with signatures of high-heat, various types of slagging and masses of crude/fragmented ceramics.

RECONSTRUCTION OF EARLY MEDIEVAL LOCAL IRON PRODUCTION AT THE SITE OF MIRANDUOLO: FROM GLOBAL TO LOCAL

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Miranduolo castle was one of the centers in the area of historical Val di Merse. An area of fundamental importance for commercial road network as well as the widespread presence of mining assets (lead, zinc, iron and copper. Miranduolo itself was in fact build on iron and copper deposits (Posedi, 2016). Miranduolo castle has been continuously inhabited from the 7th to the 14th century, and since its origin it had the characteristics of specialised iron-making village. Excavations at the site started in 2001 and are still ongoing. This study focuses on the investigation of the metallurgical remains recovered during the excavations of 2014 and 2015. The material investigated includes samples of the local mineralisation, smelting slags and fragments of iron metal. These samples were analysed by X-ray powder diffraction, scanning electron microscopy and energy dispersive X-ray spectrometry, micro-Raman spectroscopy and Inductively Coupled Plasma Mass Spectrometry. The analyses were aimed at generating a mineral and chemical dataset mapping the smelting process based on the work of Charlton et al. (2010, 2012), linking mineral association with chemical fractionation during the smelting process with the aim of establishing changes in raw material procurement. The study enters in a wider recontextualisation of the metallurgical chaine-operatoire trying to define the new socio-economic contexts and organisations. In the most Ancient area excavated at the site it is possible to recognise all the activities of metal production: grinding, roasting, smelting and smithing (La Salvia & Anguilano, 2015). The activities dated to the VII century seem to indicate continuity and stability of production at the site. It is the interest of the research group to understand if during this long period of activity the site was benefitting from the purchase of raw material coming from different mines in the surrounding areas. The methodological challenge in the attempt to distinguish raw material with a very similar geological imprint is tackled through the combined use of a series of analytical techniques in the attempt of establishing a fine-tuned observation of the material dimension.

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ELEGANT SIMPLICITY: IRONWORKING IN MEDIEVAL PEASANTRY'S COMMON TOOLS AND INSTRUMENTS

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The Basquesmith project aims to investigate ironworking production during Early Medieval (EM) times by applying microscopic techniques –OM, SEM-EDS/WDS– on an assemblage of one hundred and two (102) iron made implements from 7th-12th centuries excavated in the rural settlements of Zaballa and Zornoztegi (Basque Country, northern Spain), a region renowned for the superior quality of its iron products from medieval times (Buchwald 2008, 168). The entire assemblage consists on common utensils, which are both rare in EM rural contexts and in metallographic studies, and therefore allows ironworking to be explored on rural implements from rural communities rather than prestige items from urban contexts, particularly when the latter assumption has purported a distorted image of the society in medieval times. Thus, the fall of the Roman Empire submerges the territories of the extinct empire as well as the rest of Europe in a deep crisis while the iron industry in particular suffers a strong regression in terms of production, distribution and consumption, and is relocated next to the new centers of power (Hinton 2005) dedicated primarily to supply the elites since "iron objects were expensive items" (Jaritz 1995), not accessible to the majority of society (rural). The usually meager archaeological evidences of just 1-2 metallic elements of early medieval chronology by settlement (e.g. Hamerow 2002) would confirm the supposed scarcity of metallic consumer goods among the peasantry. Recent archaeological interventions in Llanada Alavesa reveal a diametrically opposite photograph. The inhabitants of rural settlements active between the sixth and fifteenth centuries enjoyed a large number (tens or hundreds) of everyday objects and agricultural tools (e.g. sickles, horseshoes, laddles, belt buckles and clasps, etc.) (Quirós Castillo 2013). The metallographic analysis reveals that they are mostly of simple but functional manufacture, consisting of simple forge of low-carbon iron frequently ended by cold-hammering, but also other techniques such as complex- or butt-welding and different materials such as phosphoric iron and steel (Larreina-Garcia & Quirós Castillo 2018).

The preliminary conclusions challenges the traditional picture of medieval peasantry without access to iron commodities that resorted to using wood instead, the latter material that constituted the ‘undisputable’ workhorse material in medieval times (Fossier 2000, p.158). An alternative scenario of relationship between the productive models of iron and the early medieval peasant communities is proposed.

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BLOOMERY SMELTING IN NORTHERN FENNOSCANDIA – NEW DISPERSAL ROUTES OF IRON TECHNOLOGY IN NORTHERNMOST EUROPE

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Current field research in northern Sweden has uncovered two of the earliest known iron production sites in northernmost Europe, showing iron technology was an integral part of the hunting-gathering subsistence already during Pre-Roman Iron Age (250–50 cal BC), with furnace remains indicating an eastern technological influence. The excavated sites are located near the villages of Sangis and Vivungi in the Arctic and Boreal Zone of northeastern Sweden; the Sangis site in the coastal area of the Bothnian Bay and the Vivungi site in the interior ~140 km north of the Arctic Circle. The geographical setting is characterized by coniferous forests, large lake systems and vast mires, rich in essential sources of limonite ore. Three bloomery furnaces with similar features were recovered during excavations in 2010 and 2017. All three consists of a rectangular frame of vertically set flat stones leaving one side open and a shaft of clay with good refractory qualities, built within and partly on this frame. The furnace shafts measured c. 0.25-0.35 m in diameter with estimated heights of c. 0.5-0.7 m. All furnaces are defined as shaft furnaces with underlying slag pits intended for multiple firings, including dump zones containing slag, technical ceramics and iron waste; at the Vivungi site even iron ore. Chemical analyses show that all analysed slags have a manganese content indicating the use of manganiferous ores, also confirmed by an analysed lake ore found at the Vivungi site. Several pieces of iron waste from iron production or initial cleansing of the iron bloom were found adjacent to all furnaces. From analyses, most of the samples are homogeneous steel with rather high carbon content (0.7-0.8 %), a feature strongly suggesting that steel was produced directly in the smelting process. Overall, furnace remains suggests a technological influence of eastern origin, indicated by several contemporary furnaces with similar features found in northeastern Finland and Russian Karelia. To clarify this, current research will further explore similarities and differences in furnace technology within this region through archaeometallurgical analyses and shed new light on the dispersal routes of iron technology in Northernmost Europe.

DID SCRAP-IRON RECYCLING IN ANTIQUITY?

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Iron prodused in a solid state, in contrast to non-ferrous metals until the XIX century. Iron production was a complicated and laborious process in ancient times, so iron objects were very much appreciated. The question is, could medieval blacksmiths use broken objects? Artifacts of large forms (axes, scythes, socks, etc.) could be reforged into small items (knives, awls, nails, clamps). But could scrap metal be used again? Is it possible from broken knives, awls, nails, clamps to get a homogeneous bloom for further use without melting? Experimental smelting in a ground bloomery furnace was carried out to test this assumption. The furnace was constructed on the model of the 14th century furnace, discovered during archaeological excavations on the Kulikovo Pole (Tula Region). Scrap metal from archaeological excavations in Ryazan (nails, clamps, horseshoes) was used as raw material. Items were cut into small pieces before smelting. Charcoal was used as fuel. Blowing was carried out with the help of an electric pump, which resembled to hand bellows by the volume of air supply. The process continued about two and a half hours. As a result, a sufficiently solid bloomery iron was obtained (the structure was ferrite and ferrite with perlite), which was forged and then a fire-iron and a billet for a nail were forged from it. Thus, in the bloomery furnace it was possible to reach the temperature and conditions at which small pieces of iron were sintered in a monolithic bloom suitable for further processing.

KULCHIGA - RARE FERROUS METALLURGICAL COMPLEX OF PRE-VOLGA REGION 13-14 CENTURIES (RUSSIA)

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The ferrous metallurgical complex of 13 centuries was found in 2018 in the Middle Volga (Russia) during the rescue archaeological excavations – Kulchiga settlement. The territory between the Sviyaga (west) and Volga (east) rivers was characterized by a low density of fortified and unfortified settlements before and during the Golden Horde period. Most of them are located near the Volga River. Kulchiga was located to the west 40 km from the Volga River, and 50 km from the large medieval regional center - the Bulgar settlement. Bulgar was the capital of the Ulus Juchi (Golden Horde) (territory of the Volga-Kama interfluve) in the 1242-1246 AD. The active development of the Volga-Sviyaga interfluve began in the Golden Horde period (13-14 centuries) with the arrival of the population on this territory.

The Golden Hoard fortified settlement nearest to Kulchiga was located 20 km away, which indicates its uniqueness and suggests that there is also an undiscovered medieval settlement nearby. This is also confirmed by the fact that some finds of the Golden Horde period were found 2 km east from Kulchiga.

A metallurgical area of about 12 by 6 meters was discovered in the excavation site. It consisted of:

- the pit with air offtake and a metallurgical furnace in the center with melting pot remains and slags,
- the tread down area with coal, ashes, slags and two used melting pots,
- the pit for water.

The partially exposed brick metallurgical furnace was found in the excavation walls. Traces of pillar pits were found near the production complex, probably for a shelter.

370 finds were found in the excavation site. The majority number of artifacts were splashes, slags, melting pot and more. Fragments of pottery from the early 13th and 14th centuries were also discovered.

Some of the finds were researched to the optical emission spectral analysis for the chemical composition, petrographic and X-ray structural analysis for the mineralogical composition. The comparative study with similar findings of the Bulgarian fortified settlement has been carried out.

The results of the comprehensive research allow to supplement the view of the development of ferrous metallurgy in the Middle Volga and the area of distribution of the Golden Horde (Ulus Juchi) in the territory between the Sviyaga and Kama rivers.

FINALLY, AN ANTIQUE STANDARD OF STEEL SEMI-FINISHED PRODUCTS!

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In ancient metallurgical contexts, steel enjoys a special prestige thanks to his mechanical behaviors: especially its hardness which can be increased by quenching. However, if one relies on discoveries of protohistoric and antique semi-products, steel remains a rare material (Dillmann et al., 2011). Certainly, there are heterogeneous products in which ferritic and steel zones coexist, but the homogeneous masses entirely composed of steel remain relatively exceptional. Yet the study of some antique objects clearly shows that both production and trade of pure steel occur (Berranger et al. 2011, Pagès et al. 2011, Pagès 2014, Berranger et al. 2017, Dillmann et al. 2017). Moreover, ancient authors such as Pliny the Elder distinguish the materials using the terms heterogeneous iron and pure steel.

The study of two antique semi -products, with identical morphology and structure, provides new perspectives on this question. Fully steeled to 0.7 / 0.9% carbon, they are bars 15 cm long and 3 x 1.5 cm section. They have been discovered in the Roman military camp Strebersdorf (Burgenland, Autriche, Groh 2009) and in the late-antiquity fortified hilltop city of Roc de Pampelune (Argelliers, Hérault, France, Pagès et al. 2005). More than 5 centuries and 1500 km separate these similar discoveries. How to interpret this? That's the question we want to answer by using the results of metallographic and LA-ICP-MS analyses and confronting them with the facts recounted by the ancient authors as Pliny the Elder.

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EARLY MEDIEVAL BOG IRON ORE SMELTING PROCESS: A CASE STUDY OF VIRJE – VOLARSKI BREG (NE CROATIA)

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Main goal of this study is to provide first results of geochemical and mineralogical analyses of iron slag and bog iron ore found at the archaeological site Virje – Volarski breg and surrounding area, which represent part of a broader data collection from archaeological sites with identified smelting activities during the late antiquity and early medieval period in the Podravina region (NE Croatia). At the Virje – Volarski breg site an early medieval iron smelting workshop was excavated in 2008. Remains of four bloomery furnaces had an in situ residue of iron slag formed during the smelting process (tap slag, furnace slag and furnace bottom slag). According to the archaeological record these furnaces were interpreted as free – standing slag – tapping bloomery furnaces. Samples for the analysis were selected according to the different types of iron slag originating from the same archaeological context, individual iron smelting furnaces i.e. individual smelts. . The aim of the analyses was to define whether there are some distinctive patterns in chemical and mineralogical composition between samples of different types of iron slag formed during the smelting process, and in what way can these patterns be indicative for the study of the iron smelting processes in bloomery furnaces. X-ray powder diffraction (XRD) was used to determine mineralogical composition of slag and bog iron ore samples. Detail geochemical characterization of samples was performed using inductively coupled plasma mass spectroscopy (ICP-MS). Results of the mineralogical and geochemical analyses of slags are compared to results of bog iron ore samples found at the site in an archaeological context as well as with the samples of possible bog iron ore found in a geological survey of the broader study area of Podravina region.

CONTROLLING POSSIBILITIES OF THE CARBON CONTENT IN THE IRON BLOOM DURING THE IRON SMELTING

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Three basic bloomery iron alloys were known and used by the medieval blacksmiths: iron, steel and phosphoric iron. Controlling the carbon and the phosphorus content in the iron bloom during the iron smelting might have an importance because the chemical composition of the iron bloom determines its workability and usability. Iron and steel were the most used iron alloys for different constructions, tools, weapons, etc., while the brittle phosphoric iron appeared mainly in pattern-welded blades and sometimes in other objects probably unintentionally.

In the Middle Ages, the carburization of iron by heating in the presence of a carbon-bearing material was a well-known technique for increasing the carbon content of the surface in some mm depth. But controlling the bulk carbon content in the whole volume of the iron bloom was only possible during the bloomery iron smelting process. In our recent research we focused on the iron smelting of the medieval Carpathian Basin between the 8th and 12th centuries (Late Avar Period, the age of the Hungarian Conquest and Árpád-age) and tried to answer the question whether it was possible to produce iron and steel deliberately by controlling the carbon content.

Seven experiments were carried out smelting the same amount of local iron ore in an embedded furnace constructed on the basis of the remains of the 10th century Fajsz-type furnace. After a first reference smelting air supply, ratio of charcoal/ore, grain size of the ore and some other parameters were changed in each following experiment. The iron blooms were forged to a billet and then hardened by water quenching. One side of the billet was ground and macro-etched using 10% Nital to reveal the carbon distribution. Rockwell-C hardness was measured on the different shades of the etched surface to evaluate the carbon content (using the hardness – carbon content chart for martensite) and carbon content was also measured in some points the means of the GD-OES method.

We found that the spatial distribution of the carbon in the resulting billets was very heterogeneous, and steel could be smelted only in case of increased charcoal/ore ratio. We realized that the changes in different technological parameters influenced the viscosity of the slag, the iron yield, etc. as well. The results also helped to understand the metallurgy of the bloomery furnace better.

METALLOGRAPHIC EXAMINATION OF ELEVEN MEDIEVAL KNIVES FROM ŠEPKOVČICA, KOBILIĆ AND OKUJE (REPUBLIC OF CROATIA)

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Archaeological excavations of the remains of medieval rural settlements conducted in 2006-2010 in Šepkovèica, Kobiliæ 1 and Okuje (Turopolje region, Zagreb County, Republic of Croatia) yielded in total 88 knives or knife fragments dated to the 11-14th century. All these artefacts were investigated by means of X-radiography and subsequently 11 selected pieces by metallography. These investigations revealed the first pattern-welded knife reported among Croatian archaeological finds (Thiele et al. 2017). Except this single unique piece none of the investigated blades was pattern-welded or provided with preserved non-ferrous decoration but three blades of the eleven bore maker's marks without any traces of non-ferrous inlaying metal.

The metallographic investigations suggested that three of the nine pieces show a forge-welded construction deliberately combining iron and steel (one of these was pattern-welded), while the other blades were most likely made from a single piece of metal: in particular three blades are iron and four are made of steel. All the blades containing steel were hardened by quenching. One of the iron knives was made entirely of phosphoric iron; such blades are reported very rarely. The construction of one of the eleven blades could not be determined reliably.

The overall proportion of good-quality knives, the fact that quenching of blades containing steel was a standard, and a relatively high proportion of blades made entirely of steel might suggest that knives used in the region of Turopolje were predominantly of good quality though simply made. The luxury-looking blades were in the Turopolje region rather rare and the single pattern-welded knife was more likely to be imported than locally produced.

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PRODUCTION AND USE OF SABERS IN THE 10TH CENTURY CARPATHIAN BASIN

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Sabers appear often in the 9–10th century Hungarian burial sites. This one-handed melee weapon with a softly curved, single edged blade (and with partly sharpened backside) was commonly used in the Central and Eastern European region, although – just like in the case of the contemporary straight bladed swords – we can conjecture a limited social level using this type of long bladed weapons. Unfortunately sabers from the time of Hungarian Conquest have not got as much attention as they should have. Despite of the numerous findings nearly from the whole Carpathian Basin, metallographic analysis has not been taken on any of them.

The aim of this work is to present the methods and the results of the first archaeometallurgical investigations on sabers from the 9–10th century Carpathian Basin. We examined blades and guards relating to four weapons (Szirmabesenyő, Karos-Eperjesszög grave II/5. and II/20; and the fourth saber from unknown site) with optical microscopy and SEM-EDS, for the purpose of mapping the change in the microstructure. On this way we could distinguish pearlitic, ferritic and in one case matrensitic structure, and conclude the forging and the heat treatment.

Investigating technological features provides a basis to make comparison with other examined sabers in Central and Eastern Europe.

BLOOMERIES AMONG THE TREES, WORKSHOPS NEAR THE HOUSES - VIRTUAL 3-D RECONSTRUCTION OF TWO EARLY MEDIEVAL IRON METALLURGICAL CENTRES EXCAVATED IN HUNGARY

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In 2001, the excavation at Kaposvár-Fészerlak unearthed more than 400 Avarian Age fea¬tures associated with iron working across a total of 17,500 m2 area. This is the second largest known Avarian ironmaking sites in Europe, featuring the most char¬acteristic structures recorded on iron reduction sites of the same period. The peculiarities of the site include wells with well-preserved wooden constructions; the source of water for iron working. The adjacent late Avarian Age cemeteries and set¬tlements and the sizeable bloomery workshops, presumably owned through special rights, shows that the site was a regional centre. The recovered bloomery workshops, found in a single archaeological layer, might have operated over the course of a surprisingly short period, between the end of the 7th century and the mid-8th century.
At Zamárdi, on the southern bank of Lake Balaton, four sites were excavated in 2005 and 2012. The nearly 1,500 archaeological features recovered from a total area of 27,700 m2 date to six periods. The Avarian Age is represented by 580 features, including nearly 100 ore roasting pits, around 20 bloomery furnaces, as well as additional traces of a half-dozen demolished bloomeries. Two reheating fireplaces and a smithy workshop also were un¬earthed. Beyond smelting-related features, 20 houses with built-in fireplaces and over 100 outdoor fireplaces were found too. The excavations revealed an iron working centre and settlements of outstanding importance in the Avarian Age that stretched more than 1 km in length. The various workshops and settlements at Zamárdi occurred sequentially; since more workshops were added southward, all the finds and features related to iron metallurgy found in the southernmost area date exclusively to the late Avarian period. The settlement features are only partially associated with the smelters' centre, and were partly found in younger archaeological layers. The complex of bloomery workshops and settlement, 1,100 m in length and 150–200 m in width, was in used from the middle of the 6th century to the end of the 9th century (much more longer period than that of Kaposvár), ranging from the Langobard era to the Hungarian conquest.
This study provides spectacular and accurate view of the workshops, furnaces and other objects of the mentioned sites using plans, structural sections and mainly 3D reconstruction drawings. The environment and layout of the sites were also presented. These virtual reconstructions were made on the basis of the results of archaeological and archaeometrical research and reconstructed smelting experiments.

THERMODYNAMIC ASPECTS OF MEGALITHIC IRON SMELTING AT NAIKUND, VIDARBHA REGION OF INDIA

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The production of wrought iron began in the Indian subcontinent around the second millennium BCE. It is established that the origin of iron metallurgy was a product of indigenous development and simultaneous beginning of iron age occurred at more than one centre in the Indian subcontinent [1,2]. The archaeological excavations conducted at Naikund , a megalithic site, 42 km north west –east of Nagpur ,Maharashtra, India have shown a valuable evidence of iron smelting furnace complete with tuyere [3]. Recently, we have reported metallographic investigations of the wrought iron samples from Mahurjhari, Naikund ,Bhagimohari, Khaiwada in the Vidarbha region of Maharashtra [4]. It revealed knowledge of steeling with hardening, quenching and tempering sequence around 900 BCE in this region. However, there is a need of detailed thermodynamic studies of iron production in order to understand the technology behind the process. Therefore, the work was undertaken to analyze thermodynamic aspects of megalithic iron smelting practice at Naikund and reported in this paper. This was the only ancient iron smelting site in India which depicted all the essential features of the iron smelting.

It was stated that the megalithic smelters succeeded in getting 350 grams of wrought iron per kilogram ore [3]. Figure shows Naikund furnace model . The combustion of charcoal, which is almost pure carbon, takes place in the tuyere. This region has the highest temperature in the furnace, which can be estimated by Adiabatic Flame Temperature considering no heat loss to the surroundings. Thermal analysis shows that the maximum temperature attained in the Naikund furnace under the optimized reducing conditions was 1338oC. As the melting point of pure iron is 1540 0C, reduction of iron was performed in solid state.

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